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AN AQUEOUS GEOCHEMICAL AND HYDROLOGIC STUDY OF THE SPRINGS AND WELLS OF THE SEVILLETA NATIONAL WILDLIFE REFUGE: EVALUATING HYDROCHEMICAL PATHWAYS

BY

AMY J. WILLIAMS

B.S., EARTH AND ENVIRONMENTAL SCIENCES,
FURMAN UNIVERSITY,
2007

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

Master of Science
Earth and Planetary Sciences

The University of New Mexico
Albuquerque, New Mexico

August 2009

DEDICATION

To my parents, for their continuing support of my educational and professional goals and for encouraging me to become anything I wanted, especially a geologist!

ACKNOWLEDGEMENTS

Funding for this research was provided by the National Science Foundation through the Hydrologic Sciences Program (NSF EAR 0538304 and 0838575 to Crossey) and the Ecology Division (NSF-DEB-0620482 to Collins) Long Term Ecological Research program at the Sevilleta National Wildlife Refuge; and student grants from the National Science Foundation Long Term Ecological Research Program at the Sevilleta National Wildlife Refuge (DEB-0620482) (Williams), the New Mexico Water Resources Research Institute W09010 (Williams/Crossey), the New Mexico Geological Society (Williams), the University of New Mexico Office of Graduate Studies Research, Projects, and Travel grant (Williams), the University of New Mexico Graduate and Professional Student Association Student Research Allocations Committee award (Williams), and the University of New Mexico Department of Earth & Planetary Sciences. I offer my sincere gratitude to my advisor, Laura Crossey, for her support and patience with the Sevilleta project and my development as a research scientist. Special thanks go to my committee, Laura Crossey, Karl Karlstrom, and Cliff Dahm for their support and encouragement, as well as Barry Kues for serving on my comprehensive exam committee. Thanks go to the personnel from the U.S. Fish & Wildlife Services at the Sevilleta NWR and Sevilleta LTER researchers and staff, specifically Dennis Prichard, Mike Parker, John Erz, Jennifer Johnson, Doug Moore, Scott Collins, and John Dewitt. Project goals would not have been met without the support of several people. Thanks go to Christine Ann Waters, Samantha Adelberg, Frankie Reyes, and the Sevilleta 2008 and 2009 REU students for sampling assistance. Thanks also to Nick Engdahl, Devin Gaugler, Missy Halick, and Travis Naibert for assistance on numerous sampling campaigns. Thanks to Abdul-Medhi Ali and Kimberly Guggliota for assistance in analytical chemistry, to Viorel Atudiori for stable isotope analysis assistance, to Victor Polyak for radiogenic isotope analysis assistance, and to John Craig for nutrient analysis assistance. Thanks also go to Yemane Asmerom for helpful suggestions, Eileen Embid for GIS assistance and Ara Kooser for PCA and inverse modeling assistance. I also want to thank my undergraduate advisor, Dr. Brannon Andersen, for instilling in me a passion for research and undergraduate education. Lastly, I thank the graduate students of 2007-2009 for their support and friendship.

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ABSTRACT

The Rio Grande is a regionally important water source, but the smaller rift springs are also a vital resource for livestock and wildlife. Several springs are located on rift-bounding faults and exhibit a mixing of larger volume meteoric recharge with small volume, chemically potent "endogenic" fluids. It has been hypothesized that deep-seated faults within the rift provide conduits for the ascent of deeply derived fluids, possibly from the lithospheric/asthenospheric mantle, while others have proposed that upwelling sedimentary basin brines at interbasin constrictions represent a significant salinity input to the modern Rio Grande.

This study (a) provides the first hydrochemical data on a comprehensive suite of springs and wells, and (b) tests and refines existing models for water quality in the rift using hydrochemistry (major, minor and trace elements, Cl/Br ratios, $\delta^{18}O$, δD, $\delta^{13}C$, and $^{87}Sr/^{86}Sr$ ratios) and geochemical modeling along a series of transects within the Sevilleta National Wildlife Refuge.

In the rift, several potential flow systems can be envisioned: 1) **exogenic fluids** in shallow unconfined aquifers with recent meteoric recharge, which are characterized by low temperatures, CO_2 values, and $^{87}Sr/^{86}Sr$ ratios, 2) **mesogenic fluids**, categorized as subregional basin fluids in Tertiary rift fill, 3) **regional/intermediate waters** residing in the confined aquifers of Paleozoic/Mesozoic sedimentary strata, 4) **deep sedimentary basin brines**, also in confined strata, and 5) **endogenic waters**, defined as deeply-circulating regional fluids that may have mantle derivation, source from faults, and are characterized by elevated temperatures, salinity, CO_2 values, and $^{87}Sr/^{86}Sr$ ratios.

Major ions indicate the interaction of five fluids with distinct hydrochemical facies: 1) **Na-Cl**, 2) **mixed ion-HCO_3**, 3) **Ca-SO_4**, 4) **mixed cation/anion** (corresponds with local precipitation chemistry), and 5) **Na-mixed anion**. $\delta^{18}O$ and δD indicate mixing between brines and the Rio Grande, and $\delta^{13}C$ values suggest a mixing of organic C and a mantle-derived C input in springs. Radiogenic $^{87}Sr/^{86}Sr$ ratios indicate mixing between endogenic fluids and meteorically-derived waters and principal component analysis indicates a common deeply-derived source in select waters.

These tracers conclude that endogenic fluids are a volumetrically small but potent addition to middle Rio Grande rift springs, and may contribute to river salinization.

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1 Introduction

1.1 Background

The American Southwest is one of the fastest growing regions in the United States, and the scarcity of water resources is a significant concern. Water management in New Mexico is a constant consideration and regional groundwater studies, including water quality surveys, have been performed to evaluate scarce resources (*Speigel 1955; Roybal, 1991; Bartolino and Cole, 2002; Plummer et al., 2004; Bauer et al., 2007; Rawling et al., 2008*). Both groundwater and surface water are important sources for many metropolitan and agricultural communities along the Rio Grande corridor, and in the arid and semiarid southwestern United States in general. The quality of groundwaters is of concern because of the general scarcity of renewable water supplies in the region. Both high salinity and trace element concentrations are regionally important in impairing water quality (*Phillips et al., 2003*; *Mills, 2003; Newton, 2004; Plummer et al., 2004; Newell et al., 2005; Anning et al., 2007*), and identifying sources of these constituents remains an ongoing problem.

Competing uses of groundwater in semiarid regions presents the difficult task of understanding the nature of a resource threatened by over development. The groundwater basins of the Rio Grande rift (including the Albuquerque, Espanola, Belen and Socorro basins) have all been the focus of groundwater studies in the past decade. An approach in this study is to consider surface and groundwater as an integrated system (*Winter et al., 1998*) Although the Rio Grande is the dominant surface water source in the region, the smaller springs that issue within the Rio Grande rift are also vital to the region. Several of these springs are located on rift-bounding faults and although many of these waters are dominated volumetrically by meteoric recharge, recent research has revealed the widespread presence of volumetrically small, but geochemically important deep fluid sources, including components from the Earth's mantle (*Newell et al., 2005; Crossey et al., 2006; Liu et al., 2006; Crossey et al., 2009*). Some of these "endogenic" waters have been identified in the Rio Grande rift in central New Mexico (*Newell, 2007*). It has been hypothesized that deep-seated faults within the rift provide conduits for the ascent of deeply derived fluids (*Newell et al., 2005; Crossey et al., 2006; Crossey et al., 2009*). Others have proposed the hypothesis that upwelling sedimentary basin brines represent a significant salinity input to the modern Rio Grande (*Mills, 2003; Phillips et al., 2003; Newton, 2004; Hogan et al., 2007; Hibbs et al., 2007; Phillips et al., 2007; Doremus et al., 2008*). This study will characterize the geochemistry of waters in a cross-rift transect located in the Sevilleta National Wildlife Refuge in central New Mexico and evaluate hypotheses for groundwater flowpaths.

Comprehension of groundwater flow requires an understanding of the complex subterranean structures influencing water movement as well as potential mixing of waters from different sources within the aquifer. In addition to identified aquifers, preferential flow paths often occur between stratigraphic units (along contacts and in paleochannels), unconformities, or along fault planes. Commonly, modeling shows that permeability along faults is orders of magnitude higher than matrix rock (*Fetter, 1994; Mazor, 1997; Ingebritsen et al., 2006; Lallahem et al., 2007*). Conversely, spatial variations in hydrologic properties can result in the same fault planes acting as boundaries, inhibiting groundwater flow (*Person et al., 2000; Rawling et al., 2001; Plummer et al., 2004*). In this study, the faults associated with the groundwater basins are examined as important for understanding the hydrogeologic connections between the surface and groundwater systems in the Rio Grande rift.

1.2 Previous Work on Sevilleta NWR Hydrology and Hydrochemistry

There is little existing literature on the geochemistry of the Sevilleta NWR and surrounding region's springs, although most are indicated on topographic maps. Many wells in the Sevilleta NWR have been lost, abandoned, or are difficult to find and sample. Spiegel (1955) provided a limited geochemical study on several springs and wells in the region, including the Rio Salado Box Springs, Dripping Springs, and San Lorenzo Springs. Roybal (1991) revisited the geochemistry of Socorro County, including some new chemistry of previously uncharacterized springs and wells in the region, but that report simply restated the sites described by Spiegel in 1955. Plummer (2004) reports extensive chemistry of the springs and wells in the Albuquerque basin, some of which overlap with the northern extent of the Sevilleta NWR. Rawling (2003) reported on the location and geology of 30 springs and seeps on and near the Sevilleta NWR, but no water chemistry was conducted.

1.3 Purpose and Scope

Until recently, regional models of groundwater flow and upwelling saline fluids were portrayed in "sandbox models", so called because the waters are shown to move through a homogenous substrate without consideration for structure or fluids derived from the unique tectonic setting of the rift (*Toth, 1963; Anderholm, 1984; McAda and Barroll, 2002; Bartolino and Cole, 2002; Mills, 2003; Phillips et al., 2003; Hogan et al., 2007*). Few existing models consider deeply-derived inputs to explain variations in water chemistry and isotopes within a given aquifer (Figure 1), and few have focused specifically on the potential role of faults as conduits within the hydrologic systems.

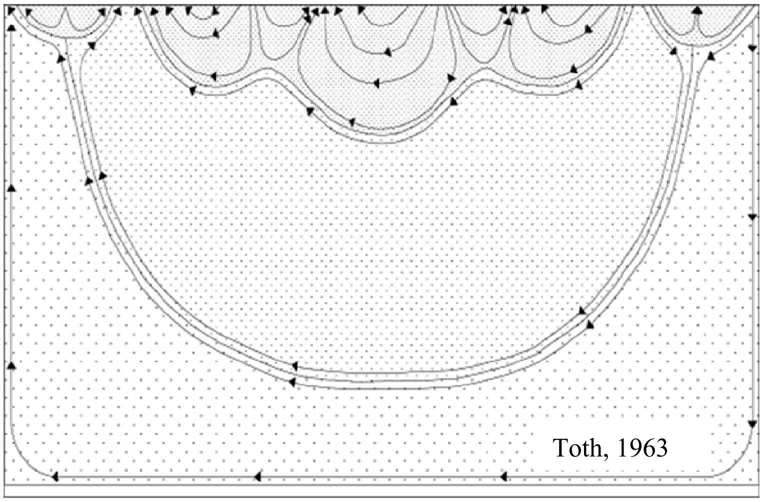


Figure 1. Until recently, this model represented a commonly accepted groundwater flow path illustration of local, intermediate, and regional extent. From Toth, 1963.

One intention of this work was to inventory, describe, and sample the springs and wells of the Sevilleta NWR and surrounding area in an attempt to understand the sources of these springs and evaluate different models for subsurface flow paths interacting in the Rio Grande rift. The goal of the regional study is to incorporate geologic structure into the placement of regional flow paths in the rift to reveal the partitions between these flow paths. This includes 1) identifying the chemical composition of the springs and groundwaters and isolating chemically similar regions, 2) delineating groundwater flow paths, 3) identifying regions of mixing, 4) identifying the major chemical and physical processes influencing isotopic and chemical composition, and 5) identifying these flow paths on a geologic framework model of the Rio Grande rift.

This thesis contains maps of the springs sampled, field parameters, select high-resolution geologic settings, results of geochemical analysis, and interpretation of groundwater flow paths based on major ions, stable and radiogenic isotopes, and geochemical forward and inverse modeling using the software program PHREEQC (*Parkhurst and Appelo, 1999*). The hydrologic study is based on information collected from 46 spring and surface waters and 15 well water samples. Several of the springs were sampled biannually to quarterly over a period of nearly two years to study temporal changes in water chemistry. We used chemical and isotopic data in conjunction with hydrogeologic information to develop a model for groundwater flow paths in the Rio Grande rift that is based on relevant geologic structures and stratigraphy.

Lastly, in provinces where there are few wells, spring geochemistry and physical and chemical field parameters are central foundations of information for subsurface flow paths, mineral-water interaction, mixing of endmember waters, and groundwater sources. It is to this end that this research was pursued.

2 Description of Study Area

2.1 Regional Geology

Following regional uplift of the Rocky Mountain/Colorado Plateau region at 70 Ma, the Rio Grande rift began to extend 25-30 Ma (*Chapin and Cather, 1994*) and extension continues today (*Russell and Snelson, 1990*). Structural relics of earlier (Ancestral Rockies and Laramide) deformation events, plus the extensional faults of the Rio Grande rift, create a complex network of faults that now influences groundwater flow (*Plummer et al., 2004*), evidenced near the study area in the small, high angle faults of the Joyita Hills in southeastern Sevilleta NWR (*Roybal, 1991; Beck et al., 1994, de Moor et al., 2005*). There are several major rift-bounding faults of importance to this study (*Chapin and Cather, 1994; Mailloux et al., 1999*), and the rift structures have been shown to enhance the transport of deep fluids to the surface (*Rzonca et al., 2003, Liu et al., 2003*).

The rift extensional structures alternate between asymmetrical east- and west-hinged half-grabens with deep rift-bounding faults on their opposing sides (*Lewis and Baldridge, 1994*). Within the northern and central Rio Grande, the rift itself is composed of 4 axial basins, with the area of interest encompassing the boundary between the Albuquerque-Belen basin and the Socorro basin (Figure 2) (see *Bartolino and Cole, 2002* and references therein). The Rio Grande rift sediments thicken throughout the Albuquerque basin and thin at the Socorro constriction (southern end of the Albuquerque basin, ~40 miles long and 5-10 miles wide [*Kelley, 1977; Roybal, 1991*]). South of the constriction, the rift becomes a series of parallel basins and intrarift tilted block uplifts (*Chapin and Cather, 1994*). Several fault systems in this region have a significant hydrologic impact on the groundwater flow paths, including the Jeter master fault on the west side and the conjugate Montosa fault on the east side (Figure 3).

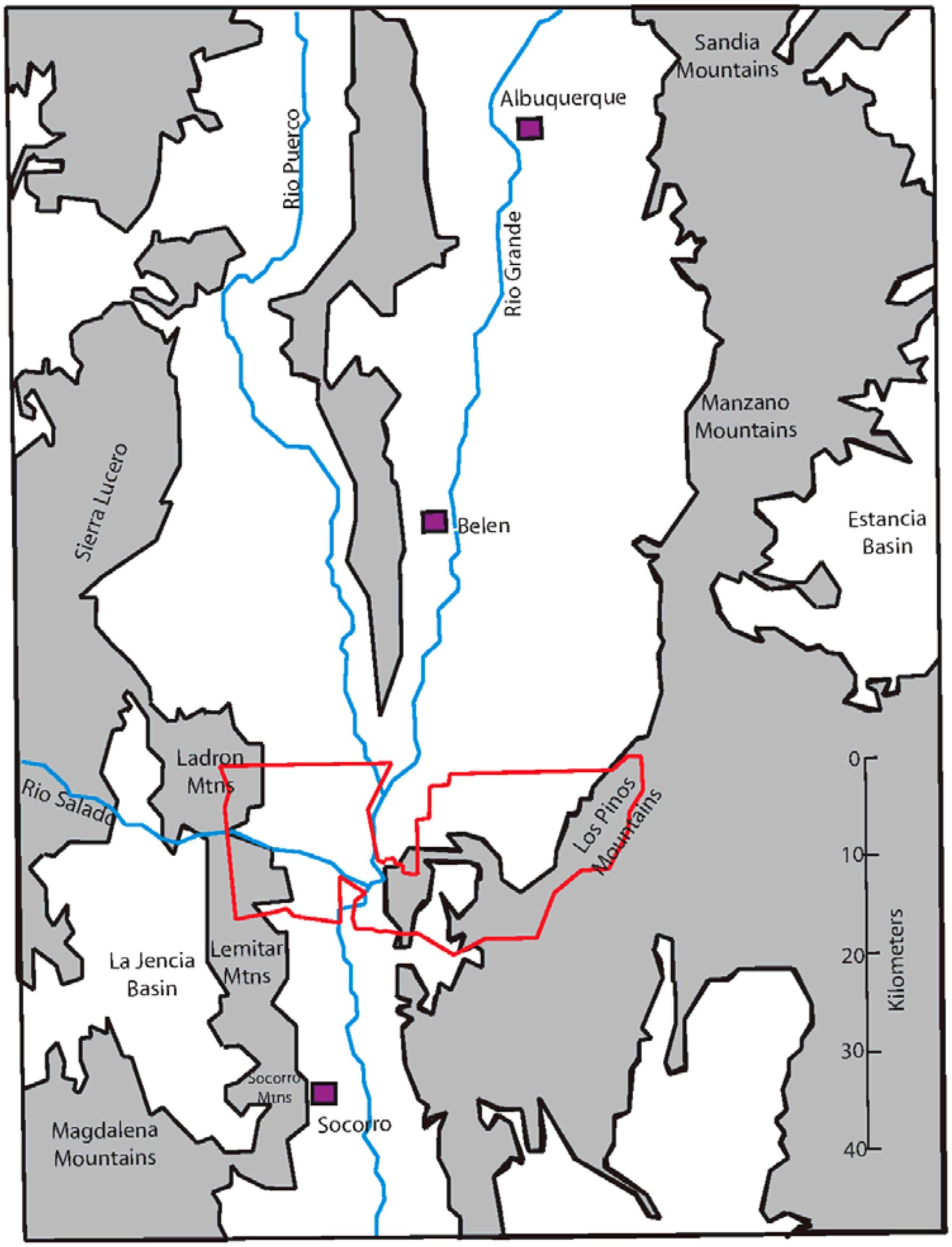


Figure 2. General location of the Sevilleta NWR in the central Rio Grande rift at the Socorro constriction. Modified from Machette, 1982. Dark regions are Miocene to Precambrian basin fill and bedrock. Includes Miocene and upper Oligocene basin-fill deposits of the Popotosa Formation and Miocene and older sedimentary and volcanic units, as well as igneous and metamorphosed bedrock. Red outline represents the borders of the Sevilleta National Wildlife Refuge.

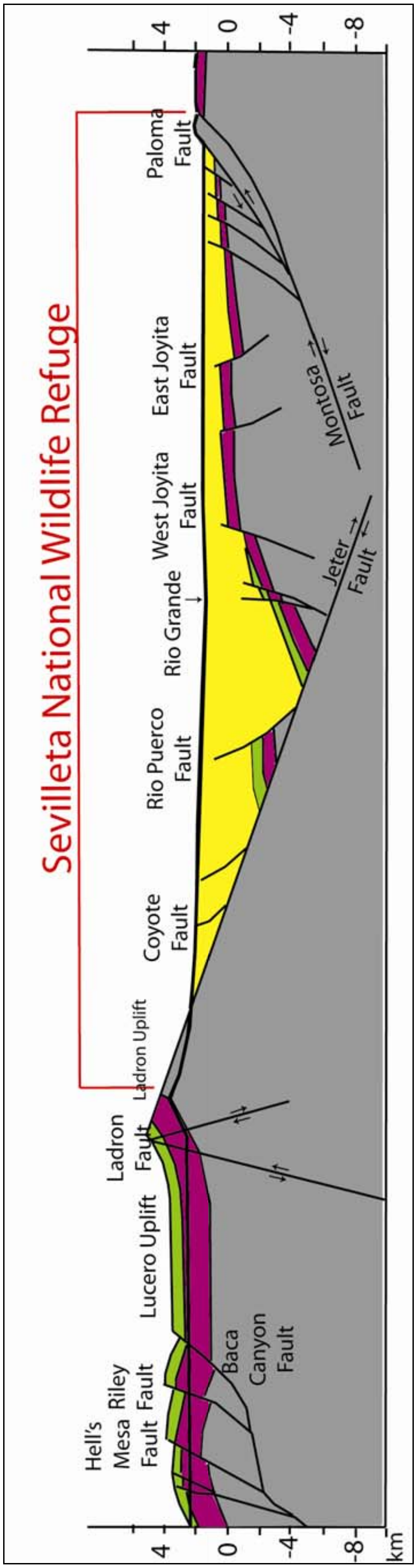


Figure 3. Modified from the Lewis & Baldridge (1994) interpretation of the Cocorp Line from Ladron Peak to the Los Piños Mountains. Major faults include, from east to west, Montosa Fault, Paloma Fault, East Joyita Fault, West Joyita Fault, Rio Puerco Fault, Coyote Fault, Jeter Fault, Ladron Fault, Baca Canyon Fault, Riley Fault, and Hell's Mesa Fault. Bold line represents current land surface.

2.2 Sevilleta National Wildlife Refuge

The Sevilleta NWR was established by the US Fish and Wildlife Service from the Campbell Family Foundation land grant in 1973. The Sevilleta LTER was established at the refuge in 1988 as part of the National Science Foundation's LTER Network "to understand how abiotic drivers and constraints affect dynamics and stability in an aridland ecosystem" (Department of Biology, UNM). The Sevilleta NWR is located approximately 80 km south of Albuquerque, NM, east of the Colorado Plateau and west of the Great Plains within the Rio Grande rift. It encompasses 1) the intersection of the Albuquerque and Socorro basins, 2) the major river system in the state, and 3) four major biotic zones: Chihuahuan Desert grassland and shrubland (south), Great Plains Grassland (north), Colorado Plateau Shrub-Steppe (west), and Piñon-Juniper (Conifer) Woodland (upper elevations of mountains). In Socorro County, the Rio Grande is supplied by the intermittent Rio Puerco and seasonally by the southern Rio Salado. Most of the Sevilleta is underlain at 19 km depth by the northern portion of the Socorro Magma Body, as determined from interpretation of the Socorro Seismic Anomaly (*Sanford et al., 1977, Balch et al., 2008, Karlstrom, unpublished*) (Figure 4). South of the study area, the Socorro Peak region was designated as a Known Geothermal Resource Area (*Sass and Lachenbrush, 1978*), but an aqueous geochemical study concluded that the waters in that region were of meteoric derivation and not connected to a hot water reservoir of the thermal system (*Gross and Wilcox, 1983*). Forty-six spring and river samples and fifteen well samples were collected from the Sevilleta NWR and surrounding regions, including Abo Pass. All sites were accessible within thirty minutes walking distance from a designated road except the Rio Salado Box springs (see Appendix C).

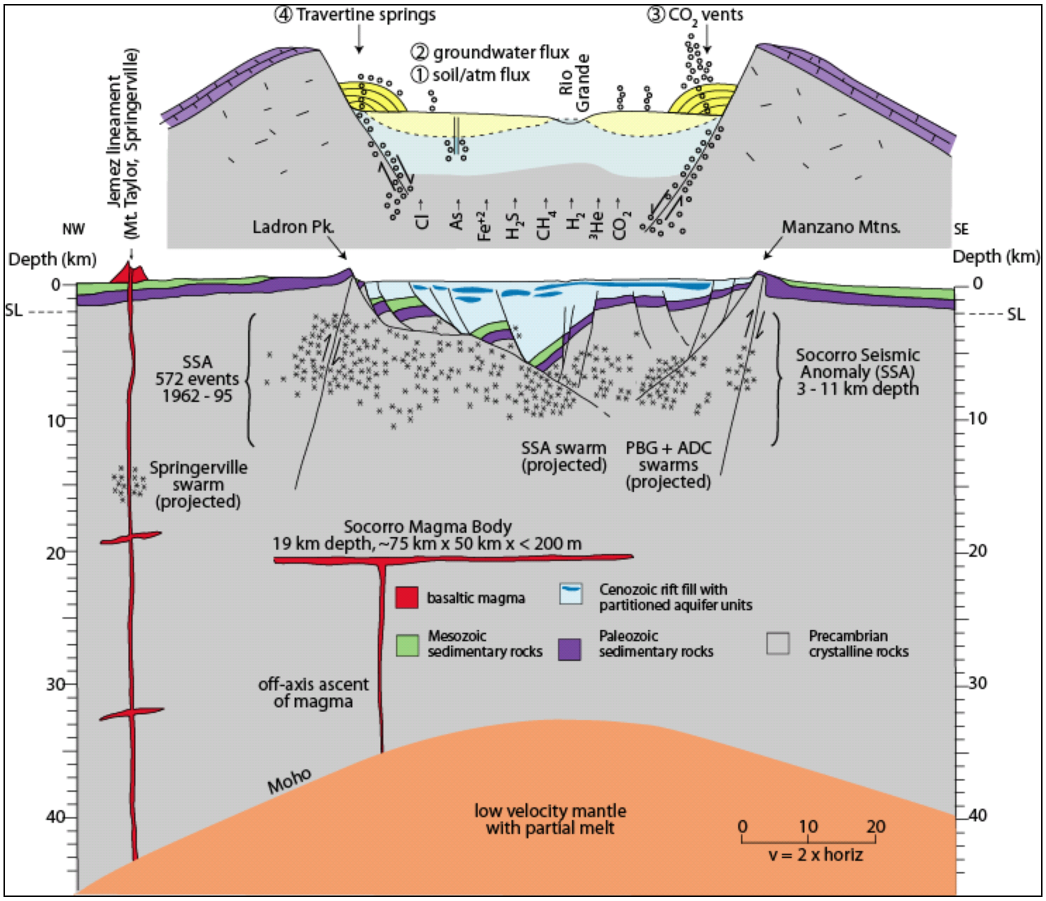


Figure 4. Portions of the rift, and specifically the Sevilleta NWR, are underlain at ~19 km depth by the Socorro Magma Body, interpreted from the Socorro Seismic Anomaly. From Karlstrom (unpublished).

Water-bearing units in the region can be found in geologic layers from the Quaternary to the Precambrian (*Roybal, 1991*). The most productive units are the Quaternary/Tertiary Santa Fe group, the Tertiary volcanics, and the Permian San Andres limestone, Yeso Formation, and Abo Formation (Figure 5). The Santa Fe group aquifer can be divided into separate systems: the shallow upper aquifer (Sierra Ladrones Formation), defined by Anderholm (1984), is in places considered a separate system from the irregularly confined shallow lower Popatosa Formation aquifer, but both are within the Quaternary/Tertiary Santa Fe Group. The lower aquifer is mostly composed of the Socorro volcanic aquifer system. These waters are pumped for irrigation, industrial, stock, and domestic uses. Depth to water ranges from 12 – 546 feet (3.7 – 166.4 meters) in Socorro County (*Roybal, 1991*). For a complete lithologic description, see Roybal (1991).

2.3 Springs and Wells

In a study from 2000-2001, Rawling (2003) reported on the condition and estimated the flow (or cessation of flow) of 26 springs and seeps on the refuge and 4 springs and seeps within close proximity of the refuge, but no chemistry was conducted.

From this preliminary report, 35 spring samples, 11 river samples, and 15 well water samples were collected from the Sevilleta NWR region (Table 1 and Figure 6). Details on each spring and well are outlined in Appendix A. These include San Lorenzo Springs 1-4 (SLS 1-4), Cibola Spring (SdC1), Milagro Seep (SdC3), Silver Creek Seep (SC1), Canyon del Ojito (SA1), Ladron Peak Springs 1 and 14 (LP1, LP14), the Rio Salado at Silver Creek (RS), the Rio Grande above and below the Rio Salado confluence (RGA, RGB), above and below the San Acacia diversion dam (SanA-DD, RG4), a drainage canal across from the San Acacia brine pool (SanA-D); and the San Acacia brine pool (sampled at the large [SanA], middle [SanA-M], and upper pools [SanA-S]). Off of the refuge, 10 springs and 1 river sample were taken, 3 on BLM land just west of the refuge (RSB09, RSB11, RSB12), and 2 at the Abo site of the Salinas Pueblo National Monument (ARS & CE), 1 at the Quarai site for the same monument (QS), and 1 on private land (Dripping Springs [DS]). Two springs, Jump Spring (JS) and “Baca Well” Spring (BWS), were collected south of the Sevilleta NWR on private land. Details on these and additional springs not sampled are outlined in Appendix A.

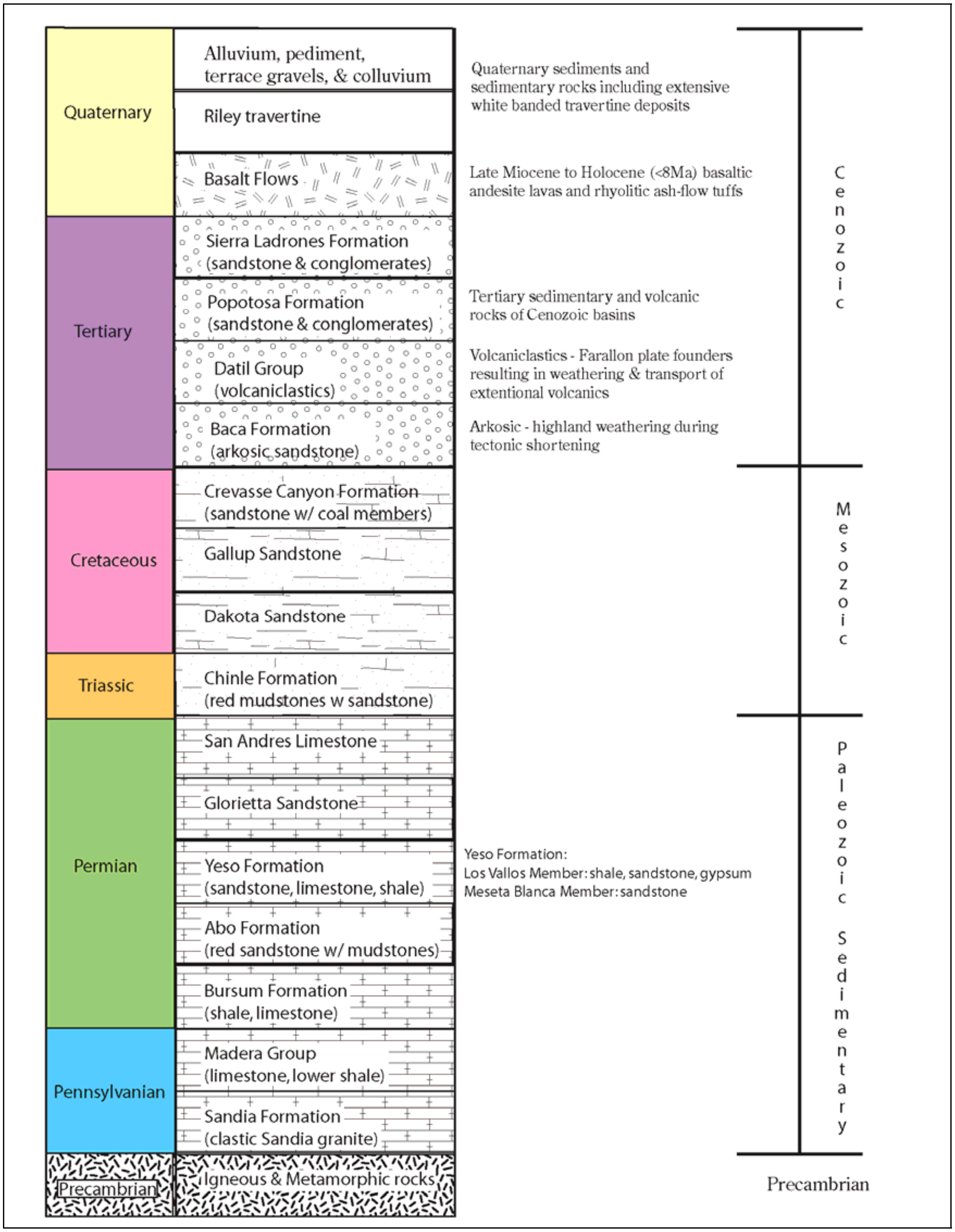


Figure 5. Generalized stratigraphic column of the study area, modified from Zilinski, 1976. The Santa Fe group aquifer consists predominately of the Tertiary Popotosa and Sierra Ladrones formations. Older aquifers active in the Sevilleta NWR include the Permian Abo and Yeso formations, the San Andrea Limestone, the fractured Pennsylvanian Madera limestone, and fractured Precambrian bedrock.

Several wells in the Sevilleta NWR have been modified from their original design as windmill-powered wells for stock tanks to solar-powered wildlife drinker tanks. The US Fish & Wildlife Service report 14 active solar-powered wells on the refuge. Twelve of these wells were sampled. They include, from east to west, Goat Draw Well (GDW), Nunn Well (NW), McKenzie Well (MW), Tomasino Well (TW), Canyon Well (CW), Gibbs Well (GW), the U.S. Fish and Wildlife Service field station (FWS), the Sevilleta LTER field station (SW), Esquival Well (EW), Bronco Well (drinker tank only, BW-T), Tule Well (TUW), and the West Mesa Well (WMW). Two non-Sevilleta wells were sampled; San Acacia Well (SanA-W) and Barella Well (BRW), both from private land and the latter from Abo Pass. The remaining solar Sevilleta NWR wells were not sampled because they were either out of order or extremely difficult to access. Details of all sampled and non-sampled wells are outlined in Appendix A.

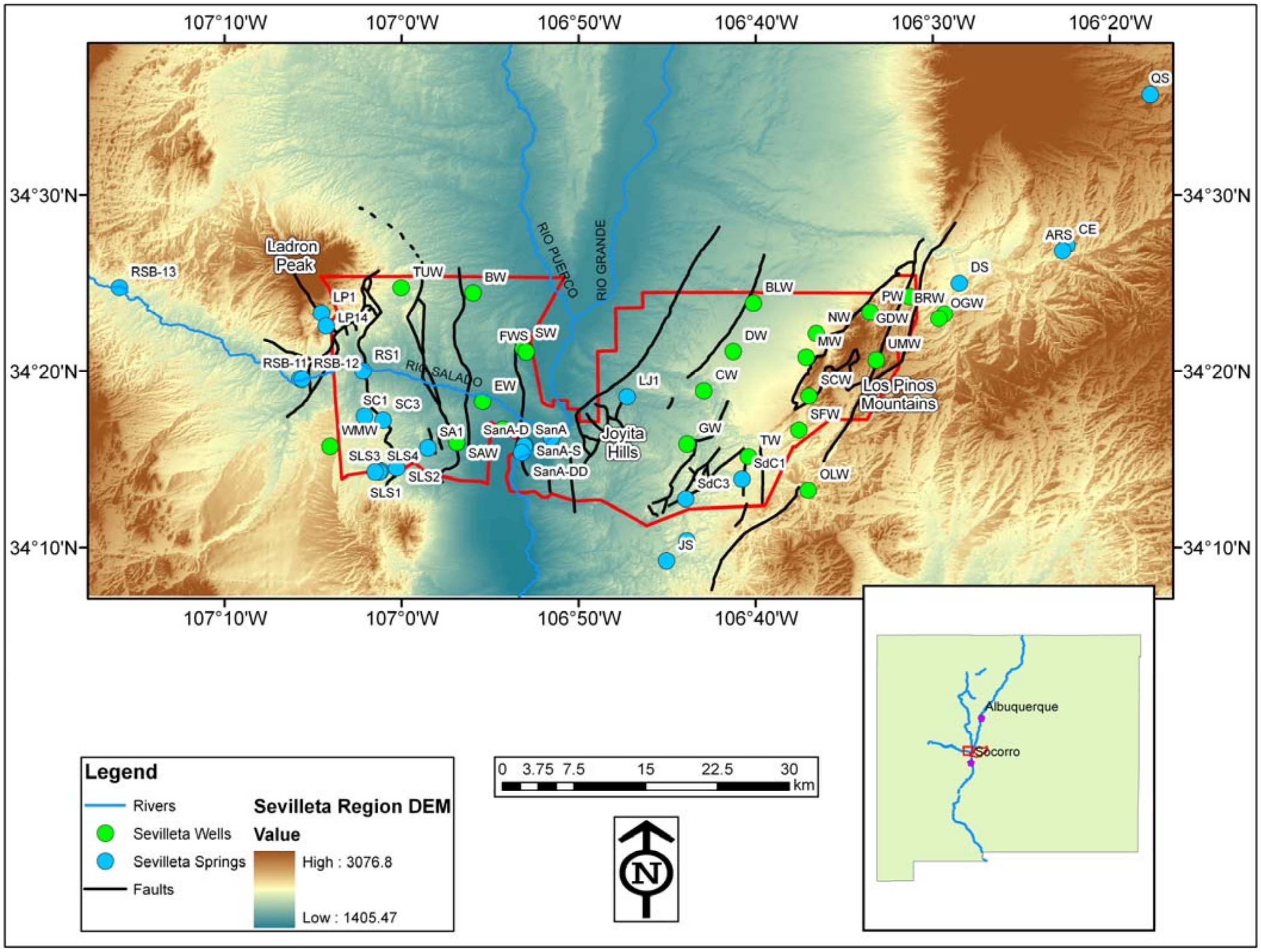


Figure 6. Digital elevation model (DEM) of the Sevilleta National Wildlife Refuge with all potential spring, surface water, and well sites (some of these were not sampled, see Appendix A). Drainages including the Rio Grande, Rio Puerco, and Rio Salado, and major faults within the Sevilleta NWR.

3 Methods

3.1 Water Sampling

Between October 2007 and April 2009, I conducted several trips to the Sevilleta NWR to sample and resample springs, rivers, and wells. Springs were sampled at base flow conditions as close to source outlets as possible. Sites were field-located with portable GPS devices. pH, conductivity, total dissolved solids (TDS), and temperature were measured in the field with an Oakton pH/CON 300 Series pH/conductivity/TDS/°C meter. Dissolved oxygen was measured with a YSI 550A Handheld Dissolved Oxygen meter. All samples were placed on ice in the field and refrigerated until analysis. When possible, spring discharge measurements were made using a bottle and stopwatch system.

Surface water samples were collected in 125 mL (for ions) and 30 mL (for isotopes) HDPE bottles. Prior to collection, each bottle was pre-conditioned three times with the sample water and emptied downstream from the locality. To minimize degassing, all unfiltered, unacidified samples were collected with zero headspace, either by submerging the bottle and capping under water or filling the bottle to overflowing and then capping. Samples destined for ICP analysis were filtered through a 0.45 μm membrane filter attached to the sampling syringe and acidified with 16N HNO_3. Samples destined for IC and alkalinity analysis were not filtered or preserved.

Well water samples were collected in 125 mL (for ions) and 30 mL (for isotopes) HDPE bottles. Wells were purged of up to 3 well volumes of water to ensure groundwater, and not borehole water, was sampled. Well purge times were calculated from the USGS Techniques of Water Resources Investigations Book 9, chapter A4. Prior to collection, each bottle was pre-conditioned three times with the groundwater and emptied outside of the well. Because of well design, some waters were collected from the well in an acid washed 500 mL HDPE bottle attached to an extension to reach the pour point, then used to fill the sample bottles. In these cases, the 500 mL bottle was also pre-conditioned three times with well water. To minimize degassing, all unfiltered, unacidified samples were collected with zero headspace by filling the bottle to overflowing and then capping. The same preservation methods used for surface samples were followed for well samples.

Waters collected for δ^{13}C analysis were unfiltered and preserved in the lab with $HgCl_2$ following the methods of Torres et al. (2005). Samples collected for ^{87}Sr/^{86}Sr, δ^{18}O, and δD were unfiltered, not preserved, and collected with zero headspace.

3.2 Water Analysis

In the laboratory, samples were refrigerated at 4°C in the dark until analysis. To minimize degassing, alkalinity samples were not filtered, as during collection only two samples contained any observable solid precipitates. Alkalinity was measured with the End Point Titration method with an Oakton Ion 6 Acorn Series pH/Ion/ºC Meter and standardized sulfuric acid. Sample bottles were opened directly before alkalinity measurement to preserve the pCO_2 of the sample. Samples were measured between 24 hours and two weeks after collection. Samples with low alkalinity were titrated with 0.02N H_2SO_4; those with high alkalinity were titrated with 0.2N H_2SO_4.

Major ion and trace element chemistry was determined at the Analytical Chemistry Laboratory in the Department of Earth and Planetary Sciences (E&PS) at the University of New Mexico (UNM). Major cations and selected minor elements (to ppm level) were determined on a Perkin-Elmer ICP-OES. Those ions determined include Ca, Mg, K, Na, Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb, Se, Si, Sr, V, and Zn. Major anions were determined on a Dionex DX-500 Ion Chromatograph. Those ions include F, Cl, Br, NO_3, NO_2, PO_4 and SO_4.

Trace element concentrations (to ppb level) and $^{87}Sr/^{86}Sr$ ratios were determined at the Radiogenic Isotope Geochemistry Laboratory in the Department of Earth & Planetary Sciences at UNM. Trace elements, including Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Pb, Se, Si, Sr, V, and Zn, were analyzed with an X-series II ICP-MS. $^{87}Sr/^{86}Sr$ ratios were determined on a Neptune MC-ICP-MS.

Stable isotopes of oxygen, hydrogen, and carbon were determined in the Stable Isotope Laboratory in the Department of Earth & Planetary Sciences at UNM. Oxygen isotope ratios in waters were determined using the CO_2 equilibration technique. The water samples (1 mL each) were injected in borosilicate vials equipped with rubber septa, which were previously purged with He- CO_2 gas mixture (0.5% CO_2). After 24 hours equilibration at 25°C, the CO_2 was measured by continuous flow isotope ratio mass spectrometry using an automated CombiPal – Gas Bench system coupled to a Thermo Finnigan Delta Plus mass spectrometer. The results were corrected using three laboratory standards (calibrated against international water standards) and are reported using the standard delta notation versus V-SMOW. Hydrogen isotope ratios were measured using the continuous flow high temperature reduction method (*Sharp et al., 2001*) using a TC-EA coupled to a Delta Plus XL Thermo-Finnigan mass spectrometer. The water samples (~2 mL each) were injected in borosilicate vials equipped with rubber septa. Carbon isotopes were analyzed by continuous flow on a Finnigan Delta Plus isotope ratios mass spectrometer with a Finnigan MAT GASBENCH 2 front-end. Carbon results are reported in ‰ relative to PDB (PeeDee Belemnite).

4 Application of Select Natural Geochemical Tracers

Environmental tracers of surface and groundwater chemistry can be grouped into two general categories (*Faure, 1986; Witcher et al., 2004*). The first includes major ions and ratios of conservative ions such as Cl, Br, B, and Li. These ions are either conservative or highly soluble and do not participate in the precipitation of minerals. They are therefore ideal to study mixing, salt dissolution, and evaporative concentration (*Hem, 1985; Phillips et al., 2003; Mills, 2003; Newell et al., 2005; Crossey et al., 2006; Crossey et al., 2009*).

The second category includes the use of isotopic compositions. Stable and radiogenic isotopes can be used to identify the relative age due to recharge, recharge source and paleoclimate (*Eby, 2004; Plummer et al., 2004*), and the host rock through which the water flowed (*Clark and Fritz, 1997; Mazor et al., 1997; Eby, 2004; Sharp, 2007*). The use of several isotopic systems allows for the cross-referencing of results. Isotopic systems utilized in this study included the stable isotopes $\delta^{18}O$, δD, $\delta^{13}C$, and the radiogenic strontium ratio, $^{87}Sr/^{86}Sr$.

Additional tools utilized include the use of aqueous geochemical models, such as PHREEQC (*Parkhurst and Appelo, 1999*), to perform chemical speciation, inverse modeling (*Federico et al., 2008),* define the pCO_2 of the waters, and calculate saturation indices with the solid mineral phases of calcite, gypsum, dolomite, and halite. Additionally, Principal Components Analysis (PCA) was utilized as a geochemical tool for providing insight into the structure of multivariate datasets (*Kreamer et al., 1996; Davis, 2002; Lee et al., 2007; Cloutier et al., 2008*).

Water quality can be affected by the original recharge composition, chemical interactions in the aquifer, and anthropogenic influences. The analysis of spatial and temporal variations in water chemistry and isotopic composition is vital to understanding the hydrologic systems in the Sevilleta NWR region.

4.1 Major Ions

Major ion chemistry is useful for delineating the spatial extent of waters with similar chemical signatures. This is directly relatable to the chemical evolution of the groundwaters which in turn significantly affected by the rocks through which the water has travelled (*Kreamer et al., 1996; Plummer et al 2004, Rawling et al., 2008; Crossey et al., 2009*). Piper diagrams are used to illustrate the relative concentrations of cations and anions. These are then projected onto the "diamond" portion of the diagram for joint interpretation as waters with similar chemistries should plot in the same region. Figure 7 explains how to read a Piper diagram. Here, hydrochemical facies are defined as waters with distinct chemistries in large part similar to the standard facies shown in Figure 7.

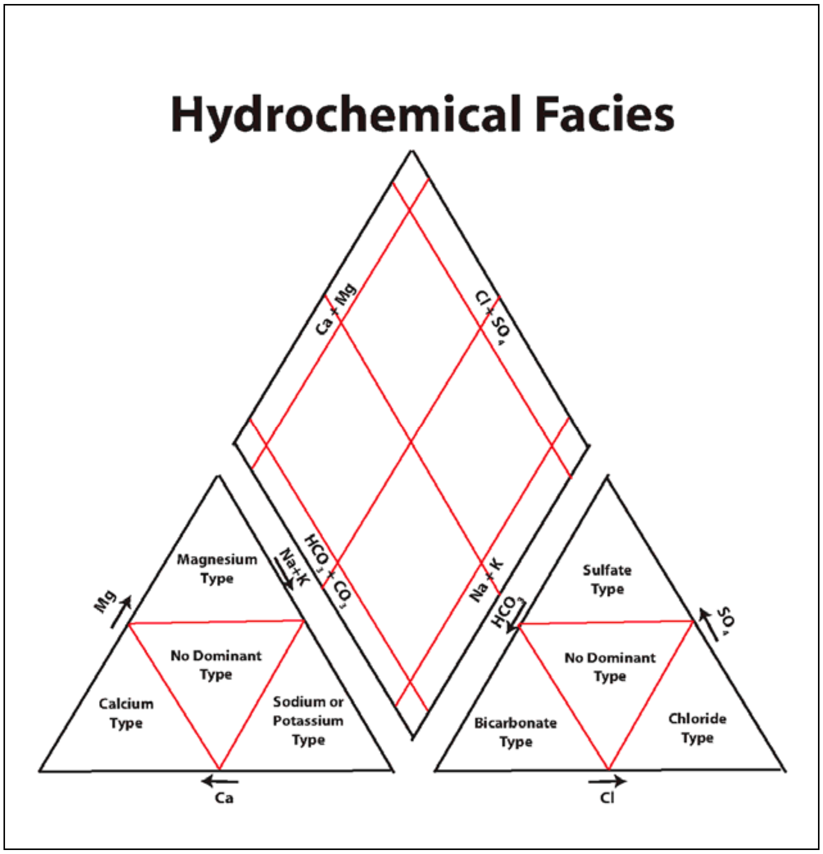


Figure 7. Modified from Back, 1966, a Piper diagram can be interpreted based on the combination of cation and anion pairs. The chemistry of a sample will plot on a specific point, which can be described via different geochemical endmembers.

4.2 Cl/Br ratios

Chloride and bromide are found in all natural waters and are useful as flow path tracers due to their predictable ratio changes due to dynamic geologic processes (*Ullman, 1985; Fabryka-Martin et al., 1991; Herczeg et al., 1991; Herczeg et al., 2001; Fontes and Matray, 1993; Love et al., 1993; Bottomley et al., 1994; Simpson and Herczeg, 1994; Herczeg and Edmunds, 2000; Kloppmann et al., 2001; Cartwright et al., 2004; Gascoyne, 2004; Cartwright and Weaver, 2005; Cartwright et al., 2006*). Cl/Br ratios in precipitation differ in an expected manner with location. While oceans (and coastal precipitation) have a constant molar Cl/Br ratio of approximately 650 (*Drever, 1997; Davis et al., 1998; Davis et al., 2001*), precipitation in arid or semi-arid climates may have lower Cl/Br ratios due to the tendency for Cl to be removed by deposition of marine aerosols in coastal areas (*Fabryka-Martin et al., 1991; Davis et al., 1998; Davis et al., 2001; Edmunds, 2001*).

After precipitation, several different natural and anthropogenic processes may alter Cl/Br ratios. Cl/Br ratios may be decreased by organic adsorption (*Gerritse and George, 1988*), and due to the exclusion of the Br ion from halite's mineral structure, Cl/Br ratios of halite are often reduced to 104–105 (*McCaffrey et al., 1987; Kloppmann et al., 2001; Cartwright et al., 2004*). Thus, halite dissolution will produce a rapid increase in Cl/Br ratios with increasing Cl concentrations. Evapotranspiration does not change Cl/Br ratios until halite saturation occurs and incongruent dissolution begins (at approximately 6.2 mol/L NaCl) at which point the brine becomes relatively enriched in Br over Cl (*Land and Prezbindowski, 1981; Fontes and Matray, 1993; Bottomley et al., 1994; Dutkiewicz et al., 2000*). Additional sources of elevated Br include membrane filtration and ion exchange (as Cl passes more readily than Br through clay) (*Kharaka and Berry, 1973*) and the presence of organic Br (*Means and Hubbard, 1985*).

4.3 Stable Isotopes of ^{18}O and D

Stable isotopes of hydrogen and oxygen are useful conservative hydrochemical tracers, as the stable isotope ratios in groundwaters are affected predictably by rock-water interaction, evaporation, and mixing (*Clark and Fritz, 1997; Guay and Eastoe, 2007*).

Specifically, δ^{18}O and δD are useful for determining different water sources, as well as identifying the altitude and climatic conditions in effect during the recharge time (*Mazor, 1997; Eby, 2004; Plummer et al., 2004, Sharp, 2007*). δ^{18}O is defined by:

$$\delta^{18}O = \frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample} - \left(\frac{^{18}O}{^{16}O}\right)_{s\tan dard}}{\left(\frac{^{18}O}{^{16}O}\right)_{s\tan dard}} x1000 \quad (\textit{Sharp, 2007})$$

Approximately 0.2% of all oxygen atoms are ^{18}O, and approximately 0.016% of hydrogen atoms are ^{2}H or D (deuterium). The ratio in parts per thousand of the heavier to lighter isotope (^{18}O /^{16}O or D/H) is expressed in the delta notation (δ^{18}O or δD) relative to the standard V-SMOW (Vienna Standard Mean Ocean Water). Negative values indicate depletion of the heavier isotope, (often referred to as a 'light' isotopic signature or ratio) (*Faure, 1986; Drever, 1997; Sharp, 2007; Rawling et al., 2008*). The Global Meteoric Water Line (GMWL) was developed as a reference line by Craig (1961) and represents the mean values of δD and δ^{18}O for world precipitation as the equation δD = 8*δ^{18}O+10. Commonly, precipitation in warmer climates (or summer) will plot on the heavier end of the GMWL, while precipitation in colder climates (or winter) will plot on the lighter (more negative) end.

Local meteoric water lines will typically plot with a slope close to 8 and with deuterium excess, which causes isotopic ratios to plot to the right of the GMWL (*Witcher, 2004*) (Figure 8). This deuterium excess (*Dansgaard, 1964*) is due to two factors: 1) evaporation, where waters develop a heavier isotopic ratio due to the preferential evaporation of lighter isotopes, and which generates a slope between 2 and 5 (*Clark and Fritz, 1997*), and 2) old and geothermal waters that undergo water-rock interaction and hydrothermal alteration will maintain their deuterium values while concentrating the heavier ^{18}O values, forcing the waters to plot horizontally to the right of the GMWL (Figure 8) (*Witcher et al., 2004*).

Lastly, latitude and altitude can exercise the most control over stable isotope values in precipitation, which can then be used to differentiate recently recharged waters from older subsurface waters recharged in the Pleistocene. δ^{18}O and δD values become lighter with increasing latitude due to the increase in rainout. Values (especially δ^{18}O) also become lighter with increasing altitude due to the fact that colder air masses hold less moisture (*Sharp, 2007*).

Local meteoric water lines for regions in central and southern New Mexico and the distribution of δD and δ^{18}O for the Rio Grande from CO to TX (Figure 9) are included as references for the Sevilleta NWR, as no LMWL exists for this region.

4.4 ^{87}Sr/^{86}Sr

The ^{87}Sr/^{86}Sr ratio is a valuable tool for interpreting flow paths by identifying the Sr signatures from the rocks with which the water has interacted (*Faure, 1986; Drever, 1997*). Sr ions commonly replace Ca ions in mineral structures because they have

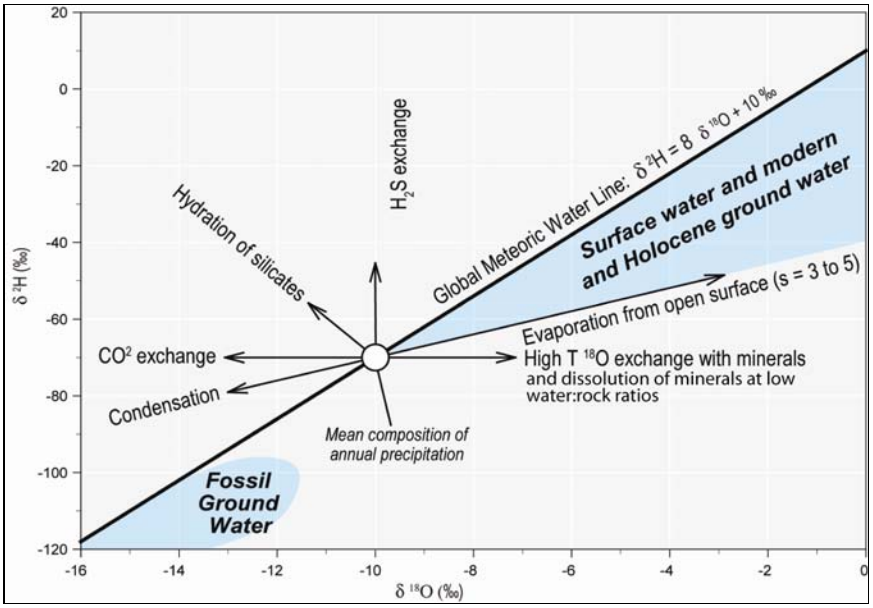


Figure 8. δ^{18}O versus δD illustrates the processes responsible for isotopic variation from the GMWL. The mean composition of annual precipiation is only an example and is not representative of the waters analyzed in the study. Modified from Bauer et al., 2007.

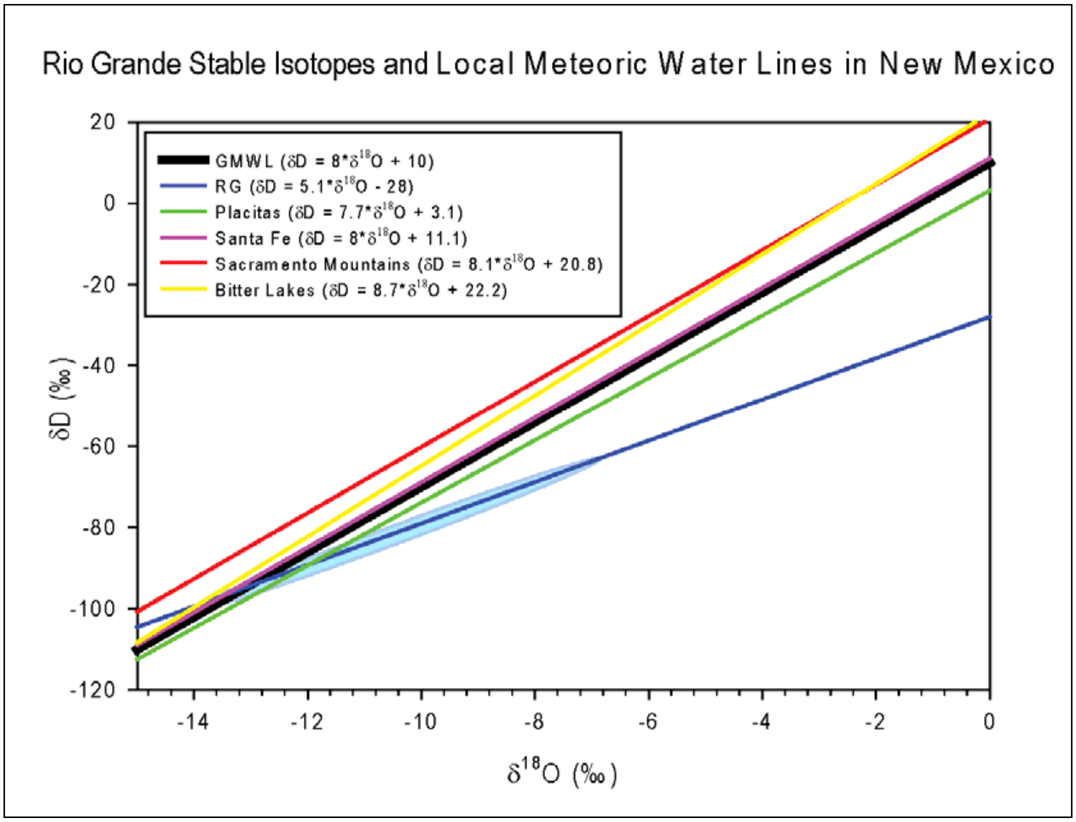


Figure 9. LMWL for regions in New Mexico. (Placitas Line [Johnson et al., 2002], Santa Fe Line [Anderholm, 1994], Sacramento Mountains Line [Peggy Johnson and Talon Newton, pers. communication], Bitter Lakes Line [Peggy Johnson and Lewis Land, pers. communication]). RG = Rio Grande stable isotopes, from headwaters in CO to TX, shown for comparison (Witcher, 2004). Blue oval on RG line denotes the actual data from the Rio Grande which represents the line.

similarly sized atomic radii and charge. The natural reservoir of radiogenic ^{87}Sr is increasing due to β-decay of ^{87}Rb, with a half-life of 48.8 x 10^9 years. ^{87}Rb can replace K due to their similar atomic radii, therefore both Ca-rich and K-rich rocks can develop high concentrations of ^{87}Sr. Because the mass differences between the isotopes of Sr are so small, the ^{87}Sr/^{86}Sr ratio is not changed by fractionation due to chemical or physical alterations (*Faure, 1986; Capo et al., 1998; Stewart et al., 1998*). The primordial ^{87}Sr/^{86}Sr ratio of 0.699 (which is determined from meteorites) has been increasing over time due to the decay to ^{87}Rb (*Clark and Fritz, 1997; Eby, 2004*).

Paleozoic marine carbonates exhibit variations in their initial $^{87}Sr/^{86}Sr$ ratios. These variations reflect large scale changes in weathering rates and terrestrial radiogenic Sr sources (*Burke et al., 1982; McArthur et al., 2001; Veizer et al., 1999*).

Radiogenic Sr is an ideal tracer with which to illustrate endmember mixing, especially with epigenic and endogenic waters such as those found in the Sevilleta NWR. The radiogenic Sr signal is high in deep crustal granites and granodiorites (specifically the Precambrian granites of the Southwest), and lower in volcanics and sedimentary sequences.

4.5 $\delta^{13}C$ and External Carbon

Carbon has three isotopes: ^{12}C is the abundant isotope, constituting 98.89% of all C isotopes. The stable isotope ^{13}C is 1.11% (*Witcher et al., 2004; Sharp, 2007*), while the radiogenic ^{14}C abundance is $1*10^{-10}$%. The ratio of $^{13}C/^{12}C$ is reported in delta notation as $\delta^{13}C$, relative to the PeeDee Belemnite (PDB) calcite standard (*Sharp, 2007*).

Figure 10 illustrates the distribution of carbon and $\delta^{13}C$ in the Earth. The mantle is by far the largest reservoir and has a distinctive -6‰ $\delta^{13}C$ signature (*Dienes, 1970; Kyser, 1986; Sheppard, 1986; Sharp, 2007*), which is useful for differentiating between organic C and mantle derived sources. $\delta^{13}C$ can be a useful tool for understanding the sources of CO_2 in aqueous systems. Waters with atmospherically derived carbon will have $\delta^{13}C$ values that range from -4 to -15‰, with an average $\delta^{13}C$ of ~-7‰ (*Drever, 1997*). Mack et al. (2000) report carbonate deposits in south central New Mexico to have $\delta^{13}C$ values between -2.2 and -5.5‰, while Monger et al. (1998) reported the $\delta^{13}C$ of organic carbon to be between -15.7 and -25‰.

Most mantle carbon enters the surficial reservoirs via mid-ocean spreading centers (*Sharp, 2007*), although mantle signatures have been discovered in terrestrial systems associated with volcanic regions, and regionally in springs of the Colorado Plateau and Rio Grande Rift (*Newell et al., 2005; Crossey et al., 2006; Crossey et al., 2009*). The other possible sources of surficial carbon are: 1) dissolution of calcite, aragonite, or dolomite that releases heavy carbon; 2) oxidation of organic material that releases lighter carbon; 3) transport of CO_2 gas from a soil atmosphere that also releases light carbon (*Sharp, 2007*); or 4) from a deep seated source (lithospheric/asthenospheric mantle) that releases heavy carbon (*Crossey et al., 2006; Crossey et al., 2009*).

To identify sources of CO_2 in the study area, water chemistry was used to estimate the contribution of carbonates to the total CO_2 in a modified approach to the methods of Chiodini et al. (2000, 2004). Using this method, the "external" or "excess" CO_2 ($C_{external}$) is estimated by subtracting out the contributions from carbonate dissolution (C_{carb}). $C_{external}$ can then be separated into contributions from organic matter ($C_{organic}$) and crustal/mantle derivation ($C_{endogenic}$). For this project, we differentiate CO_2 sources to the $C_{external}$ division level. Subtraction of carbonate dissolution is accomplished via the following set of equations (all ions are presented as mol/L):

$Ca_{gyp} = Ca - SO_4$

If Ca_{gyp} is negative ($SO_4 > Ca$), then it is corrected to zero (Ca_{gyp}^*)

$C_{carb} = Ca_{gyp}^* + Mg$

$C_{external} = HCO_3 - Ca_{gyp}^* - Mg$ (from *Crossey et al., 2009)*

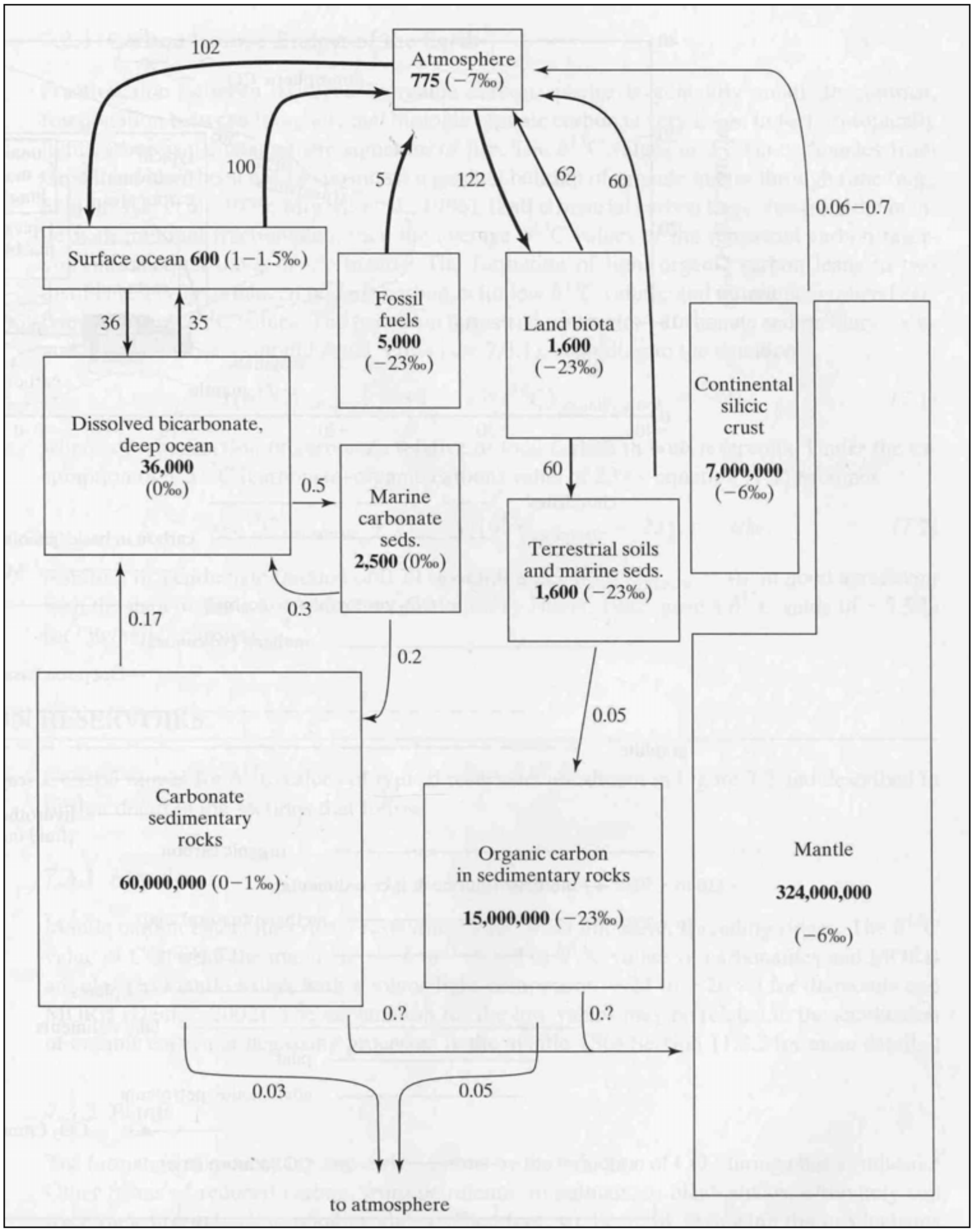


Figure 10. Carbon cycle, showing amounts, fluxes, and δ^{13}C values for Earth's reservoirs. Amount is in 10^{15}g. δ^{13}C values are in parentheses. Flux arrow thickness is proportional of relative rate. From Sharp, 2007.

Measured HCO_3, Ca, Mg, and SO_4 concentrations can be used to calculate 1) the [Ca] due to gypsum dissolution (Ca_{gyp}), then 2) the [HCO_3] derived from Ca/Mg carbonate dissolution (C_{carb} = [Ca+Mg-SO_4]). The external carbon is then $C_{external}$=DIC-C_{carb}, where DIC = dissolved inorganic carbon. This method assumes that Ca + Mg concentrations from silicate-water interaction are insignificant.

4.6 Principal Components Analysis (PCA)

The geostatistical software program Vista was used to calculate the Principal Components of the dataset. PCA is a method for transforming data to expose a simple pattern that is assumed to exist in a multivariate dataset (*Davis, 2002*). The utilization of PCA on the major, minor, and trace element measurements from spring and well waters can be useful for differentiating waters with similar chemistries, but different sources (*Kreamer et al., 1996; Cox, 1996; Yelken, 1996; Reghunath et al., 2002; Yacob, 2004; Cloutier et al., 2008*), as well as studies constraining saline water intrusion (*Laaksoharji et al., 1999b; Lee et al., 2007*). Previous investigations have demonstrated that groundwaters obtain their trace elements from the rocks through which they have flowed. This suggests that PCA is an excellent method for identifying groundwater flow paths in the Sevilleta NWR, as several springs with unique chemistries may issue from one geologic unit, but the predominant flow path is through a different lithology. The application of three principal components is the common method utilized for delineating similar hydrochemical facies, as the first three principal components typically represent the majority of the dataset variability (*Lee et al., 2007*).

PCA was applied to a subset of the Sevilleta NWR geochemical dataset that consisted of 31 water samples and 10 parameters. These parameters include pH, Na, K, Ca, Mg, HCO_3, Cl, SO_4, δD, and $\delta^{18}O$. Some parameters were excluded due to the following reasons: 1) variables with "additive characteristics" (*Cloutier et al., 2008*) such as TDS and conductivity; 2) variables where most samples have concentrations below the detection limit, such as NO_3, PO_4, and trace elements such as arsenic, 3) variables not analyzed for most of the sample set i.e. $^{87}Sr/^{86}Sr$, $\delta^{13}C$, and DO, and 4) variables that show small variation such as SiO_2.

5 Results

5.1 Water Chemistry

Data for selected field parameters (latitude, longitude, pH, temperature and conductivity) are shown in Table 1. The waters sampled for this study range in pH from 5.7 to 9.8, range in temperature from 2.8°C to 31.6°C, are dilute to saline (640 [SC1] to 53,800 [SanA] μS), and have alkalinities of 56.1 to 526 ppm HCO_3 (Table 2). Plummer et al. (2004) reported that the bulk precipitation for the Sevilleta NWR (1989-1995) had a pH of 5.4.

The Sevilleta NWR waters exhibit variable endmembers including chloride, bicarbonate, and sulfate endmembers (Figure 11). Newell et al. (2005) suggested that "these hydro[chemical] facies may correlate to different tectonic provinces in the Rio Grande rift".

5.1.1 Major Ions

This suite of geochemical tracers was used to analyze the geochemistry of 46 surface samples and 15 wells in and near the Sevilleta NWR. Water compositions cluster into five distinct hydrochemical facies (Figure 11): 1) a **Na-Cl** composition [18 sites]; 2) a **mixed cation-HCO_3** composition [6 sites]; 3) a **Ca-SO_4** composition [4 sites]. The fourth hydrochemical group was a **mixed cation/anion** composition [15 sites] and corresponds to local precipitation chemistry; and 5) a **Na-mixed anion** composition [1 site] (Table 2).

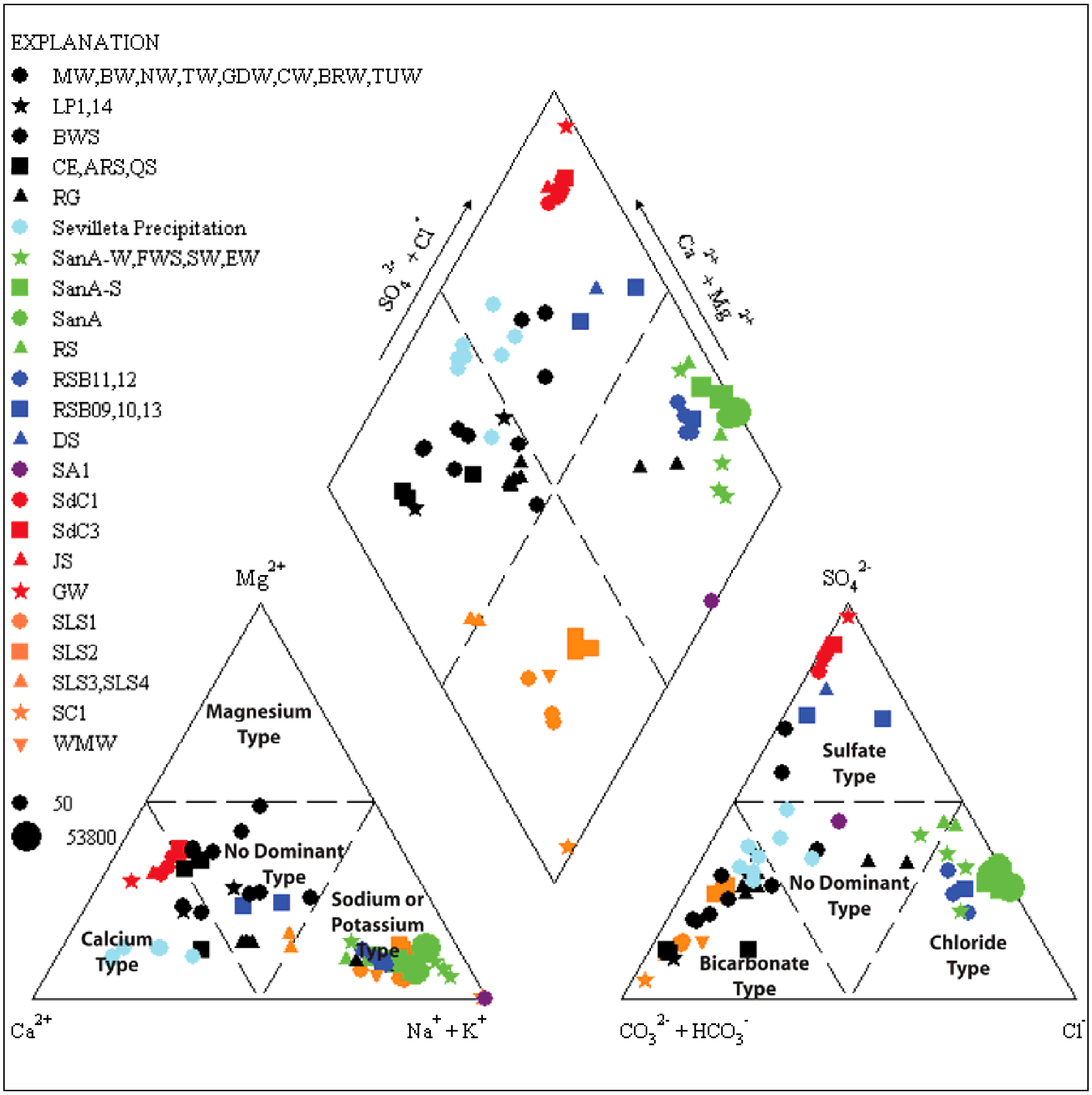


Figure 11. Detailed Piper diagram color coded to illustrate the major chemistry of the Sevilleta NWR waters. The projection of the chemistries on this figure demonstrates that the waters collected represent every major potential hydrochemical group. Symbol size corresponds to total dissolved solids (TDS, 50-53800ppm).

5.1.2 Nutrients

Nutrient analyses can be useful for understanding nutrient limitations and determining the health of an ecosystem. Total dissolved nitrogen (TDN) and dissolved organic carbon (DOC) were determined for a select number of Sevilleta NWR springs and wells. TDN values ranged from 6.04 ppm N (TW) to 0.10 ppm N (SW). DOC values ranged from 32.49 ppm C (SanA) to 1.90 ppm C (WMW). These values are reported in Table 3.

5.1.3 Trace Elements

Barium, fluoride, boron, and arsenic are consistently higher in CO_2-charged springs (*Newell et al., 2005; Crossey et al., 2006*) and are often associated with higher salt content (*Plummer et al., 2004; Crossey et al., 2009*). Table 4 lists the concentrations of As, B, Ba, Li, and Sr. Only a few sites exhibited elevated levels of these trace elements (>1 ppm), including, **[As]** SA1, **[B]** RS, all SanA pools, SanA-D, SdC1, SdC3, RSB11, RSB12, SanA-W, FS, SW, **[Ba]** RSB10, RSB11, RSB12, RSB13, **[Li]** SanA and SanA-M, RSB10, RSB11, RSB12, and **[Sr]** RS, all SanA pools, SanA-D, SanA-DD, SdC1, SdC3, RSB10, RSB11, RSB12, RSB13, DS, JS, BWS, SanA-W, FWS, TW, GW, CW, EW, BRW, and TUW. Table 5 contains the concentrations of an additional twenty-four trace elements.

5.1.4 Cl/Br ratios

[Cl] ranged from 6.04 (SC1) to 26,964 ppm (SanA) and [Br] ranged from 0.02 (RG) to 21.8 ppm (SanA). The Cl/Br ratios for the major anion groups are as follows: Cl/Br ratios of HCO_3–dominated water ranged from 20.4 (SC1) to 155 (SLS3); Cl/Br ratios of SO_4–dominated water ranged from 13.5 (SdC3) to 149 (SdC1); and Cl/Br ratios of Cl-dominated water ranged from 352.7 (RGA) to 2834.0 (RS). Cl/Br ratios can be found in Table 2.

5.2 Stable Isotopes of $\delta^{18}O$ and δD

Stable isotopes of well waters generally fall along the GMWL, while springs and river waters plot to the right of the GMWL. Well waters range from -51.6 to -88.1‰ (δD) and -7.5 to -11.7‰ ($\delta^{18}O$), while springs and surface waters range from -41.7‰ to -73.1‰ (δD) and -5.1‰ to -9.3‰ ($\delta^{18}O$). The San Acacia lower brine pool had a δD value of 1.6 and a $\delta^{18}O$ value of 8.3. Stable isotopes of $\delta^{18}O$ and δD are reported versus V-SMOW in Table 4.

5.3 Stable Isotopes of $\delta^{13}C$

Stable isotopes of C ranged from –2.6‰ (GW) to –18.2‰ (RSB12) versus PDB. The RSB12 sample was previously reported in Newell, 2007. The next heaviest sample was –14.8‰ (RGA). The $\delta^{13}C$ (CO_2) values are presented in Table 4.

5.4 $^{87}Sr/^{86}Sr$

$^{87}Sr/^{86}Sr$ ratios from the Sevilleta NWR ranged from 0.7090 (SdC1) to 0.7152 (RSB12). Several of these values fall within the range of 0.706-0.710 for marine carbonate values (*Crossey et al., 2006*), and all are lower than the range of 0.735 - 0.740 for granitic basement (value from the Colorado Plateau, which is comparable to Rio Grande rift granitic basement)(*Crossey et al., 2009*). $^{87}Sr/^{86}Sr$ ratios are reported in Table 4.

5.5 Principal Component Analysis

The majority of dataset variance is accounted for by the first three principal components (PC) calculated from 10 eigenvectors corresponding to the chemical variables in Figure 12 and including the San Acacia lower brine pool. The first PC accounts for 69.4% of the total variance in the dataset, while the second PC accounts for

14.6% and the third PC, 6.9%. This shows that 90.9% of the proportion of variance can be accounted for by the first three principal components.

The process was repeated with the same 10 eigenvectors, but the San Acacia lower brine pool was not included in the analysis. The first PC accounts for 55.4%, the second PC accounts for 16.8%, and the third PC, 10.3% of the total variance in the dataset. This shows that 82.6% of the proportion of variance can be accounted for by the first three principal components. See Table 6 for the principal component values of these variables and Table 7 for the principal component values of the sampling sites.

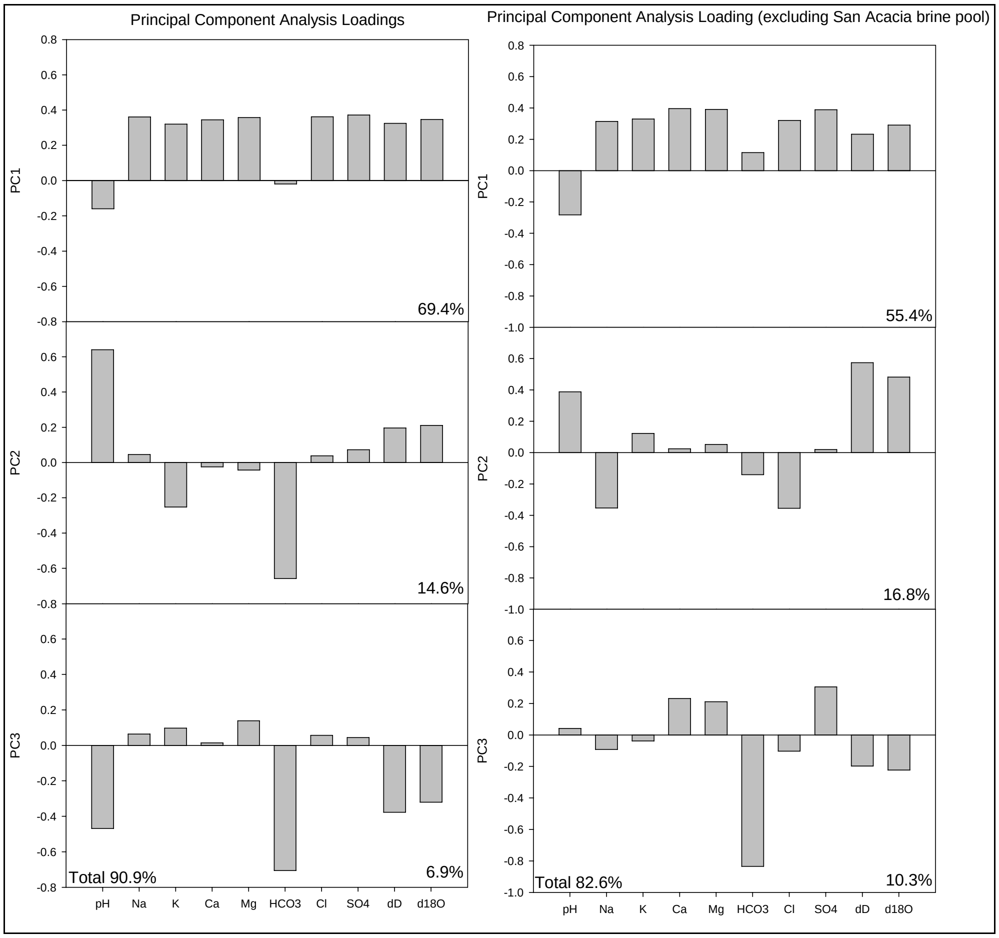


Figure 12. Distribution of first, second, and third principal component loadings for 10 chemical variables from the springs, surface, and well waters in the Sevilleta NWR. Graph 1 shows the loadings for 37 waters, including the San Acacia brine pool. Graph 2 shows the loadings for 35 waters, not including the lower brine pool. Subsequent PCA figures will be for the analysis that excludes the lower brine pool.

5.6 PHREEQC

PHREEQC version 2 is a program developed by the USGS (*Parkhurst and Appelo, 1999*) to perform low-temperature aqueous geochemical calculations. The code was used to evaluate the state of saturation with respect to mineral phases as well as to compute equilibrium pCO_2 based on pH, alkalinity, and ionic strength. It was also used to speciate all waters sampled and calculate the saturation indices of calcite, gypsum, dolomite, halite, and CO_2, as well as perform binary mixing modeling and inverse modeling to identify potential endmember chemistries.

5.6.1 Saturation Indices

The saturation indices computed for some secondary minerals, such as calcite, dolomite, gypsum, and halite, are reported in Table 8. These minerals were chosen as the likely minerals affecting water chemistry through solution/precipitation reactions based on geologic mapping efforts. Most waters in the Sevilleta NWR are supersaturated with respect to calcite and undersaturated with respect to gypsum (Figure 13). Those that are undersaturated with respect to calcite are two San Lorenzo Spring 2 (SLS2) samples, the Rio Grande below the diversion dam (RG4), one Cibola Spring (SdC1) sample, Rio Salado Box 12 Spring (RSB12) and Riley Spring (RSB13), Ladron Peak Spring 1 (LP1), Sevilleta Field Station well (SW), Barella well (BRW), and Tule Well (TUW). It is noteworthy that RSB12 is undersaturated with respect to calcite, although it flows through the Pennsylvanian Madera limestone. Those waters that are supersaturated with respect to gypsum are two San Acacia brine pool (SanA) samples and Milagro Seep (SdC3), which sources from the gypsiferous Permian Yeso Formation .

Groundwater equilibrated with atmospheric CO_2 should have a $pCO_2 < 10^{-3.5}$ (partial pressure of CO_2 at atmospheric pressure) (*Drever, 1997; Crossey et al., 2006)*. Using PHREEQC, the pCO_2 values of all Sevilleta NWR springs and wells has been calculated, yielding the following: 6 samples have pCO_2 values $<10^{-3.5}$ and 42 samples have pCO_2 values between $10^{-3.5}$ and 10^{-2}. The other 14 samples have pCO_2 values ranging from $10^{-1.98}$ to $10^{-0.21}$ (Table 8).

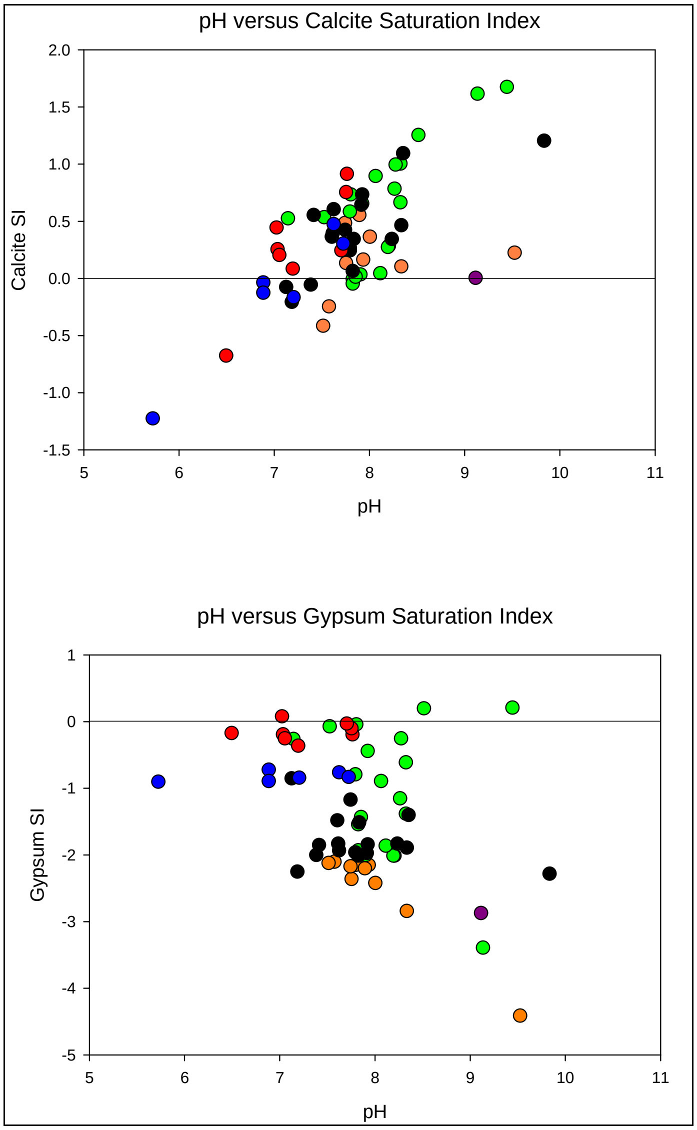


Figure 13. pH versus saturation indices of calcite and gypsum. Most samples in the Sevilleta NWR are supersaturated with respect to calcite and undersaturated with respect to gypsum. Symbol colors are the same as in Figure 11.

5.6.2 Binary (Two-component) Mixing Models

Binary (or simple two-component mixing) modeling was used to account for the changes in chemistry that may occur during diagenetic alteration. Modeled mixtures between endmembers can be used to estimate the composition of intermediate waters in the study area. Figure 14 shows the evolution between a low salinity mixed ion water and the San Acacia upper pool (dashed line) and the evolution between the RSB12 spring and the San Acacia upper pool (solid line) in terms of calcite saturation index and TDS (ppm).

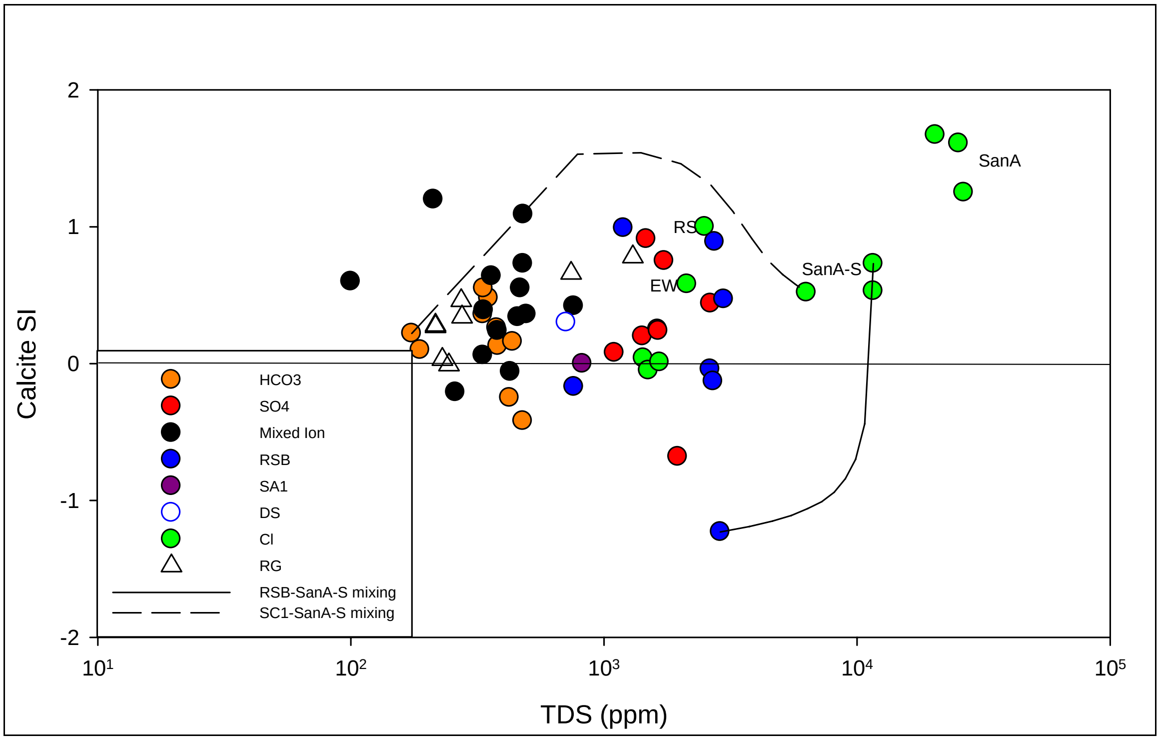


Figure 14. Calcite saturation indices versus TDS (ppm). Solid line represents the evolution of the RSB12 spring and the San Acacia upper pool. Dashed line represents the evolution of SC1 (mixed ion water) to the San Acacia upper pool.

5.6.3 Inverse Modeling

Inverse modeling was utilized to calculate mass balance exchanges to identify evolution between rainwater and select springs from the hydrochemical facies previously defined. The major ion chemistry was the basis for choosing select solid phases as reactants in these processes. The user defines the initial and final water compositions and the solid phases allowed to evaporate, precipitate, and dissolve. The set of equations by which the model solves for solid phases is outlined in Federico et al. (2008). Additional explanations of inverse modeling can be found in Glynn and Brown (1996), Parkhurst (1997), Lecomte et al. (2005), and Glynn and Plummer (2005).

6 Discussion, Modeling, & Regional Interpretations

6.1 Major Ions

The five hydrochemical facies can be defined by their endmember composition (Figure 15). The first group is a **Na-Cl** composition which consisted of the San Acacia brine pools (SanA, SanA-M, SanA-S), Rio Grande diversion channel (SanA-D) and Rio Grande above the San Acacia dam (SanA-DD), Rio Salado Box Springs (RSB-11 and 12) and river at Silver Creek and above and below the Rio Salado Box Springs (RS, RSB10, and RSB09, respectively), and the Sevilleta (SW), Fish and Wildlife (FWS), Esquival (EW), and San Acacia (SanA-W) wells. The second group, with a **mixed cation-HCO_3** composition, consisted of the San Lorenzo Springs (SLS1-4), West Mesa well (WMW), and Silver Creek Seep (SC1). The third group, with a **Ca-SO_4** composition, consisted of Cibola Spring (SdC1), Milagro Seep (SdC3), Jump Spring (JS), and Gibbs (GW) well. The fourth group, with a **mixed cation/anion** composition that corresponds with local precipitation chemistry, consisted of the Rio Grande at the confluence of the Rio Salado (RGA, RGB), Ojo del Abo Spring (ARS), Canon Espinoza Seep (CE), Quarai Spring (QS), Baca Well Spring (BWS), Ladron Peak Springs (LP1 and 14), Tomasino (TW), Nunn (NW), McKenzie (MW), Goat Draw (GDW), Canyon (CW), Bronco (BW), Barella (BRW), and Tule (TUW) wells. The fifth, with a **Na-mixed anion** composition, consisted of Canyon del Ojito Spring (SA1). The average precipitation chemistry for eight meteorological stations on the Sevilleta NWR (east and west sides) for one year is also reported in Figure 15. The bulk precipitation chemistry for the Sevilleta NWR from 1989-1995 is reported in Table 9.

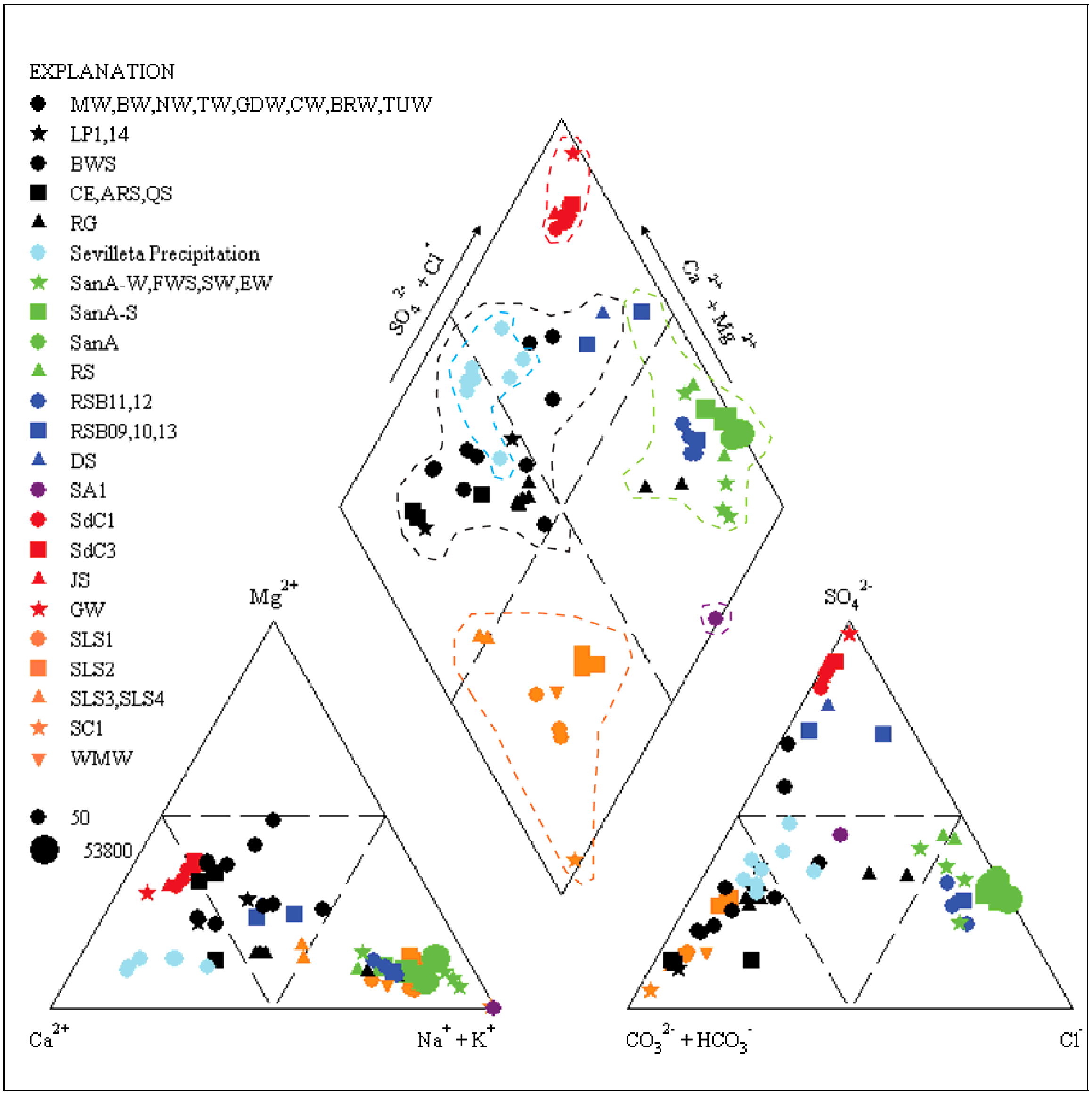


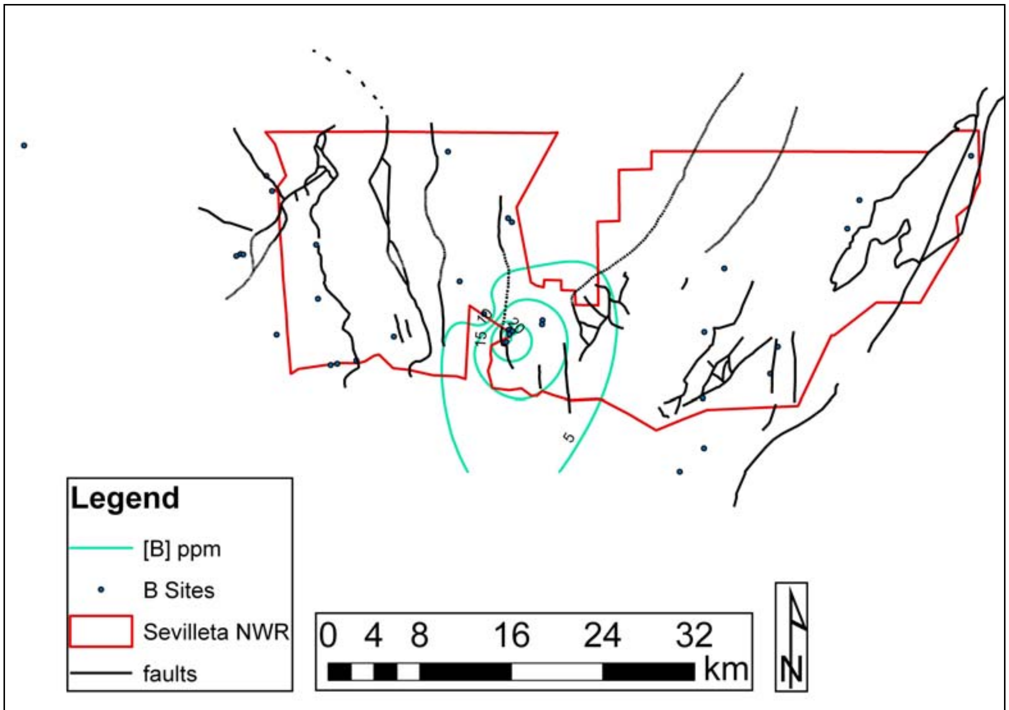
Figure 15. Piper diagram of Sevilleta NWR waters with hydrochemical facies delineated. The first is a Na-Cl composition (green outline), the second a mixed cation-HCO_3 composition (orange outline), the third a Ca-SO_4 composition (red outline), the fourth a mixed cation/anion composition that corresponds with local precipitation chemistry (black outline; blue outline for precipitation only), and the fifth a Na-mixed anion composition (purple outline). Symbols are scaled based on TDS (50-53800ppm).

6.2 Trace Elements

Elevated levels of B, Ba, Li, and As are often associated with the presence of a geothermal component (*Plummer et al., 2004; Crossey et al., 2009*) and As concentrations were found to exceed US drinking waters standards (10 ppb) in some springs (*CFR, 2004*). In the Sevilleta NWR, sites of elevated conductivity also correspond to elevated trace element concentrations at the San Acacia brine pool and Rio Salado Box (Figure 16), and often elevated trace element concentrations are consistent with geothermal and deeply-circulated waters (*Witcher et al., 2004*).

Trace element spidergrams were developed for select elements from most waters. Trace element concentrations for Ba, Li, Sr, Al, B, Cu, Fe, Mn, and Si were plotted in Figure 17 to show the relative concentrations of elements in the hydrochemical facies previously defined. Most waters demonstrated elevated concentrations (>0.1ppm) of Sr, Al, B, and Si which can be derived from their host rocks, but the Cl-rich waters (green) which have the highest concentrations of trace elements of all waters may have a different source.

Figure 18 is a spidergram of the same trace elements for the Cl-rich waters only. The San Acacia system (SanA) and the Rio Salado Box springs (RSB) have the highest trace element concentrations of all Cl-rich waters (red and blue hatch marks, respectively). This trend suggests that these spring systems derive from a similar, deep source that may carry a geothermal component.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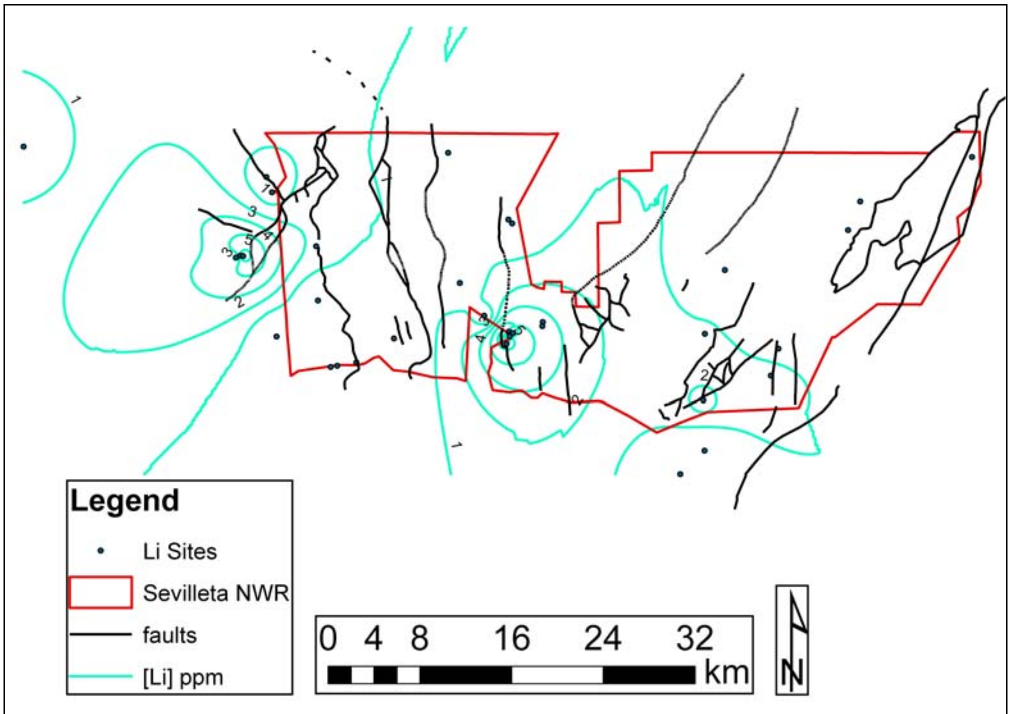
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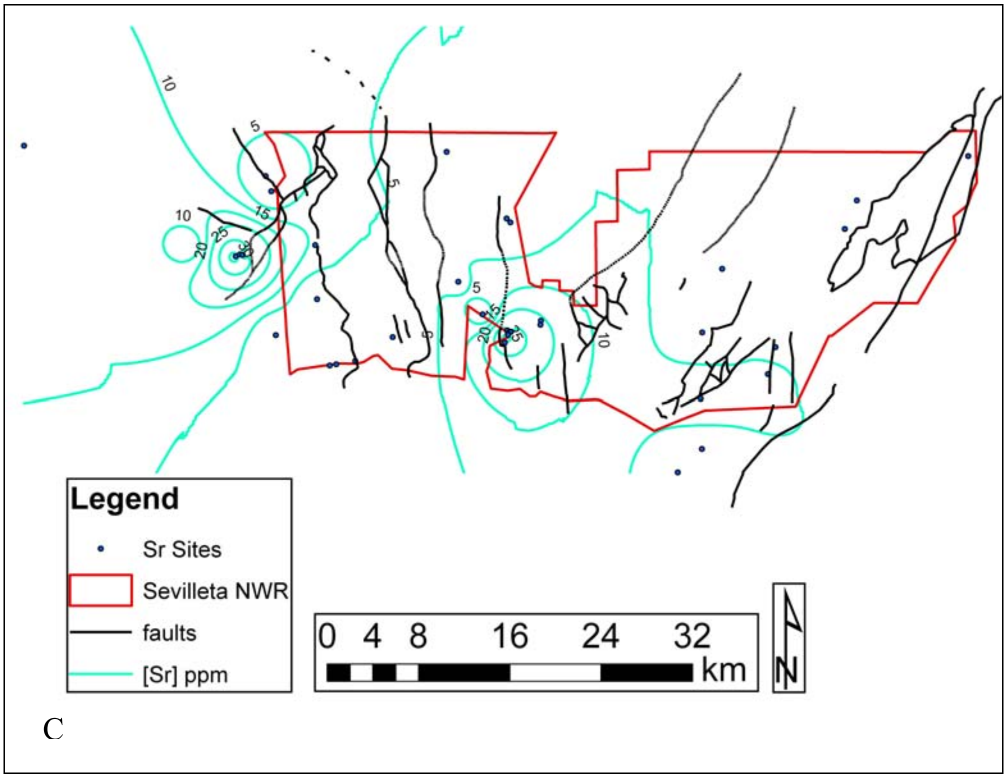

Figure 16a, b, c. Concentrations of the trace elements B, Li, and Sr in springs and wells in the Sevilleta NWR. Both Li and Sr outline two tectonically controlled geochemical "hot spots" in the refuge, while B is only evident from the San Acacia brine pool.

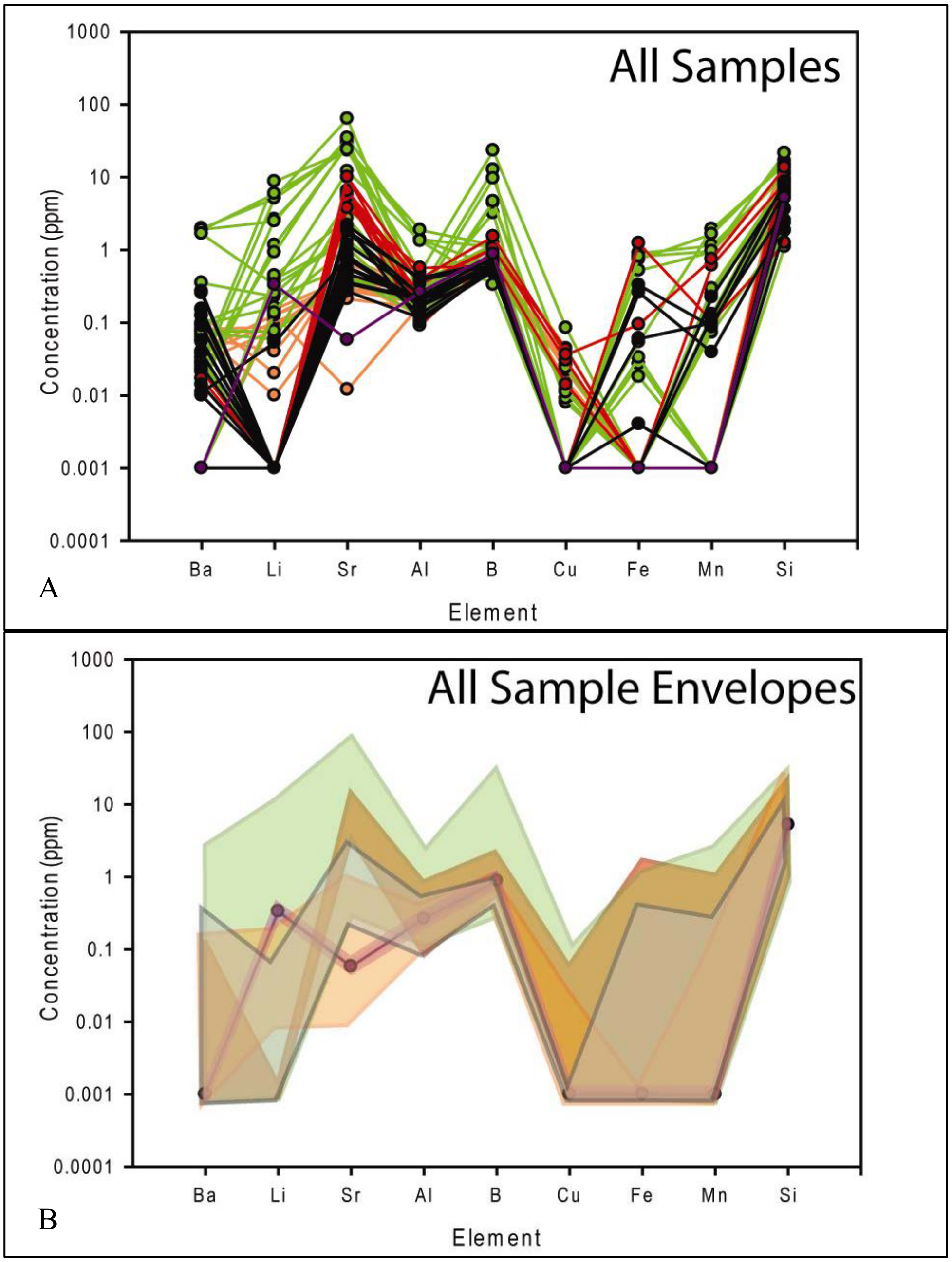

Figure 17a. Trace element spidergram for waters shows that most waters have elevated concentrations (>0.1ppm) of Sr, Al, B, and Si. 17b. Envelopes for ranges of trace element concentrations divided by their respective hydrochemical facies. The Cl-rich waters (green) consistently show elevated trace element concentrations. Group color is the same as in Figure 11.

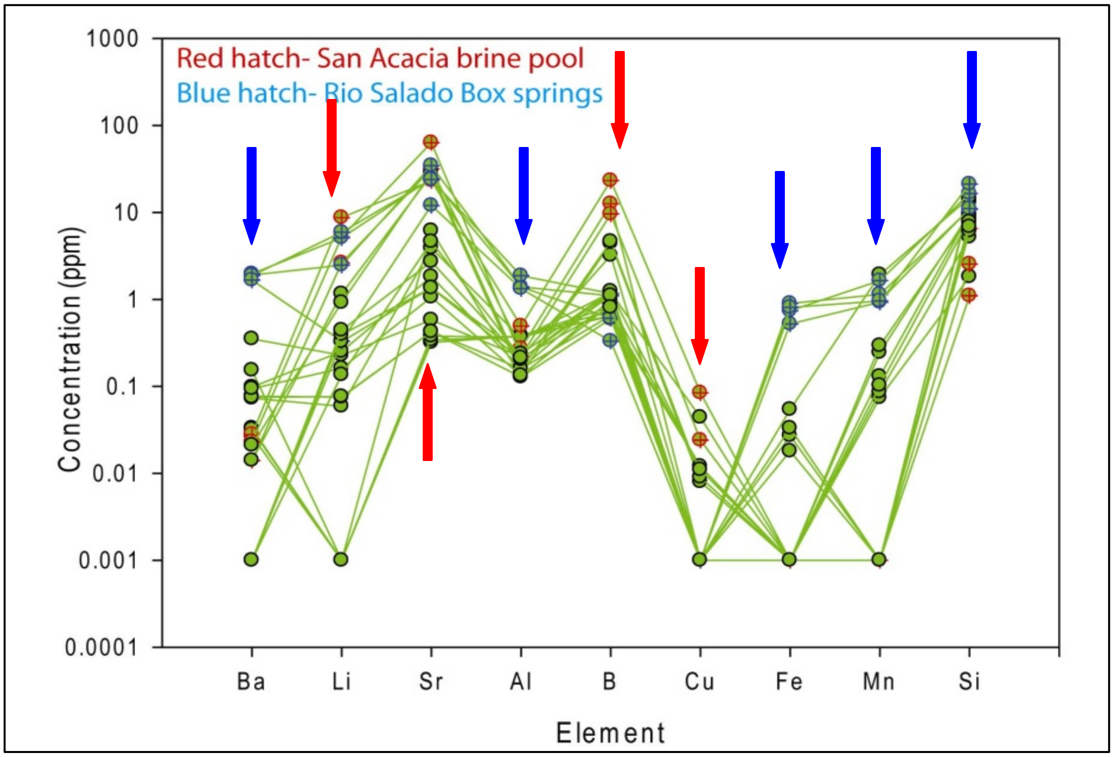

Figure 18. Trace element spidergram of Cl-rich waters from the Sevilleta NWR. Blue hatch marks identify the Rio Salado Box Springs while red hatch marks denote waters from the San Acacia system. Combined, these two spring systems have the highest trace element concentrations of all Sevilleta NWR waters, suggesting they have a similar deep-seated source.

6.3 Cl/Br ratios

Cl/Br ratios suggest a mixing of fresh water with deeply derived water to achieve the Cl/Br ratio of the San Acacia upper pool. Evaporative concentration accounts for the subsequent increase in [Cl] to the San Acacia brine pool. The apparent decrease in the Cl/Br ratio from the San Acacia upper pool to the San Acacia brine pool may be due to evapotranspiration in the presence of halite saturation, which allows for incongruent dissolution and an increase in [Br] but not [Cl] (Figure 19).

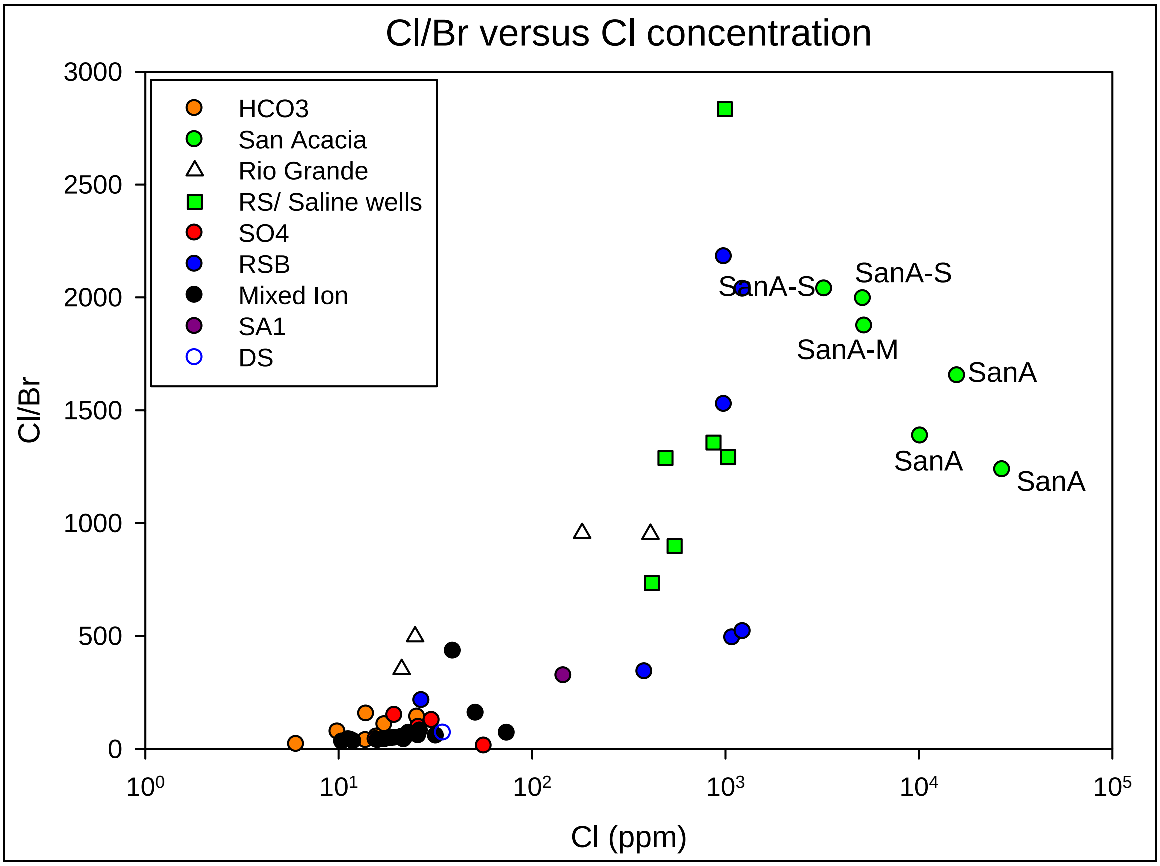

Figure 19. Cl/Br ratio versus [Cl] for Sevilleta NWR waters. The increase in [Cl] and Cl/Br ratios are attributed to the endogenic source water mixing with the higher Cl/Br waters in the rift fill to produce the San Acacia upper pool and RSB spring chemistries. The increase in [Cl] and decrease in Cl/Br from the upper pool (SanA-S) to the lower brine pool (SanA) can be explained by evapotranspiration and halite saturation.

6.4 Stable Isotopes of ^{18}O and D

Stable isotope data indicate that the mixed ion water group has a meteoric origin, and that most of the other hydrochemical groups are modified from modern meteoric origins (Figure 20). Most waters plot to the right of the GMWL, and some exhibit horizontal trends, suggesting that mineral-rock interaction exerts some control on the groundwater composition. Additionally, the observation that the linearly regressed San Acacia evaporation line extends from the large terminal brine pool to the upper pool and also passes through the Rio Salado Box spring 12 suggests a connection between the

RSB12 spring system and the upper San Acacia pool (SanA-S), such as that the RSB12 spring may represent a similar derivation or geochemical evolutionary history source for the SanA-S upper pool, which then evaporates to the observed chemistry of the SanA lower brine pool.

Three of the Cl-rich wells (SanA-W, FWS, and SW) demonstrate lighter $\delta^{18}O$ and δD values that correspond with the values for the modern Rio Grande (Figure 20), suggesting that these wells are fed by altered Rio Grande water. All other Cl-rich samples have heavier ratios, suggesting that their waters are geochemically different from the Rio Grande. Proximity of the RSB and SanA values to each other suggest that they have a similar source which provides the observed $\delta^{18}O$ and δD values. SdC3 and DS plot horizontally to the right of the GMWL, suggesting considerable water-rock interaction with gypsum and limestone, respectively.

A mixing model of δD versus [Cl] demonstrates a ternary mixing trend between the San Acacia upper pool (SanA-S), the Rio Grande (RG), and waters with low Cl concentrations (e.g. SC1) (Figure 21). Endpoints were chosen based on Cl concentration. Curves depict results of binary mixing models based on endmember waters. Most of the mixed ion waters plot in a wide swath on the left of the model, indicating differing levels of rock-water interaction. Because of the variability in the stable isotopes of the mixed ion water samples, which is due to differing levels of water-rock interaction, identifying one endmember is difficult.

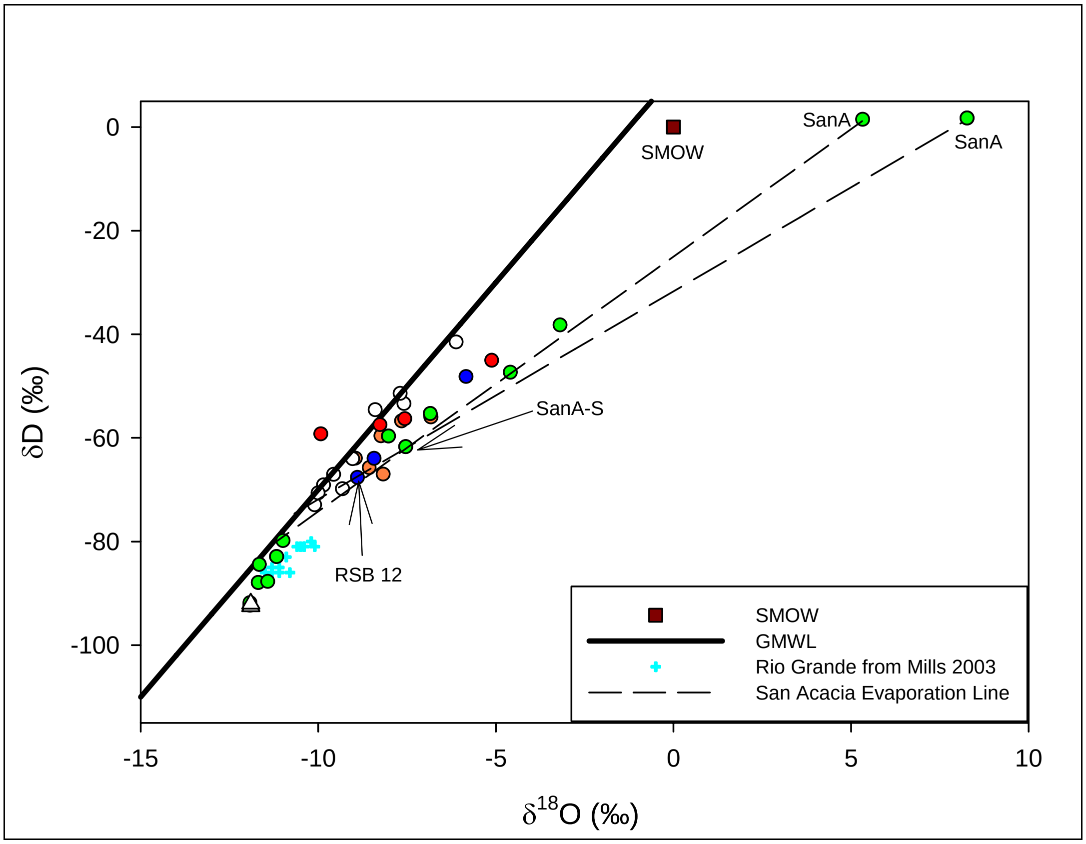

Figure 20. Stable isotope composition of springs, surface water, and groundwaters from the Sevilleta NWR, Rio Grande values from Mills 2003 study, GMWL, and two evaporation lines (dashed) between the San Acacia upper pool and lower brine pool. Symbol colors are the same as in Figure 11.

The Figure 21 mixing model was developed to mix the San Acacia upper brine pool (SanA-S) with the Rio Grande (RG) to determine the percent mixture required to produce the salinity measured downstream of both, at the San Acacia Diversion Dam (DD). The model indicates that a mix of 1-2% of the San Acacia upper brine pool with the river will yield the downstream measurements, suggesting a slow seep of briny water underground from the brine pools to the river.

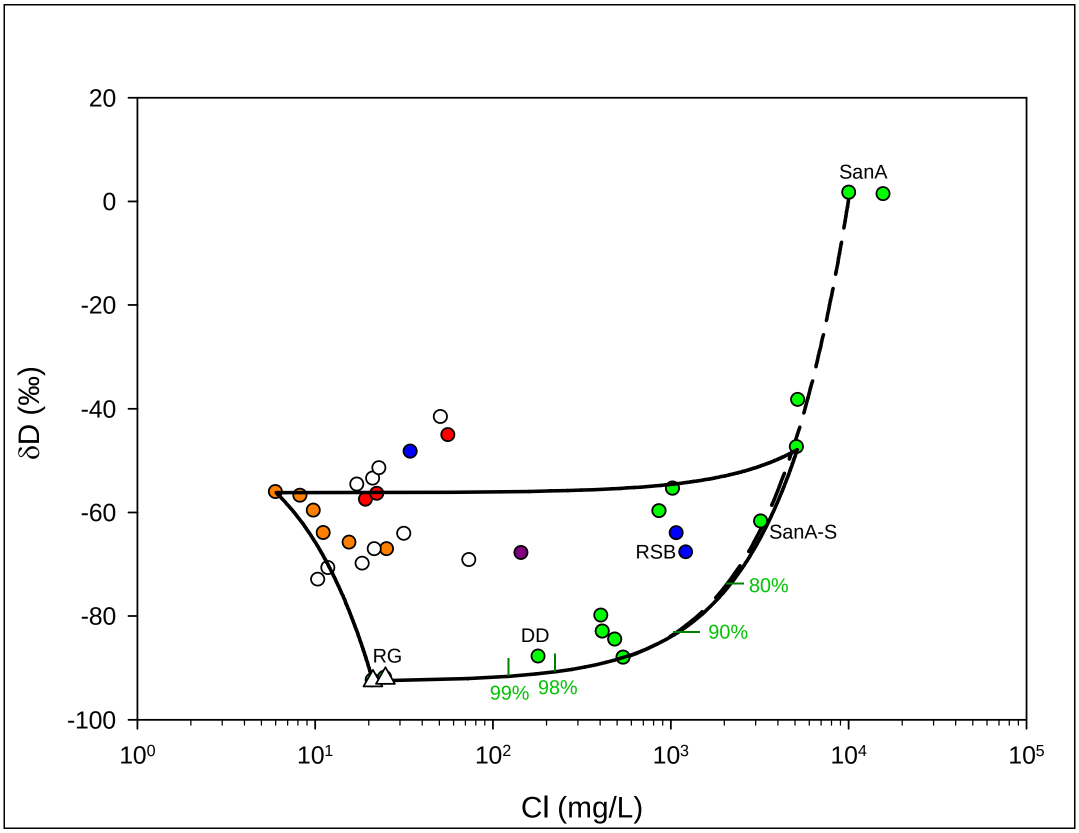

Figure 21. Mixing model of δD versus Cl concentration. Mixing lines identify the saline endmember (SanA-S, green), the least saline endmember (orange), and Rio Grande (RG) (triangle). The dashed line represents the evaporation curve from the San Acacia upper pool to the lower brine pool. RG= Rio Grande, DD= San Acacia Diversion Dam, RSB= Rio Salado Box Spring, SanA-S= upper San Acacia pool, SanA= San Acacia lower brine pool. Symbol colors are the same as in Figure 11.

6.5 δ^{13}C Mixing and External Carbon

Although most δ^{13}C data from the middle Rio Grande basin has been interpreted to reflect a mixing of meteoric recharge with older, mineralized waters (*Plummer et al., 2004*), work in the northern Rio Grande rift suggests that the δ^{13}C of some CO_2 exsolving springs are mantle derived, while several others are sourced from marine limestone (*Newell, 2007*). Selected δ^{13}C analysis from the Sevilleta NWR suggested mixing with isotopically light organic carbon, but combined analyses indicate the presence of highly endogenic CO_2 in some Rio Grande rift samples (*Newell et al., 2005*). Extensive $\delta^{13}C$ analyses will aid in delineating the deeply sourced fluids from the shallow DIC sources.

By removing the component of dissolved inorganic carbon (DIC) from simple dissolution of carbonate minerals using major ion chemistry as described previously, the external sources of CO_2 can be isolated. Figure 22 depicts simple two-component mixing models for carbon. Endmembers are those of Crossey et al. (2009), where an organic endmember of -28‰ was chosen because the $\delta^{13}C$ of marine plankton is between -20 and -30‰ (*Deines, 1980*), and several estimates for Earth's mantle are shown (-3 through -9). The results from this analysis suggest that a small flux of deeply-derived CO_2 is carried to the surface by springs in the Sevilleta NWR. The springs reflect a mixing of the -28‰ organic carbon influence of the shallow to intermediate subsurface with the -6‰ mantle signal. In Figure 22, yellow symbols that plot along the -6‰ mantle derived influence represent springs from northern New Mexico (*Newell, 2007*), where shallow magmatism is documented and CO_2 degassing should be expected.

6.6 $^{87}Sr/^{86}Sr$ Mixing

Springs with deeply-circulating sources should carry a radiogenic signature from the regional basement. The highest $^{87}Sr/^{86}Sr$ ratio for waters of this study, 0.7151, was found at the Rio Salado Box Spring 12, and correlation with conductivity and trace elements suggests a fraction of the water has undergone deep circulation through Precambrian basement (Figure 23). The flow path through Pennsylvanian limestone to reach the surface may account for the reduced $^{87}Sr/^{86}Sr$ ratio upon surfacing. The other two samples with elevated $^{87}Sr/^{86}Sr$ ratios (SLS1 and SA1) identify with the range of $^{87}Sr/^{86}Sr$ in volcanics, which is the lithology from which these two source. The five

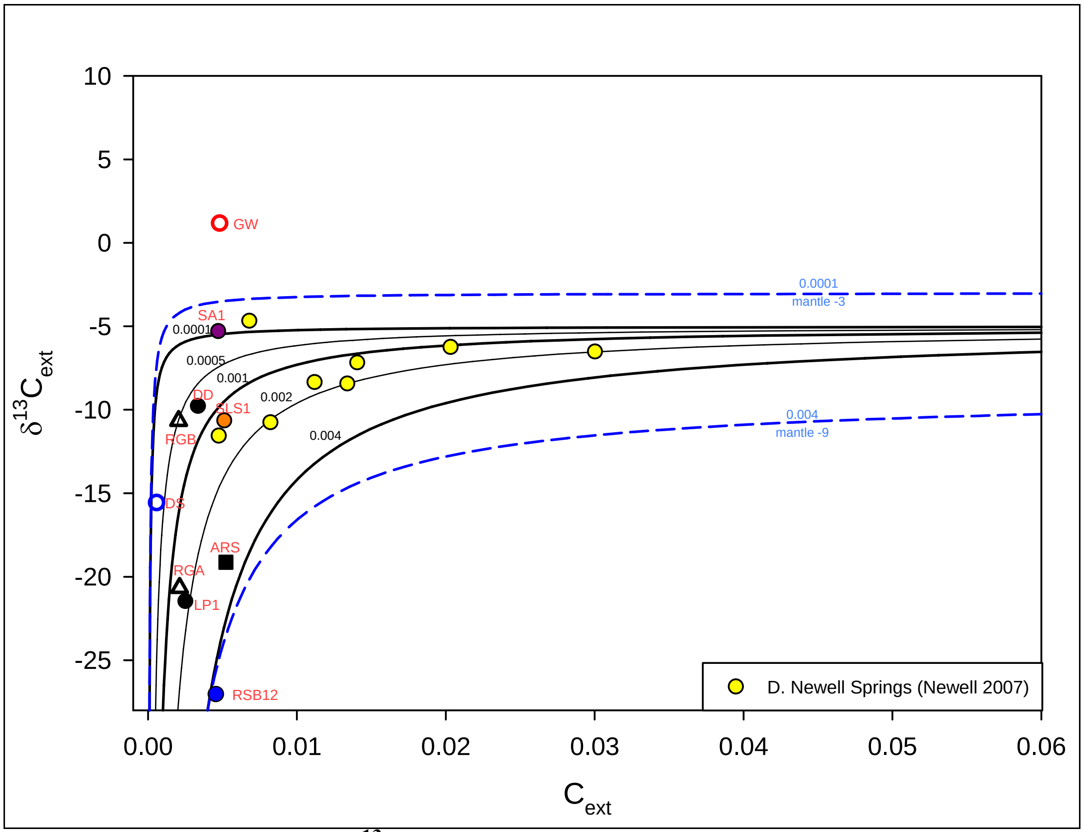

Figure 22. Mixing model of $\delta^{13}C_{external}$ versus $C_{external}$ for springs and surface waters from the Sevilleta NWR. $C_{external}$ refers to carbon from organic or deep sources, and not from the dissolution of carbonate minerals. Model curves were chosen to encompass the majority of data points based on empirically derived endmembers: $\delta^{13}C_{organic}$ = -28 ‰ and $\delta^{13}C_{endogenic}$ = -6 ‰. Dashed lines represent a wider range for endogenic compositions ranging from $\delta^{13}C$ = -3‰ to -9‰ (*Sano and Marty, 1995*). Yellow symbols are Rio Grande rift samples from Newell, 2007. Figure modified from Chiodini et al. (2004) and Crossey et al. (2009).

samples with lower $^{87}Sr/^{86}Sr$ ratios group within the carbonate range, as most of this water interacts with limestone in some capacity. Dripping Springs sources in the Pennsylvanian Madera limestone, while Tomasino well, Gibbs well, and Cibola Spring all source near the Madera limestone, and likely interact with this carbonate as it is interbedded within their respective source units (Figure 24). As a reference, the $^{87}Sr/^{86}Sr$ ratio range for Paleozoic marine carbonates is 0.706 - 0.710, and 0.735 - 0.740 for granitic basement from the region (C*rossey et al., 2009*).

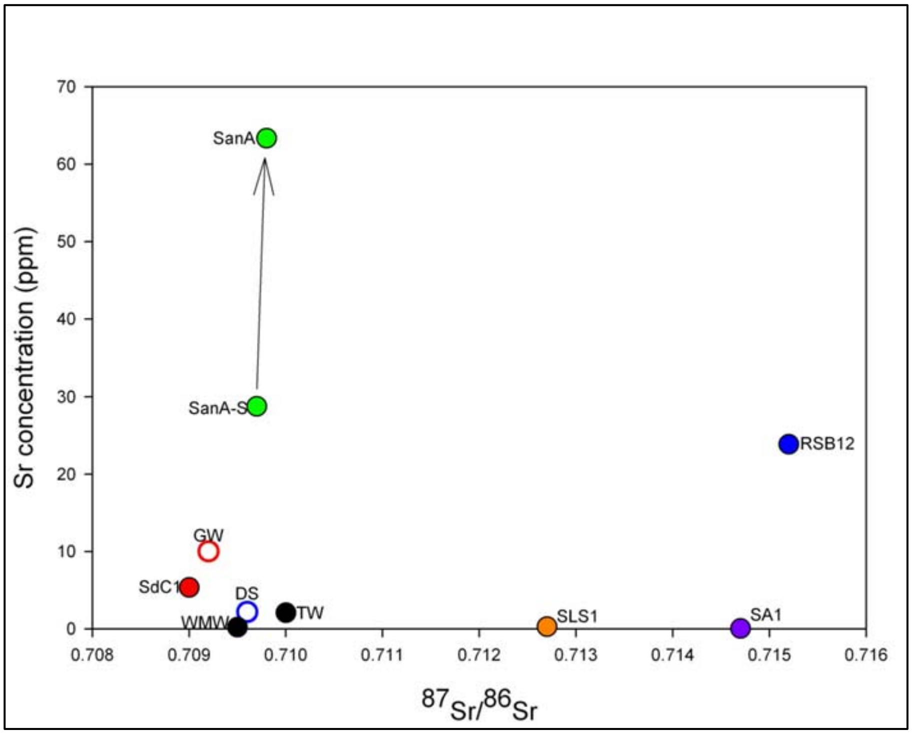

Figure 23. Mixing model of Sr concentration versus radiogenic Sr. The range for SLS1 and SA1 reflects the radiogenic Sr signal of tertiary volcanics, while the values for SdC1, GW, WMW, DS, and TW reflect the range for carbonate-influenced waters. SanA-S and RSB12 reflect a mixing between the influence of underlying carbonates and a deeply derived source water. The solid arrow represents the evaporative concentration of Sr to the San Acacia lower brine pool from the original SanA-S composition. Symbol colors are the same as in Figure 11.

A bimodal mixing model of radiogenic Sr versus non-radiogenic Sr endmembers can elucidate the sources of radiogenic Sr signatures in the Sevilleta NWR. As portrayed in Figure 25, Model A represents a mix of waters wherein the concentration of the radiogenic Sr endmember is much less than the concentration of the non radiogenic Sr endmember. This model provides the closest fit for most of the data and reflects a simplistic binary mixing of a small volume of basement derived (0.735) Sr with a larger volume of non-radiogenic, carbonate-derived Sr (0.709). Model B represents a mix of

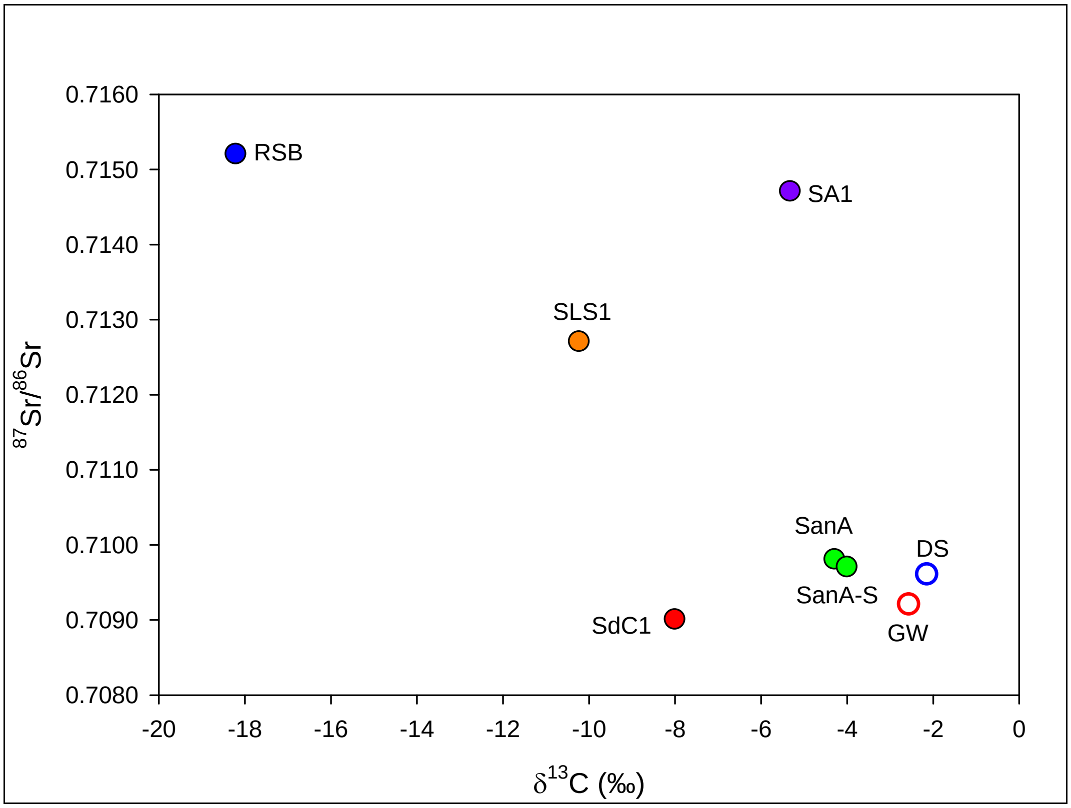

Figure 24. ^{87}Sr/^{86}Sr versus δ^{13}C indicates the presence of a water (RSB) with an organically derived carbon source and elevated ^{87}Sr/^{86}Sr ratio, suggestive of a deeply-derived fluid that mixed with isotopically light shallow fluids. The San Acacia upper pool chemistry represents a carbonate-derived δ^{13}C signal, as the waters undergo alteration during ascension.

waters wherein the concentration of the non-radiogenic Sr endmember is much less than the concentration of the radiogenic Sr endmember. This model is another simple binary mix of a high volume, highly concentrated basement derived Sr endmember with a small volume of the carbonate-derived, non-radiogenic Sr. Evaporation can account for the increase in Sr concentration of the San Acacia brine pool without a similar increase in the radiogenic portion of the Sr. Both mixing models demonstrate that the Rio Salado Box springs and the San Acacia pool system sources can be explained by a mixing of higher volume radiogenic Sr endmember with a smaller volume of non-radiogenic Sr endmember, and that these endogenic waters have followed a different evolutionary flow path than the other waters sampled in the Sevilleta NWR.

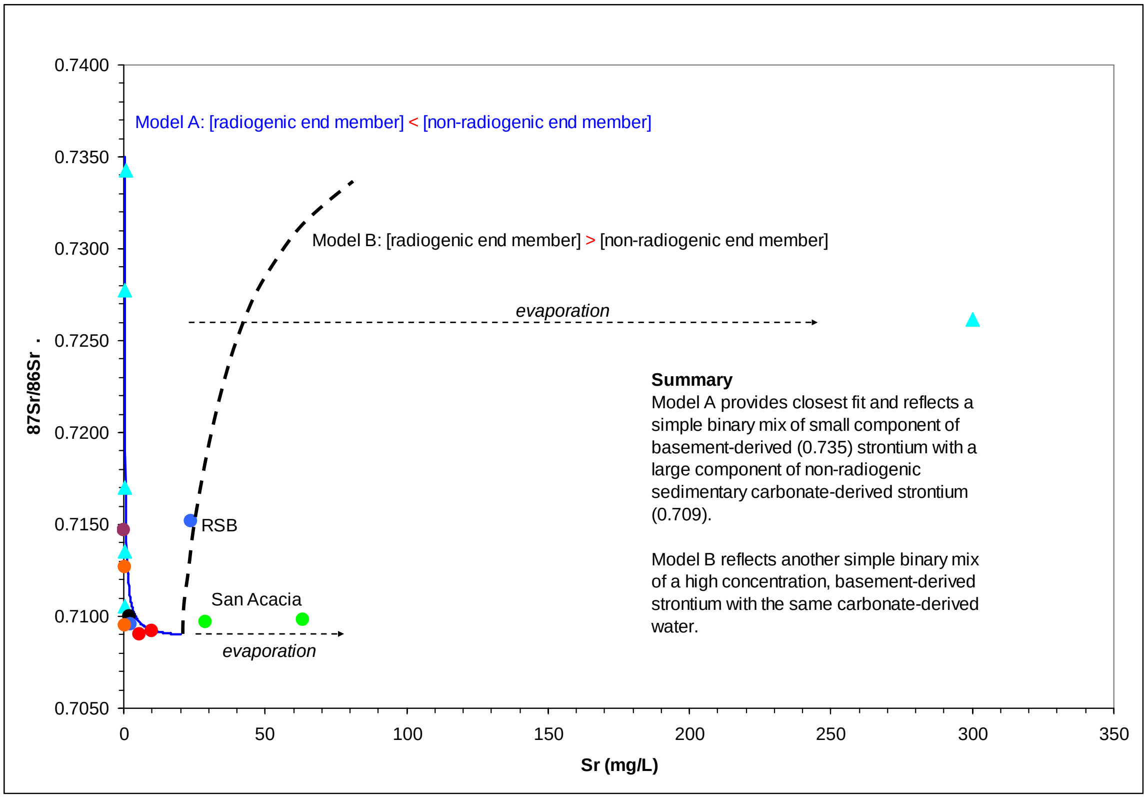

Figure 25. Mixing model of Sr concentration versus radiogenic Sr ratios. Two mixing lines with different proportions of radiogenic Sr versus non-radiogenic Sr signatures can account for the elevated Sr concentrations and radiogenic signatures of the Rio Salado Box Springs and the San Acacia spring. Colored circles correspond to Figure 11. Blue triangles are from Colorado Plateau waters (*Crossey, unpublished data*).

6.7 Structure

The extensional faults of the Rio Grande rift create a complex network of faults that now influences groundwater flow. By applying the theory of geochemical tracers, we can now place realistic flow paths in their proper geologic context. Cross-section lines correspond to those on the Sevilleta NWR map (Figure 26). Figures 27-29 are geologic cross sections of the Sevilleta NWR as interpreted from the New Mexico state geologic map and relevant geologic quadrangles. For all cross-sections the gray layers are

Precambrian bedrock, purple denotes Paleozoic layers, green represents Mesozoic layers, and yellow identifies Cenozoic layers. Colored boxes correspond to the hydrochemical groups outlined on Figure 11.

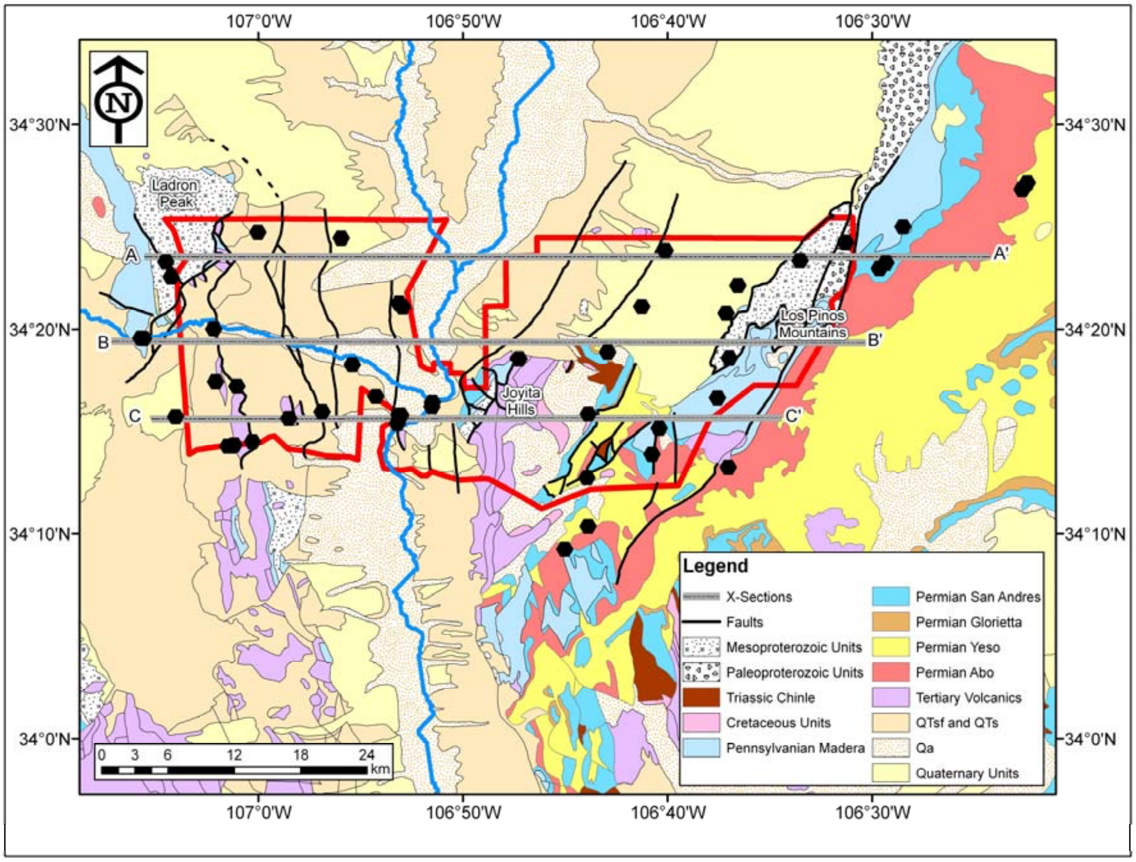

Figure 26. Geologic map of the Sevilleta NWR with sample sites and three cross sections outlined in grey.

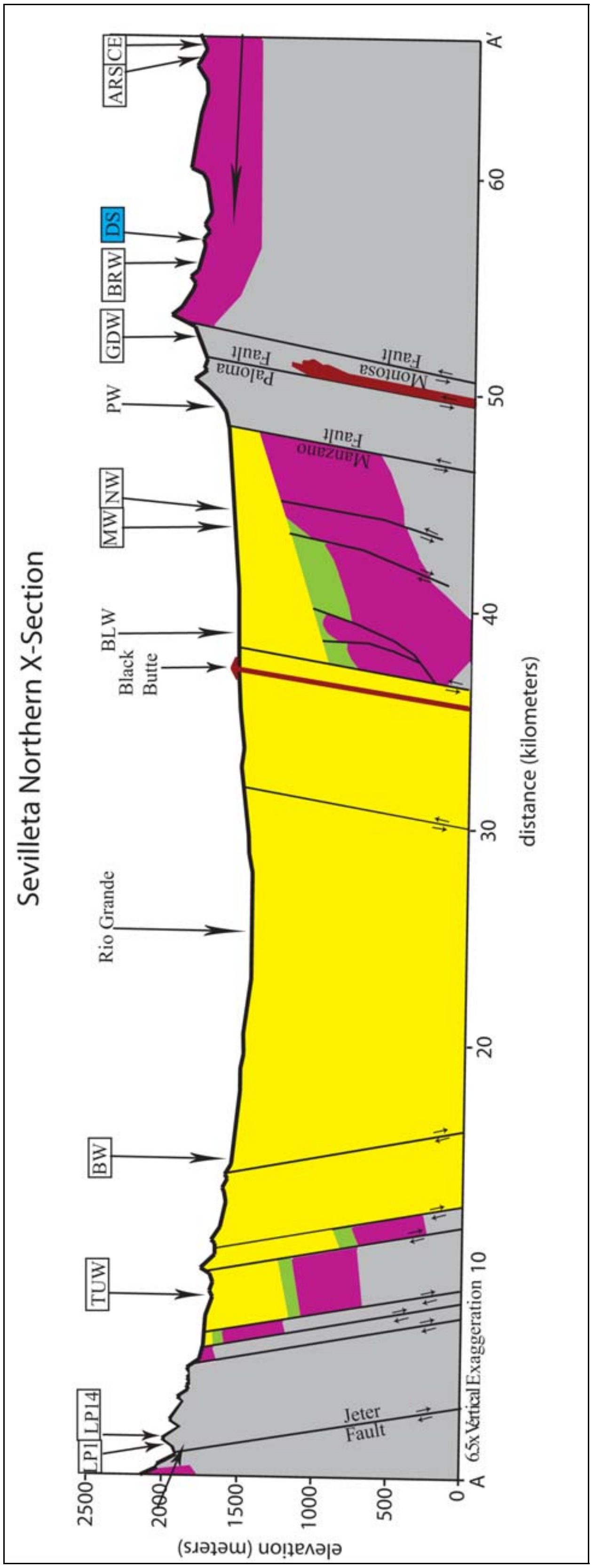

Figure 27. Northern geologic cross-section of the Sevilleta NWR. Sample sites are as follows: LP1, LP14 - Ladron Peak Springs 1 & 14; TUW - Tule 222 Well; BW - Bronco Well; BLW - Black Well; MW - McKenzie Well; NW - Nunn Well; PW - Pino Well; GDW - Goat Draw Well; BRW - Barella Well; DS - Dripping Springs; ARS - Ojo de Abo Spring; CE - Canon Espinoza Seep. Box colors correspond to those in Figure 11.

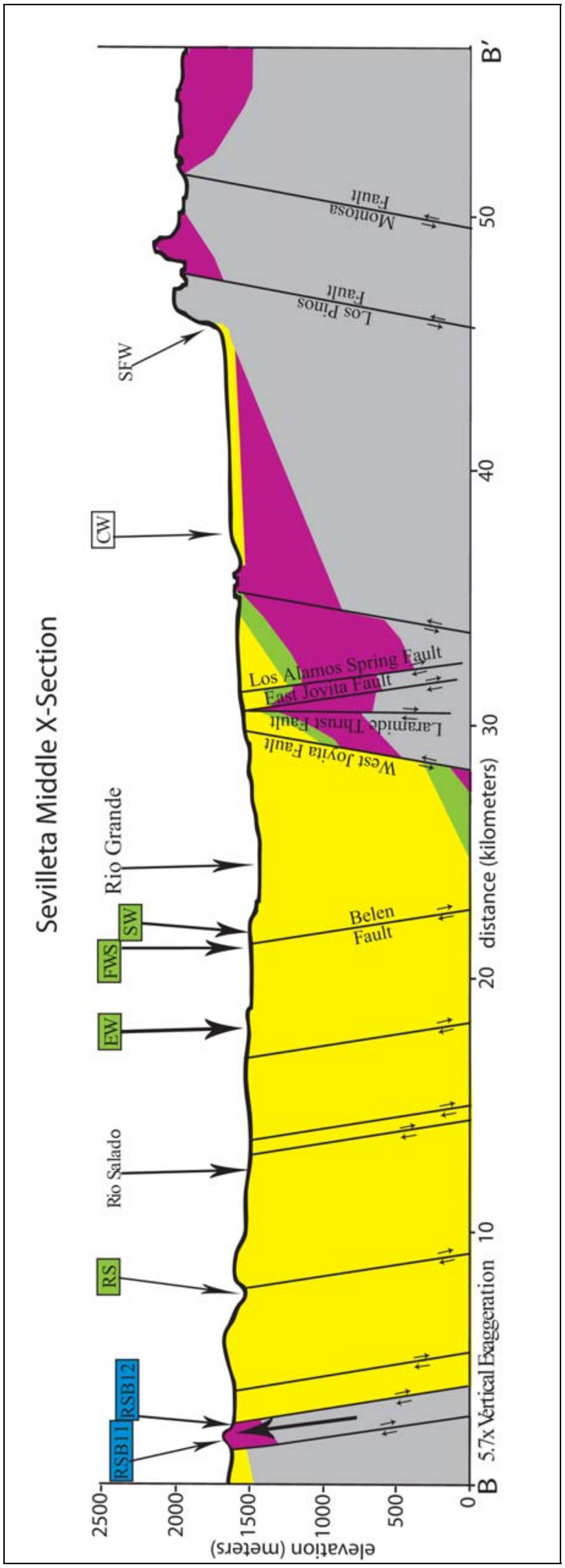

Figure 28. Middle geologic cross-section of the Sevilleta NWR. Sample sites are as follows: RSB11, RSB12 - Rio Salado Box Springs 11 & 12; RS - Rio Salado at Silver Creek; EW - Esquival Well; FWS - Fish & Wildlife Services field station well; SW - Sevilleta LTER field station well; CW - Canyon Well; SFW - Sepultura Flats Well. Box colors correspond to those in Figure 11.

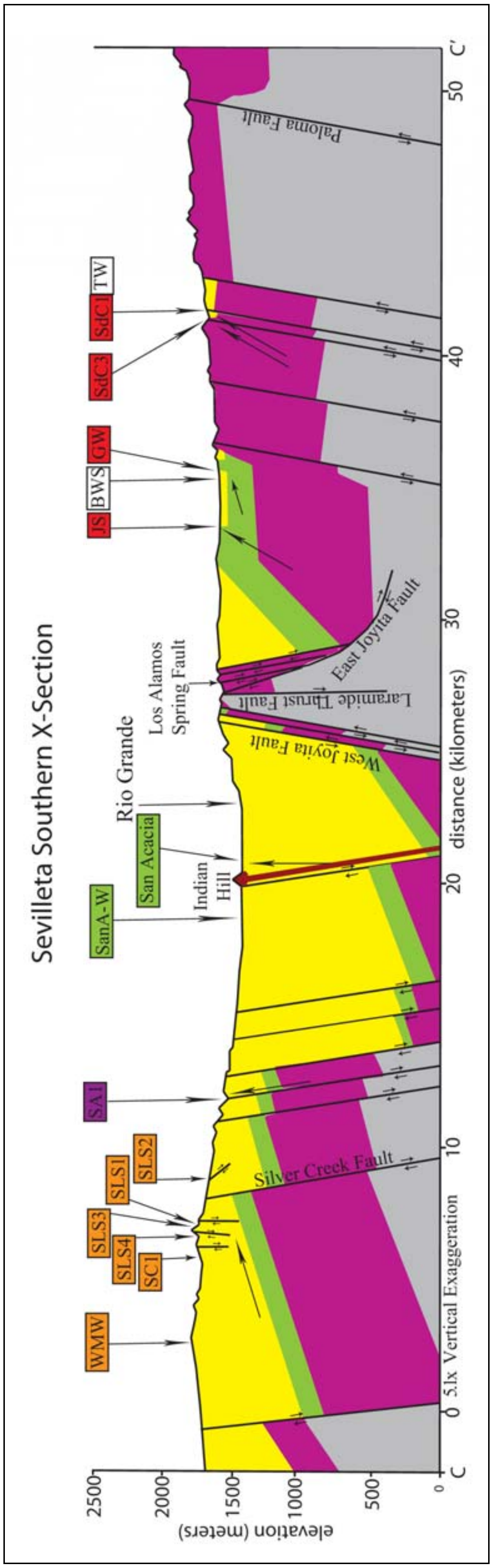

Figure 29. Southern geologic cross-section of the Sevilleta NWR. Sample sites are as follows: WMW - West Mesa Well; SC1 - Silver Creek Seep; SLS1-4 - San Lorenzo Springs 1 -4; SA1 - Canyon del Ojito Spring; SanA-W - San Acacia Well; JS - Jump Spring; BWS - Baca Well Spring; GW - Gibbs Well; SdC3 - Milagro Seep; SdC1 - Cibola Spring; TW - Tomasino Well. Box colors correspond to those in Figure 11.

. On the northern cross-section (Figure 27), wells are mostly shown with the exception of two shallowly circulating springs. On the west, the two Ladron Peak springs are shown with a small source path based on their chemistry, which is similar to meteoric water, suggesting that the water recharges in the mountain front and percolates through fractures in the bedrock to these springs. On the east, a larger source path is identified flowing towards Dripping Springs.

On the middle cross-section (Figure 28), wells are mostly found. On the west, the only two springs are the Rio Salado Box Springs 11 and 12. Due to their chemistry, the source path begins in the gray basement rock, which is consistent with major ion chemistry, trace element concentrations, $\delta^{13}C$ values, and $^{87}Sr/^{86}Sr$ ratios.

The southern cross-section contains most of the springs in the Sevilleta NWR (Figure 29). The largest source path is to the source of the San Acacia brine pools from a buried intrarift fault. The smaller flow paths include the sources to the San Lorenzo Springs and Silver Creek Seep, the chemistries of which are HCO_3-rich, and are therefore modified meteoric waters which have undergone mild digenetic alteration with the volcanics through which they flow. Canyon del Ojito Spring (SA1) shows a possible deeper source, as the spring has a constant discharge (<2 L/minute), some CO_2 degassing, and major chemistry analysis indicates that the spring chemistry plots between the HCO_3 springs and the Cl-rich springs of San Acacia and the Rio Salado Box. Smaller flow paths to Jump Spring, Cibola Spring and Milagro Seep indicate that the waters may have traveled a long way in the Permian Abo and Yeso formations, from which the high sulfate signature is derived. The waters themselves may not be deeply derived, but were probably altered from the eastern mountain front recharge water. This interpretation is based on major ion chemistry and field parameters.

Some preliminary flow path models were originally developed to illustrate local, mesogenic, intermediate, and region-wide flow paths in a structure-free setting (Figure 30a). Local paths could represent seasonal to decadal recharge, while mesogenic waters recharge on the order of hundreds to thousands of years. Intermediate waters would have residence times of thousands to tens of thousands of years, and regional waters could require more than tens of thousands of years to recharge. These flow paths conceptually encompass four of the flow paths hypothesized in this research. Figure 30b illustrates an interpretation of the upwelling of sedimentary basin brines without the context of rift structure. Figure 31 attempts to reconcile these flow paths with a structural interpretation.

6.8 Principal Component Analysis

The first PC shows high positive loadings for Na, K, Ca, Mg, Cl, SO_4, δD and $\delta^{18}O$ (Table 6), indicating the dominance of the saline waters near San Acacia. The second PC shows a high positive loading for pH and a high negative loading for HCO_3, which is expected as the two are related and should vary together. The third PC shows negative loadings for δD and $\delta^{18}O$, which should also be expected to vary together as well. Comparison of PC1 and PC2 indicates that the San Acacia upper pool, some SO_4 waters, and RSB springs are statistically different from the other waters (Figure 32), but comparison of averaged PC1 versus average PC2 reveals a clearer picture (Figure 33).

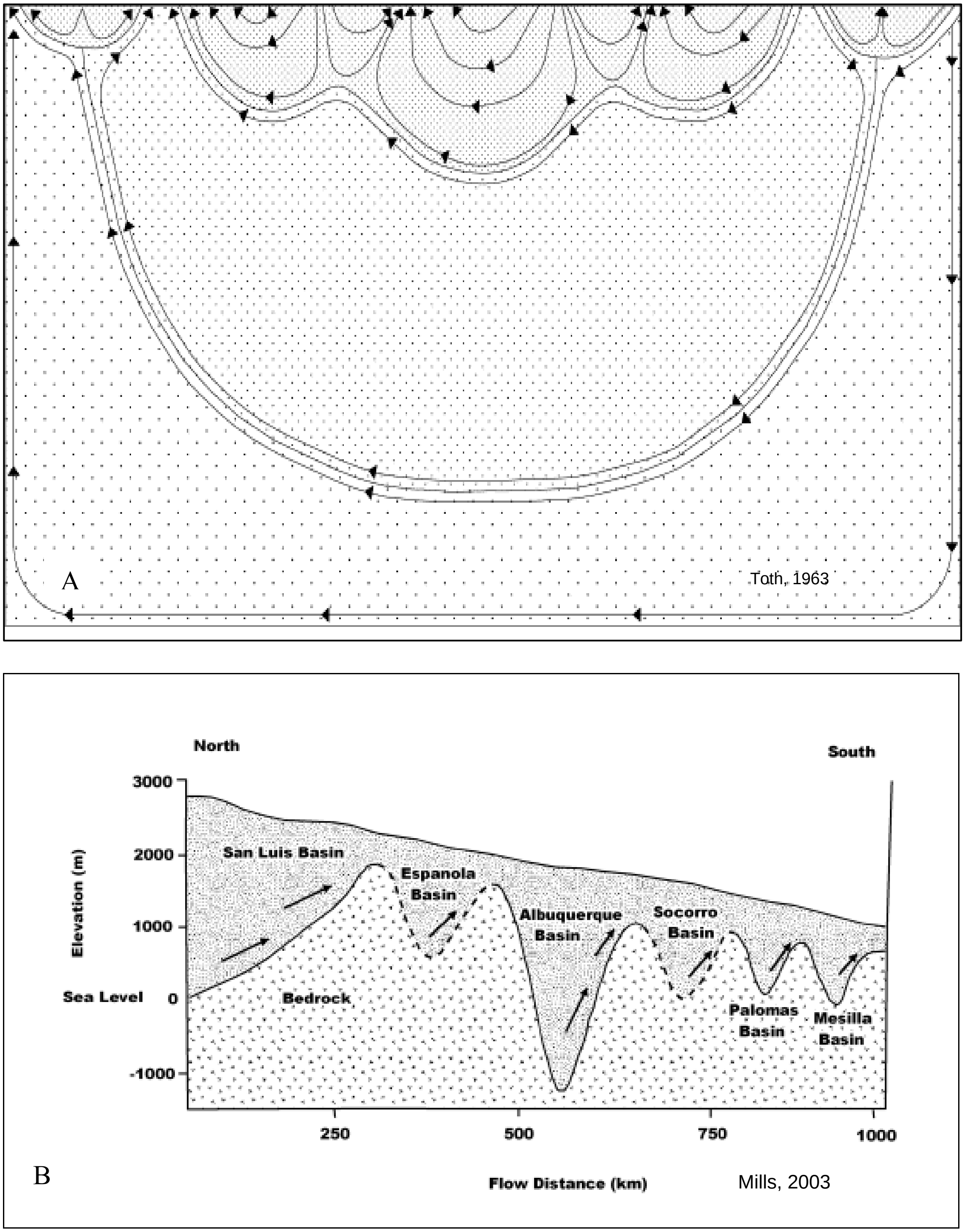

Figure 30a. Local, intermediate, and regional flow paths depicted in a structure free setting (Toth, 1963). 30b. Schematic hydrogeologic cross section parallel to the Rio Grande (Mills, 2003) showing flow paths of upwelling brines at basin termini.

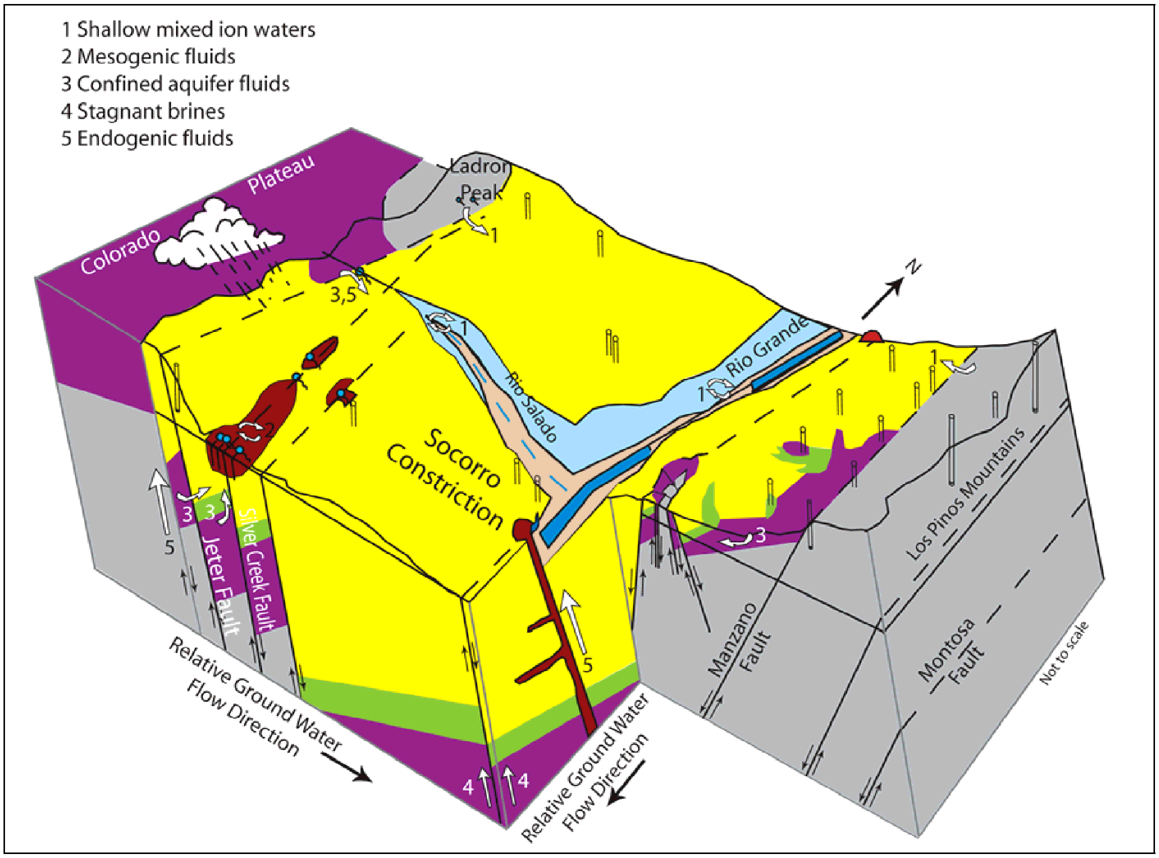

Figure 31. 3D schematic diagram of the Sevilleta NWR and related geologic units. Major faults are labeled and the west side springs are marked. Flow paths are numbered as previously discussed.

The San Acacia upper brine pool (SanA-S) is isolated from the other waters, as would be expected. RSB and SanA-S plot in the same quadrant, indicating that they are related and may derive from the same deep-seated source. The RG samples and saline wells (FWS, SW, SanA-W) plot together, reinforcing the assumption that the chemistry of these well waters are similar to Rio Grande water. See Table 7 for PC1, PC2, and PC3 of select samples.

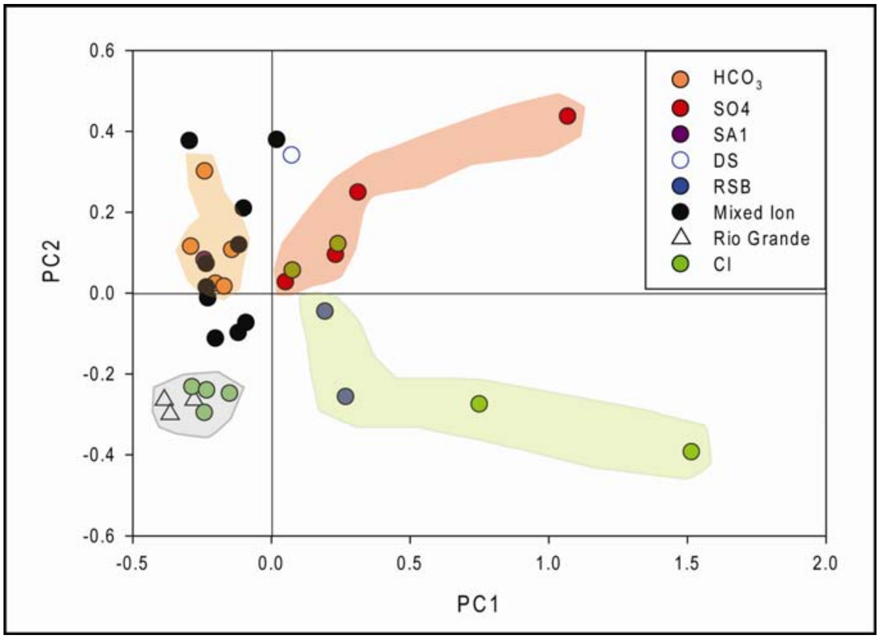

Figure 32. PC1 versus PC2. Comparison of Principal Components for 35 waters in the Sevilleta NWR. Some waters are labeled according to their endmember affiliation, while others (SA1, DS) are isolated for comparison. The colored groups isolate the RSB and SanA-S (green), RG and saline wells (gray), HCO_3 waters (orange), and SO_4 waters (red).

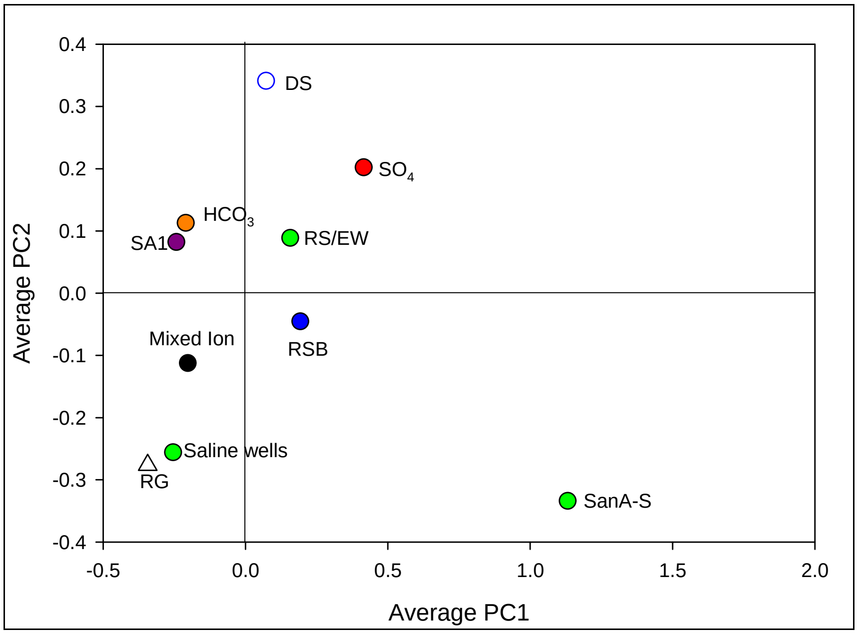

Figure 33. The first and second principal components for each hydrochemical group were averaged to develop a PCA-based endmember mixing plot. SanA, SanA-S, saline wells (FWS, SW, SanA-W), and RS and EW were separated to identify trends within the Cl-rich waters. The proximity of RSB and SanA-S indicates that they are related.

6.9 PHREEQC

6.9.1 Saturation Indices

RSB12 is again a spring of interest as the PHREEQC calculated calcite saturation index reports that RSB12 is undersaturated with respect to calcite, although it sources in the Pennsylvanian Madera limestone. This, combined with the observation that the RSB12 spring forms a small (30 cm high) fountain of water (*Rawling 2003*), suggests that the water is actively degassing CO_2 and surfacing quickly, without allowing adequate time to equilibrate with the Madera limestone calcite.

6.9.2 Binary Mixing Model

Mixing of a low salinity water with the San Acacia upper pool 1 was conducted to assess whether the mixing would identify intermediate waters (Figure 34) (dashed line). The line passed through one point, LP14, a mixed ion with a high [TDS] relative to the other mixed ion waters, suggesting that a meteoric endmember may be a mixing component for the San Acacia upper pool chemistry. Mixing of the RSB12 spring and San Acacia upper pool (AW011309-SanA-S) was also carried out to identify potential intermediate waters between these waters (solid line). No intermediate waters were identified, and this again suggests that the RSB12 spring source is related to the San Acacia upper pool source. The observation that both mixing lines avoid the bulk of the waters suggests that the source of the San Acacia upper pool and Rio Salado Box springs travel along hydrologic fast paths. Lastly, this mixing line suggests that the observed chemistries are derived from water-rock interaction of a shallowly circulating water and a component of the deeply derived fluid. See Table 10 for binary mixing models.

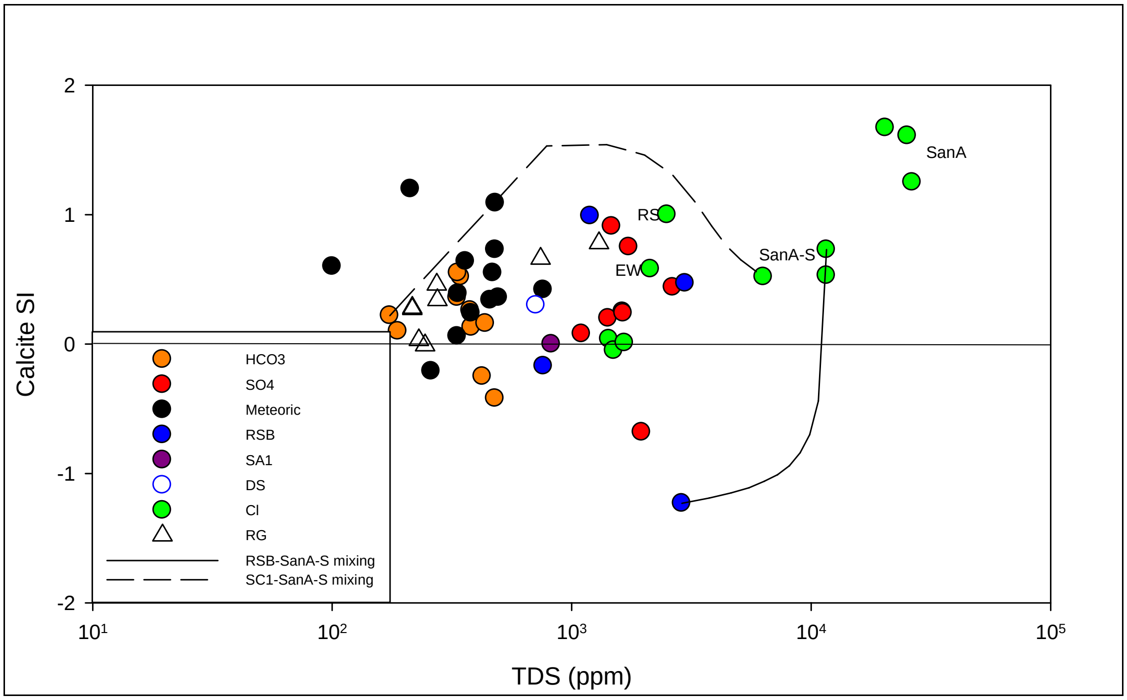

Figure 34. Binary mixing model of San Acacia source with 1) a mixed ion water (dashed line) and with 2) the RSB12 spring (solid line).

6.9.3 Inverse Modeling

Using a modified method from Federico et al. (2008), we developed inverse models for five Sevilleta NWR waters of different endmember composition. Input data are pH, temperature, major ions, Si and Al concentrations.

Solution 1, rain to SLS1, describes the evolution of rain water to the San Lorenzo Spring 1. I selected H_2O(g), calcite, dolomite, CO_2(g), gypsum, halite, albite, K-feldspar, gibbsite, and Ca-montmorillonite as the solid phases allowed to undergo evaporation, precipitation and dissolution. Eight models were produced (Table 11) and albite was the only mineral always dissolved in all of the models. Water was chosen to evaporate 6 times and Ca-montmorillonite was modeled to precipitate 7 times. In five models CO_2 must degas from the water. This model suggests that the water is deriving the Na-HCO_3 signature from the tertiary volcanics through which the water flows.

Solution 2, rain to SdC1, describes the evolution of rain water to Cibola Spring. I selected the same solid phases as for the SLS1 model, adding chalcedony and barite. Five models were produced and in all of the models, dolomite, gypsum, and halite are required to dissolve, water is required to evaporate, and K-feldspar is required to precipitate. In four models CO_2 must degas from the water. These results suggest that although the spring sources in Permian Abo sandstone, they must pass through the gypsum-rich Yeso Formation, which is stratigraphically youger than the Abo Formation and is located to the east in the subsurface, suggesting that the source for these waters is diagenetically altered rainwater from the mountain front which has interacted with the abundant Permian beds on the east side of the Sevilleta NWR to produce the Ca-SO_4 signature.

Solution 3, rain to SC1, describes the evolution of rain water to the Silver Creek seep, which is a low chloride water located in Tertiary volcanics. I selected $H_2O(g)$, calcite, dolomite, $CO_2(g)$, gypsum, albite, Ca-montmorillonite, chlorite, K-mica, and talc as the solid phases. Five models were produced and in all of the models albite dissolves, water evaporates, and gypsum and K-mica precipitate. In four models, Ca-montmorillonite and talc precipitate, and in three models CO_2 must degas from the water. Similar to the SLS1 model, these results suggest the water is deriving the Na-HCO_3 signature from the tertiary volcanics through which the water flows.

Solution 4, rain to SanA-S, describes the evolution of rain water to the San Acacia upper pool. I selected the same solid phases as for the SLS1 model, adding only chalcedony. Eighteen models were produced and in all halite must be dissolved. The only other mineral of consequence in the model, calcite, is modeled to precipitate in 14 models and dissolve only in 1. In nine models, CO_2 must degas. As an aside, if the RSB springs and SanA-S have similar sources, modeling has predicted that both of these waters will interact with kaolinite, gibbsite, and illite, and allow for substantial diagenetic reactions. The large number of potential models suggests that the San Acacia upper pool is not just altered rainwater, but is a mixture of precipitation, shallowly circulting fluid, and a deeply derived source.

Solution 5, rain to NW, describes the evolution of rain water to the Nunn well sample. I selected H_2O(g), calcite, dolomite, CO_2(g), gypsum, gibbsite, albite, Ca-montmorillonite, K-mica, and kaolinite as the solid phases. Five models were produced and in all dolomite and albite must be dissolved, water must be evaporated, and K-mica must be precipitated. Four models predict that CO_2 must degas. These results suggest that although the water sampled from Nunn well has a large precipitation input, the waters are interacting with dolomite, which is not surficially expressed and may be a significant CO_2 source to waters in the northeastern Sevilleta NWR.

7 Evaluation and Conclusions

On the basis of water chemistry, including major ions, trace elements, $^{87}Sr/^{86}Sr$ ratios, and stable isotopes of oxygen, hydrogen, and carbon, we conclude that the flow paths originally hypothesized do exist and interact in the Rio Grande rift. These include 1) the exogenic fluids (mixed ion waters such as CE, BRW, ARS, NW, GDW, CW, MW, TUW); 2) mesogenic fluids, which should be separated into two groups: fluids derived from the Albuquerque basin upgradient of the Sevilleta NWR (RG, FWS, SW, SanA-W) and fluids that derive from mountain-front recharge through Tertiary strata (either Santa Fe rift fill or volcanics), such as SA1, SC1, the SLS springs, and WMW; and 3) regional waters that source from or are heavily influenced by Paleozoic strata, such as DS, SdC1, SdC3, GW, JS, TW, and QS. RSB11 and RSB12 demonstrate an endogenic signature, but the specific source of these springs and the San Acacia spring is less certain. This report suggests that the SanA-S (upper pool) and the Rio Salado Box springs are a mixture of the endogenic waters and chemically-evolved basin fluids circulating in either the thick fill of the Rio Grande rift or the thin veneer of Paleozoic strata on the rift flanks, respectively. These altered waters travel along preferential flow paths that may extend deep into the subsurface. The San Acacia brine pool itself is a result of this mixing and evaporation, and it is these high chloride waters that percolate into the Rio Grande, influencing the high salinity observed at San Acacia.

Several spring waters in the Rio Grande rift source from faults and exhibit unique chemistries which differentiate them from meteorically recharged groundwaters. These waters have deeply sourced chemical components (based on major chemistry, $^{87}Sr/^{86}Sr$ ratios, and stable isotopes of oxygen, hydrogen, and carbon), which are related to the tectonic setting of the Rio Grande rift (*Newell, 2007*). Unlike the hot springs of Yellowstone or northern New Mexico, these springs are cold. It has been suggested that the high-chloride waters are not geothermal waters, but are rather mobilized by geothermal fluids (*Newton, 2004; Hogan et al., 2007*) and the presence of deep faults.

Beyond the extensive and novel chemical analyses of the Sevilleta NWR waters, our contribution includes the integration of rift structure with geochemistry, allowing for the incorporation of realistic subsurface flow paths into a structure that includes rift faults which function as geochemical fast paths.

It is clear that there are large structures in the subsurface that control the upwelling of high-chloride waters into the shallow aquifer. Previous studies could not develop a satisfactory salinization mechanism; they only agree that zones of anomalously high permeability (faults) permit the transfer of high-chloride, high-conductivity waters from depth. This work suggests that the large rift-bounding and intrarift structures controlling Rio Grande rifting also control the flow of endogenic waters, that these waters can experience extensive diagenetic alteration as they undergo subterranean travel in Tertiary rift fill, and that they are surficially expressed at the Rio Salado Box springs and the San Acacia source.

Table 1. Sample Locations and Field Parameters

***Bronco Well (BW) field parameters are for the well only. All other values reported are for the separate drinker tank.**

Sample ID	Spring	Date Sampled	Latitude decimal degree	Longitude decimal degree	T (°C)	pH	Conductivity (µS)
AW102107-SLS1	San Lorenzo Spring 1	10.21.07	34.23915	-107.01978	13.1	7.80	756
AW061308-SLS1	San Lorenzo Spring 1	06.13.08	34.23915	-107.01978	24.5	7.76	780
AW072908-SLS1	San Lorenzo Spring 1	07.29.08	34.23915	-107.01978	25.9	8.01	668
AW102107-SLS2	San Lorenzo Spring 2	10.21.07	34.24176	-107.00479	16.2	7.58	849
AW011808-SLS2	San Lorenzo Spring 2	01.18.08	34.24179	-107.00480	13.2	7.52	962
AW072908-SLS2	San Lorenzo Spring 2	07.29.08	34.24179	-107.00480	21.0	7.94	889
AW052009-SLS2	San Lorenzo Spring 2	05.20.09	34.24179	-107.00480	23.8	7.54	943
AW060509-SLS3	San Lorenzo Spring 3	06.05.09	34.23816	-107.02110	23.8	7.75	704
AW102107-SLS4	San Lorenzo Seep 4	10.21.07	34.23817	-107.02489	19.4	7.90	670
AW102107-RS1	Rio Salado	10.21.07	34.33355	-107.03635	16.7	8.33	5020
RG030809-1	Rio Grande	03.08.09	34.27416	-106.85740	8.3	8.21	434
RG030809-2	Rio Grande	03.08.09	34.26797	-106.85910	8.6	8.20	433
RG030809-3	Rio Grande	03.08.09	34.25644	-106.88610	10.2	7.91	461
RG030809-4	Rio Grande	03.08.09	34.25597	-106.88850	10.6	7.83	487
AW102107-SanA	San Acacia Brine Pool (Southernmost)	10.21.07	34.26267	-106.88520	14.0	9.14	50400
AW062708-SanA	San Acacia Brine Pool (Southernmost)	06.27.08	34.26184	-106.88480	23.5	9.45	41000
AW011309-SanA	San Acacia Brine Pool (Southernmost)	01.13.09	34.26600	-106.88503	9.6	5.59	53800
AW011309-SanA-M	San Acacia Middle Pool	01.13.09	34.26362	-106.88440	9.6	4.93	23200

Table 1 cont. Sample Locations and Field Parameters

Sample ID	Spring	Date Sampled	Latitude decimal degree	Longitude decimal degree	T (°C)	pH	Conductivity (µS)
AW071808-SanA-S	San Acacia upper pool (Northernmost Pool)	07.18.08	34.26361	-106.88416	26.8	7.15	12720
AW011309-SanA-S	San Acacia upper pool (Northernmost Pool)	01.13.09	34.26492	-106.88200	6.0	4.46	23300
AW011309-SanA-D	San Acacia Ditch	01.13.09	34.26249	-106.88445	11.1	7.30	2600
AW011309-SanA-RGA	RG Above RS Confluence	01.13.09	34.27368	-106.85840	5.9	7.39	547
AW011309-SanA-RGB	RG Below RS Confluence	01.13.09	34.27041	-106.85878	5.9	7.79	550
AW011309-SanA-DD	RG above San Acacia diversion dam	01.13.09	34.25641	-106.88696	8.4	7.58	1483
AW102007-SdC1-1	Cibola Spring	10.20.07	34.23136	-106.67952	17.4	7.04	3240
AW011808-SdC1-1	Cibola Spring	01.18.08	34.23142	-106.67944	2.8	6.50	3930
AW061208-SdC1-1	Cibola Spring	06.12.08	34.23142	-106.67944	26.9	7.06	2840
AW072908-SdC1-1	Cibola Spring	07.29.08	34.23142	-106.67944	31.6	7.77	2950
AW102007-SdC3	Milagro Seep	10.20.07	34.21214	-106.73248	26.3	7.03	5140
AW060509-RSB09	Rio Salado Below Springs	06.05.09	34.33833	-107.06445	20.6	8.07	5480
DN04-RSB10	Rio Salado Above Springs	12.30.04	34.32457	-107.09901	10.3	8.28	2390
DN04-RSB11	Rio Salado Springs	12.30.04	34.32612	-107.09576	9.6	7.63	5950
AW060509-RSB11	Rio Salado Springs	06.05.09	34.32795	-107.09562	24.3	6.89	5750
DN04-RSB12	Rio Salado Springs	12.30.04	34.32578	-107.09361	21.3	5.73	5770
AW060509-RSB12	Rio Salado Springs	06.05.09	34.32758	-107.09457	21.9	6.89	5410

Table 1 cont. Sample Locations and Field Parameters							
Sample ID	**Spring**	**Date Sampled**	**Latitude decimal degree**	**Longitude decimal degree**	**T (°C)**	**pH**	**Conductivity (µS)**
DN04-RSB13	Riley Spring	12.30.04	34.41224	-107.26581	13.5	7.21	1522
AW071708-CE	Canon Espinoza	07.17.07	34.45223	-106.37361	24.2	7.63	748
AW071708-ARS	Ojo del Abo Spring	07.17.08	34.44695	-106.37778	25.0	7.42	941
AW072508-QS	Quarai Spring	07.25.08	34.59486	-106.29520	18.8	7.92	719
AW080108-SC1	Silver Creek Seep	08.01.08	34.29063	-107.03484	22.8	9.53	640
AW080708-SA1	Canyon del Ojito Spring	08.07.08	34.26070	-106.97526	22.5	9.12	1640
AW082208-DS	Dripping Springs	08.22.08	34.41652	-106.47504	22.1	7.73	1471
AW090408-JS	Jump Spring	09.04.08	34.15396	-106.75057	20.9	7.20	2200
AW090408-BWS	Baca Well Spring	09.04.08	34.17261	-106.73151	20.3	7.61	986
AW101208-LP1	Ladron Peak Spring	10.12.08	34.38821	-107.07538	17.9	7.19	517
AW101208-LP14	Ladron Peak Spring	10.12.08	34.37611	-107.07101	18.8	8.36	959
AW042208-SanA-W	San Acacia Well	04.22.08	34.27861	-106.90445	17.3	8.12	2850
AW061908-SW	Sevilleta Field Station Well	06.19.08	34.35454	-106.88548	27.5	7.83	3810
AW062008-FWS	Fish & Wildlife Station Well	06.20.08	34.35145	-106.88251	25.1	7.86	3340
AW062308-MW	McKensie Well	06.23.08	34.34632	-106.61897	21.9	7.83	665
AW060409-BW*	Bronco Well	06.04.09	34.40735	-106.93271	31.4	8.29	503
AW062408-NW	Nunn Well	06.24.08	34.36891	-106.60946	21.8	7.80	750
AW062608-TW	Tomasino Well	06.26.08	34.25266	-106.67362	21.7	7.62	877
AW072908-TW	Tomasino Well	07.29.08	34.25266	-106.67362	25.1	7.93	738
AW062608-GW	Gibbs Well	06.26.08	34.26434	-106.73134	24.4	7.71	3210
AW062708-GDW	Goat Draw Well	06.27.08	34.40395	-106.52169	21.0	7.84	937

Table 1 cont. Sample Locations and Field Parameters

Sample ID	Spring	Date Sampled	Latitude decimal degree	Longitude decimal degree	T (°C)	pH	Conductivity (µS)
AW071808-CW	Canyon Well	07.18.08	34.31472	-106.71555	22.0	7.75	1499
AW072208-EW	Esquival Well	07.22.08	34.30450	-106.92360	25.5	7.80	4290
AW080108-WMW	West Mesa Well	08.01.08	34.26217	-107.06735	22.4	8.34	380
AW082208-BRW	Barella Well	08.22.08	34.38744	-106.48897	17.4	7.13	1280
AW060409-TUW	Tule Well	06.04.09	34.41834	-107.02639	22.1	7.39	855

Table 2. Major Ion Chemistry

All ions measured in ppm. * Bronco Well data is for the drinker tank, not the well. 'mdl'= method detection limit. Mdl for ions is as follows (in ppm): Ca, Mg, & Na=0.2, K=0.5, Cl & SO_4=0.1, Br=0.05

Sample ID	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	HCO_3 (ppm)	Cl (ppm)	Br (ppm)	SO_4 (ppm)	Cl/Br	Error %
AW102107-SLS1	35.7	6.5	106	18.2	370	17.2	0.2	49.3	108	-1.5
AW061308-SLS1	22.0	4.3	120	2.4	333	15.7	0.3	48.0	52.6	-1.8
AW072908-SLS1	20.4	3.8	119	2.3	326	13.8	0.4	45.2	38.2	-1.9
AW102107-SLS2	19.5	13.0	122	17.6	328	26.0	0.2	109	118	-4.0
AW011808-SLS2	17.6	11.6	150	3.2	314	25.5	0.2	113	142	0.9
AW072908-SLS2	19.0	11.9	135	1.7	327	21.5	0.5	102	46.3	-2.1
AW060509- SLS3	46.6	9.9	71.3	3.6	368	13.9	0.1	38.0	155	-6.8
AW102107-SLS4	48.8	13.7	66.3	17.0	342	9.9	0.1	33.6	75.9	1.1
AW102107-RS1	182	45.4	1140	43.9	255	1034	0.8	1273	1292	2.9
AW101108-RS	285	62.8	771	28.3	168	992	0.4	1129	2834	-0.6
RG030809-1	39.0	7.2	36.3	4.3	152	20.0	0.1	53.1	407	0.3
RG030809-2	38.7	7.1	36.1	4.3	151	20.0	0.0	53.0	1025	0.2
RG030809-3	40.5	7.5	38.3	4.5	150	20.5	0.0	53.4	1066	2.7
RG030809-4	42.7	8.1	42.8	4.6	158	25.3	0.0	61.8	652	1.4
AW102107-SanA	505	954	15290	700	238	26964	21.8	3.5	1237	1.4
AW062708-SanA	920	319	6984	100	110	10153	7.3	6859	1387	-6.5
AW011309-SanA	872	960	11425	360	201	15793	9.6	8445	1654	0.3
AW011309-SanA-M	525	216	3717	367	369	5228	2.8	3476	1874	-2.5
AW071808-SanA-S	480	161	1941	25.5	438	3240	1.6	1956	2038	-6.6
AW011309-SanA-S	622	228	3432	96.9	275	5147	2.6	2829	1995	-1.7
AW011309-SanA-D	80.3	21.8	367	17.1	314	409	0.4	414	951	-6.6

Table 2 cont. Major Ion Chemistry

Sample ID	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	HCO_3 (ppm)	Cl (ppm)	Br (ppm)	SO_4 (ppm)	Cl/Br	Error %
AW011309-SanA-RGA	43.5	8.0	38.9	6.1	174	21.2	0.1	64.9	353	-2.0
AW011309-SanA-RGB	43.6	8.0	38.8	6.1	165	24.9	0.1	74.5	497	-3.6
AW011309-SanA-DD	61.2	14.6	185	11.2	244	182	0.2	231	955	-5.2
AW102007-SdC1-1	381	161	103	16.4	386	30.3	0.2	1637	126	-5.4
AW011808-SdC1-1	354	161	115	8.5	270	19.4	0.1	1514	150	-0.6
AW061208-SdC1-1	343	130	96.8	1.1	263	19.4	0.4	1538	47.3	-7.1
AW072908-SdC1-1	367	126	95.7	3.1	241	21.7	0.4	1833	52.3	-13.0
AW102007-SdC1-2	419	181	126	16.8	289	25.9	0.3	1869	96.0	-3.1
AW102007-SdC3	636	299	96.4	182	364	56.4	4.2	2986	13.5	-3.6
AW060509-RSB09	155	49.0	686	28.6	293	981	0.6	593	1527	-1.2
DN04-RSB10	322	144	304	304	202	382	1.1	1642	342	0.6
DN04-RSB11	186	60.7	730	60.9	364	1085	2.2	661	493	-2.9
AW060509-RSB11	193	70.0	693	28.4	393	1059	0.5	830	2037	-7.4
DN04-RSB12	175	49.0	775	62.7	403	1229	2.4	547	520	-4.7
AW060509-RSB12	155	49.0	686	28.6	391	981	0.5	593	2181	-4.7
DN04-RSB13	128	43.1	119	4.4	216	26.8	0.1	518	215	0.1
AW071708-CE	77.4	31.0	29.9	1.2	411	10.5	0.3	48.0	31.2	-2.0
AW071708-ARS	90.4	42.1	44.2	1.2	526	18.6	0.4	56.8	45.7	-2.1
AW072508-QS	74.0	9.9	12.6	57.3	267	51.2	0.3	38.6	159	-1.1
AW080108-SC1	1.0	0.2	128	0.8	325	6.0	0.3	12.5	20.4	-1.5
AW080708-SA1	1.7	0.3	357	11.7	291	146	0.5	347	325	-0.7
AW082208-DS	122	49.3	101	33.7	162	34.6	0.5	620	70.7	-4.1
AW090408-JS	254	83.7	51.0	5.5	220	15.6	0.4	1100	41.5	-10.4
AW090408-BWS	61.3	47.5	49.3	6.1	398	25.8	0.4	156	59.5	-6.8

Table 2 cont. Major Ion Chemistry

Sample ID	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	HCO_3 (ppm)	Cl (ppm)	Br (ppm)	SO_4 (ppm)	Cl/Br	Error %
AW101208-LP1	55.2	13.4	24.6	1.2	258	11.5	0.3	24.7	39.6	-1.3
AW101208-LP14	80.8	33.1	62.9	7.3	319	39.0	0.1	175	434	-1.7
AW042208-SanA-W	24.1	19.4	405	15.1	189	489	0.4	230	1288	-2.3
AW061908-SW	28.9	17.6	538	5.0	214	416	0.6	517	734	0.7
AW062008-FWS	40.3	33.0	559	5.5	177	546	0.6	506	898	0.5
AW062308-MW	36.3	16.3	41.6	1.6	151	31.9	0.6	64.9	57.4	-0.5
AW062308-BW-T*	19.1	11.3	39.7	2.0	93.4	21.3	0.4	71.9	52.0	-0.5
AW062408-NW	45.8	24.8	26.6	1.8	211	21.8	0.5	65.2	41.2	-0.1
AW062608-TW	65.6	32.0	25.7	2.6	326	17.3	0.4	68.0	41.4	-2.7
AW072908-TW	64.0	32.3	25.0	2.4	326	15.9	0.4	69.3	38.0	-2.5
AW062608-GW	495	142	53.8	11.4	56.1	22.4	0.4	2125	55.8	-8.0
AW062708-GDW	63.1	25.8	62.0	3.3	198	74.1	1.1	155	70.1	-3.6
AW071808-CW	94.3	24.6	41.8	1.6	205	23.1	0.3	256	70.2	-5.4
AW072208-EW	181	69.3	573	9.8	192	867	0.6	656	1357	-1.7
AW080108-WMW	11.9	2.2	45.4	1.6	140	11.2	0.3	22.3	40.	-6.0
AW082208-BRW	140	35.1	65.1	26.9	248	11.9	0.4	449	33.4	-1.5
AW060409-TUW	36.3	41.5	39.9	3.4	351	26.4	0.3	84.1	79.9	8.1

Table 3. Total dissolved nitrogen and dissolved organic carbon concentrations for select springs and wells in the Sevilleta NWR.

Sample Name	TDN +/- 0.01 mg/L N	DOC +/- 0.05 mg/L C
AW 061208-SdC1-1	0.32	3.75
AW 061308-SLS1	0.69	2.97
AW 061908-SW	0.10	2.37
AW 062008-FWS	0.13	2.23
AW 062308-MW	5.81	2.38
AW 062308-BW-T	1.41	3.41
AW 062408-NW	0.31	3.09
AW 062608-GW	2.24	2.83
AW 062608-TW	6.04	2.95
AW 062708-SanA	5.46	32.49
AW 062708-GDW	0.22	2.58
AW 071808-CW	4.58	2.32
AW 072208-EW	0.85	2.48
AW 072908-SdC1-1	0.43	5.95
AW 072908-SLS1	1.60	3.03
AW 072908-SLS2	0.48	2.40
AW 072908-TW	2.17	2.90
AW 080108-SC1	0.39	2.68
AW 080108-WMW	0.43	1.90

Table 4. Select Trace Elements, $^{87}Sr/^{86}Sr$ Ratios, and Stable Isotopes
All samples reported in ppm. <mbd = less than method detection limit. Mdl for ions is as follows (in ppm): As=.025; B, Ba, Li, Sr=.010. '-' = not determined. '*' = previously reported in Newell (2007). Trace element concentrations determined on an ICP-OES.

Sample ID	As (ppm)	B (ppm)	Ba (ppm)	Li (ppm)	Sr (ppm)	$^{87}Sr/^{86}Sr$	δD (‰)	$\delta^{18}O$ (‰)	$\delta^{13}C$ (‰)
AW102107-SLS1	<mbd	0.81	0.08	0.09	0.44	-	-	-	-
AW061308-SLS1	<mbd	0.67	0.04	0.13	0.30	0.71265	-65.9	-8.5	-
AW072908-SLS1	<mbd	0.68	0.04	0.10	0.28	-	-	-	-10.2
AW102107-SLS2	<mbd	0.84	<mbd	0.15	0.41	-	-	-	-
AW011808-SLS2	<mbd	0.69	0.03	0.08	0.36	-	-67.2	-8.1	-
AW072908-SLS2	<mbd	0.57	<mbd	0.13	0.38	-	-	-	-
AW060509-SLS3	0.04	0.79	0.21	0.15	0.80	-	-	-	-
AW102107-SLS4	<mbd	0.75	0.06	0.04	0.64	-	-59.8	-8.2	-
AW102107-RS1	<mbd	1.19	0.07	0.06	3.88	-	-55.5	-6.8	-
AW101108-RS	<mbd	0.99	0.15	<mbd	6.14	-	-	-	-
AW102107-SanA	<mbd	34.04	0.03	8.68	23.20	-	-	-	-
AW062708-SanA	<mbd	12.56	0.01	2.63	31.60	-	1.6	8.3	-
AW011309-SanA	<mbd	9.57	0.02	5.21	63.36	0.70974	-	-	-4.3
AW011309-SanA-M	<mbd	4.41	0.01	1.16	27.03	-	-	-	-4.8
AW071808-SanA-S	<mbd	3.20	0.35	0.23	0.58	-	-61.9	-7.5	-
AW011309-SanA-S	<mbd	4.62	0.02	0.92	28.78	0.70969	-	-	-4.0
AW011309-SanA-D	<mbd	1.21	0.10	0.25	1.82	-	-	-	-
AW011309-SanA-RGA	<mbd	0.65	0.08	0.08	0.43	-	-	-	-14.8
AW011309-SanA-RGB	<mbd	0.60	0.08	0.08	0.42	-	-	-	-7.7
AW011309-SanA-DD	<mbd	0.87	0.09	0.16	1.06	-	-	-	-8.0
AW072908-SdC1	<mbd	0.79	0.09	<mbd	5.36	0.70897	-	-	-8.0

Table 4 cont. Select Trace Elements, ^{87}Sr/^{86}Sr Ratios, and Stable Isotopes

Sample ID	As (ppm)	B (ppm)	Ba (ppm)	Li (ppm)	Sr (ppm)	^{87}Sr/^{86}Sr	δD (‰)	δ^{18}O (‰)	δ^{13}C (‰)
AW102007-SdC3	<mbd	1.53	0.02	<mbd	9.94	-	-45.2	-5.1	-
AW060509-RSB09	0.04	1.03	0.11	0.40	3.72	-	-	-	-
DN04-RSB10	-	0.60*	1.90*	2.48*	34.50*	-	-	-	-
DN04-RSB11	-	1.10*	1.97*	5.10*	24.44*	-	-64.1	-8.4	-
AW060509-RSB11	0.05	1.15	0.10	0.50	3.97	-	-	-	-
DN04-RSB12	-	1.17*	1.88*	5.90*	23.88*	0.71508	-67.8	-8.9	-18.2*
AW060509-RSB12	0.05	1.02	0.04	0.54	3.11	-	-	-	-
DN04-RSB13	-	0.33*	1.67*	0.33*	11.98*	-	-	-	-
AW071708-CE	<mbd	0.58	0.25	<mbd	0.58	-	-73.1	-10.1	-
AW071708-ARS	<mbd	0.58	0.27	<mbd	0.86	-	-70.0	-9.3	-10.8
AW072508-QS	-	0.51	0.15	<mbd	0.27	-	-41.7	-6.1	-
AW080108-SC1	<mbd	0.62	<mbd	0.13	0.01	-	-56.2	-6.8	-
AW080708-SA1	0.16	0.88	<mbd	0.33	0.06	0.71457	-67.9	-8.8	-5.31
AW082208-DS	<mbd	0.62	0.01	<mbd	2.19	0.70958	-48.4	-5.8	-2.13
AW090408-JS	<mbd	0.62	0.01	<mbd	3.74	-	-	-	-7.91
AW090408-BWS	<mbd	0.51	0.06	<mbd	1.18	-	-	-	-
AW101208-LP1	<mbd	0.58	0.03	<mbd	0.34	-	-	-	-12.2
AW101208-LP14	<mbd	0.59	0.05	<mbd	0.56	-	-	-	-
AW042208-SanA-W	<mbd	1.24	<mbd	0.33	1.36	-	-84.6	-11.6	-
AW062008-FWS	<mbd	1.10	<mbd	0.44	2.71	-	-88.1	-11.7	-
AW062308-MW	<mbd	0.66	0.04	0.00	0.47	-	-64.2	-9.0	-
AW062308-BW-T	<mbd	0.63	0.01	0.05	0.80	-	-53.6	-7.6	-
AW062408-NW	<mbd	0.64	0.01	<mbd	0.36	-	-67.2	-9.5	-

Table 4 cont. Select Trace Elements, $^{87}Sr/^{86}Sr$ Ratios, and Stable Isotopes

Sample ID	As (ppm)	B (ppm)	Ba (ppm)	Li (ppm)	Sr (ppm)	$^{87}Sr/^{86}Sr$	δD (‰)	$\delta^{18}O$ (‰)	$\delta^{13}C$ (‰)
AW062608-TW	<mbd	0.63	0.12	<mbd	1.95	-	-54.7	-8.4	-
AW072908-TW	<mbd	0.57	0.09	<mbd	2.09	0.70996	-	-	-
AW062608-GW	<mbd	0.76	<mbd	<mbd	10.02	0.70914	-56.5	-7.5	-2.55
AW062708-GDW	<mbd	0.49	<mbd	<mbd	0.76	-	-69.3	-9.8	-
AW071808-CW	<mbd	0.77	<mbd	<mbd	1.79	-	-51.6	-7.7	-
AW072208-EW	<mbd	0.81	<mbd	0.14	4.60	-	-59.9	-8.0	-
AW080108-WMW	<mbd	0.52	0.07	0.01	0.21	0.70948	-64.1	-8.9	-
AW082208-BRW	<mbd	0.69	<mbd	<mbd	1.81	-	-70.8	-10.0	-
AW060409-TUW	0.05	0.58	0.08	0.05	1.38	-	-	-	-

Table 5. Trace Elements from select samples determined from ICP-MS Analysis
All concentrations reported in ppm; <bb = below combined detector and blank background noise; Be, Bi, Cd, Ga, Pb, and Tl were <bb for all samples and are not reported here.

Sample	Ag	Al	As	Ba	Co	Cr	Cs	Cu	Fe	Li	Mn	Ni	Rb	Se	Sr	U	V	Zn
AW061308-SLS1	<bb	0.08	0.01	0.08	<bb	<bb	<bb	<bb	0.03	0.13	0.01	<bb	<bb	0.01	0.33	0.01	0.04	<bb
AW072908-SLS2	<bb	0.04	0.02	0.02	<bb	<bb	0.01	<bb	0.02	0.15	0.01	<bb	0.01	0.01	0.42	0.02	0.04	0.03
AW102107-SLS4	<bb	0.01	0.01	0.09	<bb	0.00	<bb	<bb	0.03	0.13	<bb	<bb	<bb	<bb	0.67	0.01	0.07	<bb
AW102107-RS1	<bb	0.04	<bb	0.12	<bb	<bb	<bb	<bb	0.08	0.52	0.23	0.02	0.04	<bb	3.98	0.01	<bb	<bb
AW102107-SanA	<bb	0.07	0.02	0.08	0.01	0.01	<bb	0.02	2.76	9.61	0.01	0.18	0.09	0.03	100.30	0.01	<bb	0.02
AW011309-SanA	<bb	0.01	0.02	0.04	<bb	0.01	<bb	0.03	0.44	5.75	0.07	0.08	0.06	0.06	43.09	0.02	<bb	<bb
AW011309-SanA-M	<bb	0.01	0.01	0.03	<bb	<bb	<bb	0.01	0.36	2.04	0.60	0.06	0.02	0.01	20.26	0.03	<bb	<bb
AW071808-SanA-S	<bb	0.01	0.01	0.05	<bb	<bb	<bb	<bb	0.38	0.82	2.10	0.04	0.02	0.01	13.05	<bb	<bb	<bb
AW011309-SanA-S	<bb	<bb	0.01	0.04	<bb	<bb	<bb	0.01	0.50	1.84	0.27	0.07	0.03	0.02	21.77	0.06	<bb	<bb
AW011309-SanA-D	<bb	<bb	0.02	0.11	<bb	<bb	<bb	<bb	0.03	0.27	0.35	0.01	0.01	<bb	1.41	<bb	<bb	<bb
AW011309-SanA-RGB	<bb	0.01	<bb	0.09	<bb	<bb	<bb	<bb	0.01	0.05	0.01	<bb	<bb	<bb	0.38	<bb	0.01	<bb
AW011309-SanA-DD	<bb	<bb	0.01	0.11	<bb	<bb	<bb	<bb	0.01	0.16	0.18	0.01	0.01	<bb	0.89	<bb	<bb	<bb
AW011808-SdC1-1	<bb	<bb	<bb	0.02	<bb	<bb	<bb	<bb	0.17	0.06	<bb	0.03	<bb	<bb	5.78	0.03	0.01	<bb
AW102007-SdC3	<bb	0.10	0.01	0.05	<bb	<bb	<bb	0.01	0.51	0.09	0.82	0.04	0.06	0.01	9.67	0.02	0.01	0.01
AW071708-CE	<bb	0.01	0.01	0.27	<bb	<bb	<bb	<bb	0.01	0.02	0.20	<bb	<bb	<bb	0.63	<bb	0.01	0.01
AW071708-ARS	<bb	<bb	0.01	0.31	<bb	<bb	<bb	<bb	0.01	0.03	0.31	0.01	<bb	<bb	0.89	<bb	<bb	<bb
AW072508-QS	0.01	0.02	<bb	0.20	<bb	<bb	<bb	<bb	0.05	0.01	0.03	0.01	<bb	<bb	0.30	<bb	<bb	0.02

Table 5 cont. Trace Elements from select samples determined from ICP-MS Analysis

Sample	Ag	Al	As	Ba	Co	Cr	Cs	Cu	Fe	Li	Mn	Ni	Rb	Se	Sr	U	V	Zn
AW080108-SC1	<bb	0.07	0.01	0.01	<bb	<bb	<bb	<bb	0.02	0.11	<bb	<bb	<bb	<bb	0.02	<bb	0.03	0.01
AW080708-SA1	<bb	0.01	0.19	0.01	<bb	<bb	0.01	<bb	<bb	0.29	<bb	<bb	0.01	<bb	0.07	<bb	0.09	<bb
AW082208-DS	0.01	<bb	<bb	0.04	<bb	<bb	<bb	<bb	0.05	0.04	<bb	0.01	<bb	<bb	2.30	0.01	<bb	0.01
AW090408-JS	<bb	<bb	<bb	0.04	<bb	<bb	<bb	<bb	0.15	0.05	0.01	0.03	0.02	<bb	4.78	0.02	<bb	<bb
AW090408-BWS	<bb	0.01	0.01	0.10	<bb	<bb	<bb	<bb	0.03	0.04	0.01	0.01	0.01	0.01	1.38	0.02	0.03	0.01
AW101208-LP1	<bb	<bb	<bb	0.04	<bb	<bb	<bb	<bb	0.04	0.03	<bb	0.01	<bb	<bb	0.37	0.01	<bb	<bb
AW101208-LP14	<bb	<bb	<bb	0.07	<bb	<bb	<bb	<bb	0.04	0.03	0.03	0.01	<bb	0.01	0.62	0.02	<bb	0.01
AW042208-SanA-W	<bb	<bb	<bb	0.03	<bb	<bb	<bb	<bb	0.02	0.35	0.05	<bb	0.01	<bb	1.58	<bb	0.02	0.03
AW061908-SW	<bb	<bb	0.01	0.01	<bb	<bb	<bb	0.01	0.02	0.37	0.01	<bb	0.01	<bb	1.47	<bb	<bb	0.06
AW062008-FWS	<bb	<bb	<bb	0.02	<bb	<bb	<bb	<bb	0.04	0.44	0.02	<bb	0.01	<bb	3.01	<bb	<bb	0.28
AW062008-FWS	<bb	<bb	0.01	0.02	<bb	<bb	<bb	<bb	0.03	0.43	0.02	<bb	0.01	<bb	2.99	<bb	<bb	0.41
AW062308-MW	<bb	<bb	0.01	0.07	<bb	<bb	<bb	<bb	<bb	0.03	<bb	<bb	0.01	0.01	0.53	<bb	0.01	0.04
AW062308-BW-T	<bb	0.01	<bb	0.04	<bb	<bb	<bb	<bb	<bb	0.05	<bb	<bb	<bb	0.01	0.87	<bb	0.01	0.03
AW062408-NW	<bb	<bb	0.01	0.05	<bb	<bb	<bb	<bb	0.01	0.04	<bb	<bb	0.01	<bb	0.39	0.01	<bb	0.06
AW072908-TW	<bb	<bb	<bb	0.13	<bb	<bb	<bb	<bb	0.07	0.05	0.09	0.01	<bb	<bb	2.13	0.01	<bb	0.38
AW062608-GW	<bb	0.01	<bb	0.01	<bb	<bb	<bb	<bb	1.65	0.05	0.20	0.03	0.01	<bb	10.23	<bb	<bb	0.21
AW062708-GDW	<bb	<bb	<bb	0.02	<bb	<bb	<bb	<bb	0.36	0.09	0.12	0.01	0.01	0.01	0.75	<bb	<bb	0.43
AW071808-CW	<bb	0.04	<bb	0.02	<bb	<bb	<bb	0.01	0.47	0.03	0.16	0.01	<bb	<bb	1.81	<bb	<bb	0.10

Table 6. Correlation Matrix of Variable Principal Component Loadings

Variable	PC1	PC2	PC3
pH	-0.2816	0.3871	0.0416
Na	0.3137	-0.3529	-0.0914
K	0.3286	0.1217	-0.0379
Ca	0.3958	0.0239	0.2315
Mg	0.3902	0.0518	0.2113
HCO_3	0.1152	-0.1420	-0.8351
Cl	0.3207	-0.3552	-0.1026
SO_4	0.3886	0.0189	0.3054
δD	0.2321	0.5738	-0.1977
$\delta^{18}O$	0.2905	0.4813	-0.2235

Table 7. Correlation matrix of Principal Component Loadings (Eigenvectors) (excluding the San Acacia lower brine pool) PC = Principal Components

Sample	PC1	PC2	PC3
AW061308-SLS1	-0.1994	0.0223	-0.1787
AW011808-SLS2	-0.1687	0.0152	-0.1514
AW102107-SLS4	-0.1410	0.1062	-0.2031
AW102107-RS1	0.2420	0.1203	-0.0329
AW071808-SanA-S	0.7517	-0.2758	-0.1495
AW011309-SanA-S	1.5169	-0.3942	0.0129
AW011309-SanA-D	-0.1486	-0.2492	-0.0385
AW011309-SanA-RGA	-0.3654	-0.2996	0.1892
AW011309-SanA-RGB	-0.3861	-0.2644	0.2047
AW011309-SanA-DD	-0.2788	-0.2646	0.0810
AW061208-SdC1-1	0.2331	0.0939	0.1306
AW102007-SdC3	1.0702	0.4359	0.1145
DN04-RSB11	0.1952	-0.0465	-0.1652
DN04-RSB12	0.2698	-0.2576	-0.2371
AW071708-CE	-0.1996	-0.1134	-0.2113
AW071708-ARS	-0.1173	-0.0993	-0.3903
AW072508-QS	0.0212	0.3782	-0.1886
AW080108-SC1	-0.2389	0.3004	-0.2228
AW080708-SA1	-0.2405	0.0810	-0.0937
AW082208-DS	0.0747	0.3401	0.0441

Table 7 cont. Correlation matrix of Principal Component Loadings (Eigenvectors)

Sample	PC1	PC2	PC3
AW090408-JS	0.0525	0.0264	0.1559
AW042208-SanA-W	-0.2841	-0.2333	0.1426
AW061908-SW	-0.2315	-0.2411	0.1106
AW062008-FWS	-0.2400	-0.2966	0.1934
AW062308-MW	-0.2334	0.0715	0.0974
AW062308-BW-T	-0.2939	0.3755	0.1330
AW062408-NW	-0.2322	0.0131	0.0390
AW062608-TW	-0.1155	0.1178	-0.1728
AW062608-GW	0.3144	0.2481	0.4917
AW062708-GDW	-0.2271	-0.0136	0.0763
AW071808-CW	-0.0985	0.2085	-0.0080
AW072208-EW	0.0775	0.0551	0.0810
AW080108-WMW	-0.2889	0.1141	0.0992
AW082208-BRW	-0.0896	-0.0745	0.0466

Table 8. PHREEQC Generated Saturation Indices

Sample ID	Calcite	CO_2	Dolomite	Gypsum	Halite
AW102107-SLS1	0.26	-2.32	-0.05	-2.16	-7.29
AW061308-SLS1	0.13	-2.25	-0.09	-2.37	-7.30
AW072908-SLS1	0.36	-2.51	0.34	-2.43	-7.36
AW102107-SLS2	-0.25	-2.13	-0.46	-2.11	-7.06
AW011808-SLS2	-0.42	-2.11	-0.85	-2.13	-6.97
AW072908-SLS2	0.16	-2.47	0.41	-2.16	-7.11
AW060509-SLS3	0.48	-2.21	0.62	-2.18	-7.58
AW102107-SLS4	0.55	-2.42	0.83	-2.21	-7.75
AW102107-RS1	1.00	-3.08	1.63	-0.62	-4.61
AW101108-RS	0.65	-2.84	0.89	-0.45	-4.79
RG030809-1	0.28	-3.14	-0.08	-2.02	-7.66
RG030809-2	0.27	-3.13	-0.10	-2.02	-7.66
RG030809-3	0.03	-2.83	-0.56	-2.01	-7.63
RG030809-4	-0.01	-2.72	-0.61	-1.94	-7.50
AW102107-SanA	1.61	-4.40	3.77	-3.40	-2.17
AW062708-SanA	1.67	-5.17	3.21	0.20	-2.97
AW011309-SanA	1.25	-3.60	2.71	0.19	-2.53
AW011309-SanA-M	0.53	-2.19	0.83	-0.08	-3.46
AW071808-SanA-S	0.52	-1.62	0.94	-0.27	-3.96
AW011309-SanA-S	0.73	-2.62	1.10	-0.05	-3.48
AW011309-SanA-D	0.78	-2.91	1.15	-1.16	-5.42
AW011309-SanA-RGA	0.46	-3.22	0.23	-1.90	-7.60
AW011309-SanA-RGB	0.34	-3.15	-0.02	-1.84	-7.54

Table 8 cont. PHREEQC Generated Saturation Indices

Sample ID	Calcite	CO_2	Dolomite	Gypsum	Halite
AW011309-SanA-DD	0.66	-3.08	0.80	-1.39	-6.04
AW102007-SdC1-1	0.25	-1.57	0.37	-0.20	-7.16
AW011808-SdC1-1	-0.68	-1.26	-1.69	-0.18	-7.27
AW061208-SdC1-1	0.20	-1.70	0.33	-0.26	-7.40
AW072908-SdC1-1	0.91	-2.43	1.74	-0.20	-7.38
AW102007-SdC3	0.44	-1.56	0.89	0.07	-6.98
AW060509-RSB09	0.89	-2.71	1.58	-0.90	-4.83
DN04-RSB10	0.99	-3.16	1.78	-0.26	-5.59
DN04-RSB11	0.47	-2.23	0.57	-0.77	-4.74
AW060509-RSB11	-0.04	-1.37	-0.18	-0.73	-4.81
DN04-RSB12	-1.23	-0.21	-2.72	-0.91	-4.69
AW060509-RSB12	-0.13	-1.38	-0.44	-0.90	-4.84
DN04-RSB13	-0.17	-1.98	-0.62	-0.85	-7.09
AW071708-CE	0.60	-2.05	1.15	-1.94	-8.09
AW071708-ARS	0.55	-1.73	1.12	-1.86	-7.68
AW072508-QS	0.64	-2.55	0.67	-1.98	-7.75
AW080108-SC1	0.22	-4.19	0.04	-4.42	-7.68
AW080708-SA1	0.00	-3.78	-0.38	-2.88	-5.90
AW082208-DS	0.30	-2.58	0.51	-0.84	-7.08
AW090408-JS	0.08	-1.94	-0.03	-0.37	-7.75
AW090408-BWS	0.36	-2.07	0.89	-1.49	-7.41
AW101208-LP1	-0.21	-1.83	-0.79	-2.26	-8.10
AW101208-LP14	1.09	-2.95	2.06	-1.41	-7.19
AW042208-SanA-W	0.04	-2.93	0.24	-1.87	-5.31

Table 8 cont. PHREEQC Generated Saturation Indices

Sample ID	Calcite	CO_2	Dolomite	Gypsum	Halite
AW061908-SW	-0.05	-2.53	0.04	-1.55	-5.30
AW062008-FWS	0.01	-2.66	0.26	-1.44	-5.16
AW062308-MW	0.06	-2.68	0.08	-2.02	-7.44
AW062308-BW-T	1.20	-5.25	2.58	-2.29	-7.64
AW062408-NW	0.24	-2.51	0.54	-1.97	-7.80
AW062608-TW	0.39	-2.15	0.78	-1.84	-7.93
AW072908-TW	0.73	-2.45	1.52	-1.85	-7.98
AW062608-GW	0.24	-3.05	0.26	-0.04	-7.60
AW062708-GDW	0.34	-2.59	0.59	-1.52	-6.92
AW071808-CW	0.42	-2.49	0.56	-1.18	-7.60
AW072208-EW	0.58	-2.59	1.10	-0.80	-4.97
AW080108-WMW	0.10	-3.22	-0.21	-2.85	-7.84
AW082208-BRW	-0.08	-1.82	-0.51	-0.86	-7.71
AW060409-TUW	-0.06	-1.88	0.25	-2.01	-7.56

Table 9. Sevilleta NWR bulk precipitation chemistry (1989-1995)
All ion concentrations in ppm; $\delta^{13}C$ measured in ‰

Sample	pH	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	HCO_3 (ppm)	Cl (ppm)	SO_4 (ppm)	Est. $\delta^{13}C$
Sevilleta precipitation	5.4	0.94	0.09	0.12	0.15	1.7	0.2	1.4	-8

Table 10. Binary mixing models between the San Acacia upper pool (Cl-rich) and 1) Silver Creek Seep (HCO_3-rich) and 2) RSB12 spring (Cl-rich).

% Silver Creek Seep to San Acacia upper pool	pH	Calcite SI	CO_2	TDS (ppm)
100%	9.53	0.22	-4.19	174
90%	9.127	1.53	-3.77	787.6
80%	8.846	1.54	-3.45	1401.2
70%	8.586	1.46	-3.16	2014.8
60%	8.314	1.31	-2.86	2628.4
50%	8.018	1.11	-2.54	3242
40%	7.738	0.91	-2.24	3855.6
30%	7.522	0.75	-2.02	4469.2
20%	7.364	0.65	-1.85	5082.8
10%	7.244	0.58	-1.72	5696.4
0%	7.15	0.52	-1.62	6310

% RSB12 to San Acacia upper pool	pH	Calcite SI	CO_2	TDS (ppm)
100%	5.73	-1.23	-0.21	2885
90%	5.759	-1.19	-0.28	3756.5
80%	5.795	-1.15	-0.35	4628
70%	5.839	-1.11	-0.42	5499.5
60%	5.894	-1.06	-0.51	6371
50%	5.961	-1.01	-0.61	7242.5
40%	6.047	-0.94	-0.72	8114
30%	6.16	-0.84	-0.87	8985.5

Table 10 cont. Binary mixing models between the San Acacia upper pool (Cl-rich) and 1) Silver Creek Seep (HCO_3-rich) and 2) RSB12 spring (Cl-rich).

% RSB12 to San Acacia upper pool	pH	Calcite SI	CO_2	TDS (ppm)
20%	6.324	-0.7	-1.06	9857
10%	6.608	-0.44	-1.38	10728.5
0%	7.81	0.73	-2.62	11600

Table 11. Results of PHREEQC Inverse Modeling

Simulation		SdC1-rain	SLS1-rain	SC1-rain	SanA-S-rain	NW-rain
Number of Models Obtained & Model Uncertainty (%)		5 (12%)	8 (10%)	5 (10%)	18 (10%)	5 (10%)
Occurrence in models: *dissolving phases*	H_2O	0	1	0	5	0
	Calcite	0	3	2	1	0
	Dolomite	5	4	2	13	5
	CO_2(g)	0	2	1	3	0
	Gypsum	5	3	0	13	0
	Halite	5	3	0	18	0
	Albite	0	8	5	10	5
	K-feldspar	0	5	0	9	0
	Gibbsite	2	6	0	8	3
	Ca-Montmorillonite	2	0	0	2	1
	Chalcedony	3	0	0	5	0
	Kaolinite	0	0	0	0	2
	Chlorite	0	0	3	0	0
Occurrence in models: *evaporating/precipitating phases*	H_2O	5	6	5	13	5
	Calcite	4	2	2	14	4
	Dolomite	0	2	2	0	0
	CO_2(g)	4	5	3	9	4
	Gypsum	0	4	5	0	0
	Halite	0	3	0	0	0
	K-feldspar	5	2	0	5	0
	Gibbsite	1	1	0	6	1
	Ca-Montmorillonite	1	7	4	11	3
	Chalcedony	1	0	0	8	0
	Talc	0	0	4	0	0
	Chlorite	0	0	1	0	0
	Kaolinite	0	0	0	0	2
	K-mica	0	0	5	0	5

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9 Appendix A – Spring and Well Details

In a study from 2000-2001, Rawling (2003) reported the condition and estimated the flow (or cessation of flow) of 26 springs and seeps on the refuge and 4 springs and seeps within close proximity of the refuge, but no chemistry was conducted.

From this report, 8 spring samples, 1 river sample, and 1 brine pool sample were collected from the Sevilleta NWR. These include San Lorenzo Springs 1-4, Cibola Spring, Milagro Seep, Silver Creek Seep, Canyon del Ojito Spring, the Rio Salado at Silver Creek, and the San Acacia brine pool (sampled at both the large lower pool and the smaller upper pool). Off of the refuge, the two Rio Salado Springs and the Rio Salado upstream and downstream of the springs were sampled in 2004 by Dennis Newell and in 2009 for this report. In Abo Pass, 3 springs were sampled, two at the Abo site for the Salinas Pueblo National Monument (ARS and CE) and one at the Quarai site for the same monument (QS). Not all are described here.

9.1 Springs

9.1.1 San Lorenzo Spring 1 (SLS1)

Location: San Lorenzo Spring 7.5 minute quadrangle, 34.23915, -107.01978, NAD83
Description: This spring is marked on the San Lorenzo Spring quadrangle. The water sources in the San Lorenzo Canyon arroyo gravels above a natural chute in the canyon where then pours over and quickly returns to the subsurface in the arroyo gravels. One willow is located next to the spring flow. The spring was flowing on July 29, 2008. Discharge was estimated by measurement on June 13, 2008 at ~2 L/ minute.
Geologic Setting: See Rawling 2003.
Hydrologic Setting and Water Source: See Rawling 2003.

9.1.2 San Lorenzo Spring 2 (SLS2)

Location: San Lorenzo Spring 7.5 minute quadrangle, 34.24176, -107.00479, NAD83
Description: This spring is marked on the San Lorenzo Spring quadrangle. It is a few feet south of the refuge fence on the north side of San Lorenzo Canyon as it is accessed through BLM land. Access to SLS1 is barred by a large rock fall that bisects the canyon.

It is a wetland area that was originally developed, as a steel box is located down gradient from the spring. The spring had restricted flow on July 29, 2008.

Geologic Setting: See Rawling 2003.

Hydrologic Setting and Water Source: See Rawling 2003.

9.1.3 San Lorenzo Spring 3 & Seep 4 (SLS3 & SLS4)

Location: San Lorenzo Spring 7.5 minute quadrangle, 34.23816, -107.02109 and 34.23817, -107.02489, NAD83

Description: SLS4 is marked on the San Lorenzo Spring quadrangle, while SLS3 is not. These springs are found west of the boundary fence in bedrock. SLS3 forms small pools in the arroyo and are surrounded by vegetation and willows. SLS4 is further north in the arroyo and also forms a pool. They were observed flowing on June 5, 2009 and October 21, 2007, respectively.

Geologic Setting: See Rawling 2003.

Hydrologic Setting and Water Source: See Rawling 2003.

9.1.4 Cibola Spring (SdC1)

Location: Sierra de la Cruz 7.5 minute quadrangle, 34.23136, -106.67952, NAD83

Description: This spring is marked on the Sierra de la Cruz quadrangle. It sources from the arroyo gravels east of Cibola Canyon. The water continues downstream through a limestone slot canyon and forms a series of plunge pools. The final pool is a <10 meter in diameter plunge pool, several meters deep. From previous research, the spring was flowing on July 17, 2002, and the flow had increased significantly by August 27, 2002 after a month of monsoon rains. From this research, the spring was flowing July 29, 2008, but was at a lower level in August when the monsoons stopped. Discharge was estimated by the bottle and stopwatch method on June 12, 2008 at ~2 L/ minute.

Geologic Setting: See Rawling 2003.

Hydrologic Setting and Water Source: See Rawling 2003.

9.1.5 Milagro Seep (SdC3)

Location: Sierra de la Cruz 7.5 minute quadrangle, 34.21214, -106.73248, NAD83

Description: This spring is not marked on the Sierra de la Cruz quadrangle. It is located 800 m east of SdC2, "Milagro Spring". It is adjacent to Arroyo Milagro, and is in a small grass-filled depression located in the gypsum of the Yeso formation. It was observed with water on October 20, 2007.

Geologic Setting: See Rawling 2003.

Hydrologic Setting and Water Source: See Rawling 2003.

9.1.6 Silver Creek Seep (SC1)

Location: Silver Creek 7.5 minute quadrangle, 34.29063, -107.03484, NAD83

Description: This seep is not marked on the Silver Creek quadrangle. It is one of several seeps that surface in the canyons of Tertiary volcanics on the east side of the Silver Creek fault. There was no obvious point source for SC1. SC1 was flowing on August 1, 2008, but not on June 5, 2009.

Geologic Setting: The seep is located in Tertiary volcanics. There are other seeps nearby which form small wetland ecosystems in the drainages perpendicular to the Silver Creek wash.

Hydrologic Setting and Water Source: Previous observations (John Dewitt, personal communication) indicate that these seeps always have water and suggest that there is a consistent source.

9.1.7 Canyon del Ojito Spring (SA1)

Location: San Acacia 7.5 minute quadrangle, 34.2607, -106.97526, NAD83

Description: This spring is located ~300 meters upstream from where it is marked on the San Acacia quadrangle. The spring is located just upstream of a 3 meter high chute where a slot canyon has formed. The water upwells from fractured bedrock and forms a continuous flow for several meters downstream of the spring. The spring was flowing on August 7, 2008.

Geologic Setting: See Rawling 2003.

Hydrologic Setting and Water Source: See Rawling 2003.

9.1.8 Rio Salado at Silver Creek (RS)

Location: Silver Creek 7.5 minute quadrangle, 34.33355, -107.03635, NAD83

Description: Sample was collected at the confluence of the Silver Creek Fault/Arroyo with the Rio Salado. The river was flowing on October 21, 2007. Discharge was visually estimated on October 21, 2007 at 20-30 L/ second.

Geologic Setting: The Rio Salado flows in its own Quaternary fluvial deposits down from its headwaters in the Sierra Ladrones. It is underlain by the Tertiary Santa Fe Group.

Hydrologic Setting and Water Source: The Rio Salado headwaters are located far west of the Sevilleta NWR in the Sierra Ladrones. It is supplied by base flow and some small springs from the headwaters to the Rio Salado Box Springs, which add a surficial component. The river becomes a losing stream again and pops up periodically in the river bed until it reaches the confluence with the Rio Grande. After a heavy rain in the western mountains, there can be small streamlets in the river bed. The bed is several miles long, and can flow at bank full under monsoon conditions.

9.1.9 San Acacia Brine Pool System (SanA & SanA-S)

Location: San Acacia 7.5 minute quadrangle, 34.26184, -106.8848 and 34.26361, -106.88416, NAD83

Description: Briney pools source in a halophytic wetland within a quarter mile of the Rio Grande.

Geologic Setting: Pools are located on the eastern flank of the Tertiary basaltic andesite neck, Indian Hill.

Hydrologic Setting and Water Source: Ultimate source is probably mixing of meteorically derived water with a series of springs that upwell saline waters from deeply penetrating faults.

9.1.10 Rio Salado Box Springs (RSB11 and RSB12)

Location: Silver Creek 7.5 minute quadrangle, 34.326115, -107.095764 and 34.325775, -107.09361, NAD83

Description: These two springs are not marked on the Silver Creek quadrangle. They are ~3.5 km west of the Sevilleta refuge on BLM land, although to access them from the Sevilleta NWR, you must pass through privately owned ranch land. They are both located along the Rio Salado where it cuts through the limestone ridge on the southwest side of

Ladron Peak. RSB12 discharges in several places from joints in bedrock on the south bank, just east of the Salado Box. It has substantial flow, enough to make a small "fountain" <30 cm high, and bubbles audibly. The eastern-most outlet has the highest discharge. RSB11 is within the eastern most side of the Salado Box and discharges in the sand and gravel bed of the river. It is an area of tens of square meters where water can be seen and heard bubbling up through the sand. The bubbling and hissing suggests that the water is probably exsolving CO_2 gas. The discharge from both springs flows east down the Rio Salado and onto the refuge. Both springs were flowing on June 5, 2009.

Geologic Setting: See Rawling 2003.

Hydrologic Setting and Water Source: See Rawling 2003.

9.1.11 Ojo de Abo Spring (ARS)

Location: Scholle 7.5 minute quadrangle, 34.446945, -106.37778, NAD83

Description: This spring is in the Abo Ruins Park within the Salinas National Monument. The spring produces several large wetland systems.

Geologic Setting: The spring sources in a Madera limestone arroyo.

Hydrologic Setting and Water Source: The water is locally sourced from the fractured Pennsylvanian Madera limestone.

9.1.12 Quarai Spring (QS)

Location: Punto de Agua 7.5 minute quadrangle, 34.59486, -106.2952, NAD83

Description: This spring is marked on the Punto de Agua quadrangle. It is located just off the walkway in the Quarai Ruins Park, part of the Salinas National Monument.

Geologic Setting: The spring is located in an outcrop of the Permian Abo formation, surrounded by Quaternary sediment on the east side of the Manzanos.

Hydrologic Setting and Water Source: The spring is located in a heavily vegetated drainage. Park personnel report that there is always some water in the drainage. The meteorically-derived chemical signal suggests that the spring is recharging from the eastern mountain front, flowing through the Pennsylvanian Madera limestone which forms the eastern mountain flank, and sourcing in the Permian Abo formation.

9.1.13 Dripping Springs (DS)

Location: Scholle 7.5 minute quadrangle, 34.41652, -106.47504, NAD83

Description: This spring is one of several marked on the Scholle quadrangle under the name Dripping Springs. It is located on Jean Sawyer-Rosas' ranch. The spring water has dissolved its source limestone, forming an inverse shelf under the limestone. The spring forms a pool in front of the limestone wall, where a vibrant wetland has been established.

Geologic Setting: The spring water drips from "fissures in calcareous shale and solution openings in the overlying limestone of the upper arkosic member of the Madera limestone. The springs are at the head of a small canyon eroded in the Madera limestone just below the contact of a shale member of the Bursum Formation. Several more small springs discharge into the Cañada Montosa" (Spiegel, 1955), which drains to Abo Arroyo.

Hydrologic Setting and Water Source: Spiegel (1955) suggested that the chemistry of Dripping Springs suggests that it is partially recharged from the Abo and Yeso Formations, but may also derive recharge from "the limestone in the hogback east of the northern Los Piños Mountains".

9.1.14 Jump Spring (JS)

Location: Mesa del Yeso 7.5 minute quadrangle, 34.15396, -106.75057, NAD83

Description: This spring is one of several marked on the Meso del Yeso quadrangle. IT is located on Jay Santillanes' ranch.

Geologic Setting: Spring sources from arroyo sediments, underwhich the Permian Yeso Formation is located.

Hydrologic Setting and Water Source: Water is probably flowing from the north and derives from the Permian Yeso Formation.

9.1.15 "Baca Well" Spring (BWS)

Location: Sierra de la Cruz 7.5 minute quadrangle, 34.17261, -106.73151, NAD83

Description: This spring is marked as the Baca Well. It is located on Jay Santillanes' ranch. A ~10ft deep pit was dug to create an artificial tank for the spring and the well pumps from the pit. The spring was sampled near the pour point in the pit.

Geologic Setting: This spring is located on alluvium, but is underlain by the Permian Yeso Formation.

Hydrologic Setting and Water Source: The water probably has minor interaction with the Yeso Formation, but the chemistry suggests that it is locally recharges, as it is not a SO_4 enriched water.

9.1.16 Ladron Peak Spring 1 (DeGeer Spring) (LP1)

Location: Ladron Peak 7.5 minute quadrangle, 34.38821, -107.07538, NAD83

Description: This spring is located west of the Sevilleta NWR on BLM land. It is marked on the Ladron Peak quadrangle and was originally developed for the DeGeer Ranch. It is located on a vegetated hill slope up gradient from an old structure and well which presumably served as a catch point for the spring flow.

Geologic Setting: See Rawling 2003.

Hydrologic Setting and Water Source: See Rawling 2003.

9.1.17 Ladron Peak Spring 14 (LP14)

Location: Ladron Peak 7.5 minute quadrangle, 34.37611, -107.07101, NAD83

Description: This spring is located west of the Sevilleta NWR on BLM land. It is not marked on the Ladron Peak quadrangle. The sample itself is from a set of pools in the arroyo. There was a willow near the spring and some vegetation near the arroyo bed.

Geologic Setting: The spring sources in Precambrian granite and metamorphosed units.

Hydrologic Setting and Water Source: The spring is probably locally recharged and moved through fractured bedrock to the spring source.

9.2 Wells

Several wells in the Sevilleta NWR have been modified from their original design as windmill-powered wells for stock tanks to solar-powered collection tanks. The US Fish & Wildlife Services report 14 active solar-powered wells on the refuge.

We collected samples from 12 of these wells. They include, from east to west, Goat Draw Well, Nunn Well, McKenzie Well, Tomasino Well, Canyon Well, Gibbs Well, the Fish & Wildlife field station well, the Sevilleta LTER field station well, Esquival Well, Bronco Well (the drinker tank only), Tule 222 Well, and the West Mesa Well. Two non-Sevilleta wells were sampled; San Acacia Well and Barella Well. The remaining solar Sevilleta wells were not sampled because they were either out of order or extremely difficult to access.

There are two types of well tanks present on the Sevilleta. Most solar wells are attached to a >1000 gallon fiberglass tank ~10 feet tall. The lids are sealed with a 2.5 foot diameter rubber washer and >10 bolts. A ladder and crowbars are required to break the seal on the rubber and lift the lid. The other solar wells are attached to metal or plastic tanks with lids latched with metal twist ties. They require only a ladder to access. Inside the tank is a plastic buoy that must be turned vertically to active the pump in the well. The groundwater pour point is in the tank. Unless otherwise noted, under full sun the solar panels are designed to run the pump at ~3 gpm.

9.2.1 Goat Draw Well (GDW)

Location: Becker 7.5 minute quadrangle, 34.40395, -106.52169, NAD83

Description: Goat Draw Well is located on the western edge of the Los Piños Mountains. It is 360 feet deep and powered by a small solar panel. The well was pumped for ~10 minutes. Appropriate time would have been 58 minutes, but the solar panel was not fully functional because it was cloudy. It became a solar well in 2002.

Geologic & Hydrologic Setting and Water Source: It is located in paleoproterozoic bedrock, and the principal water-bearing layer is probably the fractured paleoproterozoic rock.

9.2.2 Nunn Well (NW)

Location: Cerro Montoso 7.5 minute quadrangle, 34.36891, -106.60946, NAD83, 2N.3E.27.114

Description: Nunn Well is located on McKenzie Flats, next to the Los Piños foothills. It is 300 ft deep, is powered by a large solar panel and pumps into a > 1000 gallon fiberglass tank. The well was pumped for 49 minutes before sampling. It became a solar well in 2005.

Geologic & Hydrologic Setting and Water Source: The well is located in Quaternary alluvium and the principal aquifer is the Santa Fe group. The depth to water was reported as 153 feet when redrilled in 2005. See Appendix B for Well Record.

9.2.3 McKenzie Well (MW)

Location: Cerro Montoso 7.5 minute quadrangle, 34.34632, -106.61897, NAD83, 1N.3E.3.121

Description: McKenzie Well is located on McKenzie Flats, south and west of Nunn Well. It is 205 ft deep, is powered by a large solar panel, and pumps into a small metal holding tank. The well was pumped between 23 and 43 minutes before sampling. It became a solar well in 2004.

Geologic & Hydrologic Setting and Water Source: It is located in Quaternary alluvium and the principal aquifer is the Santa Fe group. The depth to water was reported as 65 feet when declared in 1984. See Appendix B for Well Declaration.

9.2.4 Tomasino Well (TW)

Location: Becker SW 7.5 minute quadrangle, 34.25266, -106.67362, NAD83, 1S.3E.6.124

Description: Tomasino Well is located along Tomasino road in the eastern extent of the Joyita Hills. It was originally reported as 48 feet deep, but was probably redrilled to the current 27 ft deep, is powered by a large solar panel, and pumps into a >1000 gallon fiberglass tank. The well was pumped for 4 minutes before sampling. It became a solar well in 2004.

Geologic & Hydrologic Setting and Water Source: It is located on the Permian Abo formation. The principal water bearing layer is probably the Abo sandstone. The depth to water was reported as 15 feet when originally drilled in 1939. See Appendix B for Well Declaration.

9.2.5 Canyon Well (CW)

Location: Becker SW 7.5 minute quadrangle, 34.31472, -106.71555, NAD83, 1N.2E.14.322

Description: Canyon Well is located west of Palo Duro road and north of Palo Duro Canyon, just north of the northern extent of the Joyita Hills. It is 128 ft deep, is powered by a large solar panel, and pumps into a small metal tank. The well was pumped for 20 minutes before sampling. It became a solar well in 2002.

Geologic & Hydrologic Setting and Water Source: The well is located on Permian Abo sandstone just north of a ridge displaying Permian Yeso, Glorietta, and San Andres units (from Canyon Well moving south). The principal aquifer is probably the Abo formation or Santa Fe group. The depth to water was reported as 43 feet when declared in 1984. See Appendix B for Well Declaration.

9.2.6 Gibbs Well (GW)

Location: Becker SW 7.5 minute quadrangle, 34.26434, -106.73134, NAD83, 1N.2E.33.323

Description: Gibbs Well is located just east of Beacon Forks road in the Joyita Hills. It is 134 ft deep, is powered by a large solar panel, and pumps into a small metal tank. The well was pumped for 9 minutes before sampling. It became a solar well in 2002.

Geologic & Hydrologic Setting and Water Source: The well is located between Cretaceous units and Quaternary alluvium. The depth to water was reported as 58 feet when declared in 1984. See Appendix B for Well Declaration.

9.2.7 Fish & Wildlife Services Field Office Well (FWS)

Location: La Joya 7.5 minute quadrangle, 34.35145, -106.88251, NAD83, 2N.1E..31.422

Description: This well is located behind the back patio at the Fish & Wildlife Services Field Office, exit 169 on Interstate 25. The well is ~250 ft deep and is made to pump at ~11 gpm. The well was pumped for 12 minutes before sampling.

Geologic & Hydrologic Setting and Water Source: The well is located on Quaternary alluvium. The principal aquifer is the Santa Fe group. The depth to water in a nearby test well was reported as 137 feet when drilled in 1975. See Appendix B for test Well Declaration and Well Record.

9.2.8 Sevilleta LTER Field Station Well (SW)

Location: La Joya 7.5 minute quadrangle, 34.35454, -106.88548, NAD83

Description: This well is located southeast of the Sevilleta LTER field station, exit 169 on Interstate 25. The water is gravity fed to tanks under the field station in the courtyard. The well itself is ~410 feet deep. It was pumped for 30 minutes before sampling.

Geologic & Hydrologic Setting and Water Source: It is located in Quaternary alluvium. The principal aquifer is the Santa Fe group.

9.2.9 Esquival Well (EW)

Location: La Joya 7.5 minute quadrangle, 34.3045, -106.9236, NAD83, 1N.1W.15.333

Description: Esquival Well is located just south of the Rio Salado on the west side. It is 193 ft deep, is powered by a large solar panel, and pumps into a >1000 gallon fiberglass tank. The lid was completely sealed to the tank, so the faucet on the bottom was turned on and the pump ran for 45 minutes before sampling. It became a solar well in 2006.

Geologic & Hydrologic Setting and Water Source: The well is located on Quaternary alluvium/ Rio Salado sediments. The principal aquifer is the Santa Fe group, with the principal water-bearing layer from 136-193 feet deep in fine to medium sand yielding an estimated 30GPM. The depth to water was reported as 10 feet when the 50 foot deep well was declared in 1984, but was reported as 44 feet when redrilled in 2007 to 193 feet. See Appendix B for Well Declaration and Well Record.

9.2.10 Bronco Well (BW)

Location: La Joya NW 7.5 minute quadrangle, 34.40735, -106.93271, NAD83, 2N.1W.10.224

Description: Bronco Well is located in the northwest section of the Sevilleta. It is 398 feet deep, is powered by a large solar panel, and pumps into a large metal tank. The pump only ran for ~4 minutes, so the upper layer of water in the collection tank was sampled. The well should be pumped for 65 minutes before sampling. It became solar in 2002.

Geologic & Hydrologic Setting and Water Source: The well is located on Quaternary alluvium. The principal water-bearing layer is probably the Santa Fe group. The depth to water was reported as 63 feet when declared in 1984. See Appendix B for Well Declaration.

9.2.11 West Mesa Well (WMW)

Location: Silver Creek 7.5 minute quadrangle, 34.26217, -107.06735, NAD83

Description: This well is located on the West Mesa at the western Sevilleta gate. The depth of the well is unknown. It is powered by a large solar panel and pumps into a large metal tank. Because the depth was unknown, the well was pumped for 24 minutes before sampling. It became solar in 2002.

Geologic & Hydrologic Setting and Water Source: It is located in Santa Fe Group. The principal water bearing layer is probably the same.

9.2.12 San Acacia Well (SanA-W)

Location: San Acacia 7.5 minute quadrangle, 34.27861, -106.90445, NAD83

Description: This well is located in the town of San Acacia. The well is 540 ft deep and the pump rate is unknown. Estimated yield is 100 GPM.

Geologic & Hydrologic Setting and Water Source: The well is located in Quaternary alluvium. The principal water bearing layer is a subrounded medium to coarse sand from 405 to 510 ft deep in the Santa Fe group. See Appendix B for Well Record.

9.2.13 Barella Well (BRW)

Location: Scholle 7.5 minute quadrangle, 34.38744, -106.48897, NAD83

Description: Barella well is located on the Dripping Springs Ranch, property of Jean Sawyer-Rosas and Luis Rosas. It is 13 feet deep, is windmill powered, and pumps through a garden hose into a large open stock tank. The well was pumped for 7 minutes and 30 seconds before sampling.

Geologic & Hydrologic Setting and Water Source: The well is located on the Pennsylvanian Madera limestone. The principal water bearing layer is fractured Madera limestone, sandstone and shale from 34 to 150 feet deep. See Appendix B for Well Record.

9.2.14 Tule 222 Well (TUW)

Location: Ladron Peak 7.5 minute quadrangle, 34.4121, -107.001, NAD83, 2N.2W.12.

Description:. Tule 222 well is located on the 222 road in the northwest section of the Sevilleta. It was 134 feet deep when drilled in 1951 and is powered by a small solar panel and pumps into a small metal tank. It was pumped for 21 minutes before sampling. It became solar powered in 2002.

Geologic & Hydrologic Setting and Water Source: The depth to water was 127.5 feet when drilled in 1951. See Appendix B for Well Record.

9.3 Additional Wells Not Sampled

The following wells are either non-functional historic wells (see Appendix A, Table 1) or are functioning wells not sampled during this research. Functionality is reported in the "description" section of each well.

Appendix A, Table 1. These are wells not sampled during for research. Several are officially abandoned and are labeled as such. Those not labeled abandoned are not solar and are probably not functional. Depth of well reported if known. ' indicates data from well log. * indicates data from Office of the State Engineer.

Well Name	**T.R.S.**	**Depth**	**Date Drilled**	**Remarks**
Kost/ Lost Well	2N.2W.14	400'	1981	
Salado #4 Well	1N.2W.2	150'		
Salado #3 Well	1N.2W.12		1950	
Salado #2 Well *	1N.1W.17	40'	1949	Abandon
Esquival #2 Well	1N.1W.16			Abandon
Salado #1 Well	1N.1W.23			Abandon
Cordova #2 Well	1S.1W.12		1947*	Abandon
Contreros Well	2N.2E.30			Abandon
Rio Bend Well	1N.1E.28.20	100'		
Rosa Well*	1S.1E.8	400'	1947	Abandon
Cordova #1Well	1S.1E.7		1947*	Abandon
Baca Well	1N.2E.31		1947*	Abandon
Beacon Light Well*	1S.2E.19	233'	1948	Abandon
Deep Well	2N.2E.36.40	735'*	1947*/1960	Abandon/ Caved in
Red Well*	1N.2E.21	80'	1949	Abandon
Yeso (Twin) Well	1S.2E.21.10	100' or 233'*	1949*	
Partition Well	1S.3E.18.10	250'		
Cottonwood Well	1S.3E.5	100'	1930	
14" Irrigation Well	1N.3E.15			450GPM
Lower Montosa Well	1N.3E.13	150'	1955	Abandon
Silver Creek Well*	1N.2W.10.10	20'	1940	
Black Well*	2N.3E.18.20	362'	1940	
Don & Pat's Well*	1N.2E.26.20		1950	Abandon

Dempster Well *	2N2E.30.40	296'	1940	
La Joya Well*	1N.1E.2.20	182'	1949	
Burro Well*	1S.1E.3.30	202'	1947	
Jack's Well	2N.1W.35.30			

9.3.1 Canyon del Ojito Well (SAW)

Location: Lemitar 7.5 minute quadrangle, 34.2661, -106.9481, 1N.1W.33, NAD83

Description: Canyon del Ojito well is located south of Alamillo road, east of the Canyon del Ojito spring. It is 182 feet deep and is powered by a solar panel. The well is last reported in summer 2008 to have caved in. It became solar in 2002.

Geologic & Hydrologic Setting and Water Source: The well is located on Tertiary volcanics. The depth to water was 124.5 feet when reported in 1984. See Appendix B for Well Record.

9.3.2 Sepultura Flats Well (SFW)

Location: Cerro Montoso 7.5 minute quadrangle, 34.2775, -106.626, NAD 83, 1N.3E.22.300

Description: Sepultura Flats well is located Sepultura Flats road on the southeast side of the Sevilleta. It is assumed to be the same as Sepultura Test well, and thus would be 140 feet deep when drilled in 1948. It became solar powered in 2003. It is reported as functional but would not pump when sampling was attempted.

Geologic & Hydrologic Setting and Water Source: The depth to water was 50 feet when drilled in 1948. See Appendix B for Well Record.

9.3.3 Sepultura Canyon Well (SCW)

Location: Cerro Montoso 7.5 minute quadrangle, 34.3099, -106.6164, 1N.3E.15.200, NAD83

Description: Sepultura Canyon well is off limits due to the close proximity to the wolf pens. It is 376 feet deep and is presumably solar or wind powered. It is functional.

Geologic & Hydrologic Setting and Water Source: The depth to water was 63 feet when drilled in 1949. See Appendix B for Well Record.

9.3.4 Oliver Lee Well (OLW)

Location: Sierra Larga North 7.5 minute quadrangle, 34.2208, -106.6172, 1S.3E.30.430, NAD83

Description: This well is located on the southeastern section of the Sevilleta Grant, but is leased to ranchers. It is 120 feet deep and is presumably wind or solar powered. Functionality is not known.

Geologic & Hydrologic Setting and Water Source: The principal water bearing layer is sandstone and a “cavity” which yields ~15GPM at 100 to 120 feet deep. The depth to water was reported as 90 feet when drilled in 2000. See Appendix B for Well Record.

9.3.5 Pino Well (PW)

Location: Becker 7.5 minute quadrangle, 34.38917, -106.559, NAD83, 2N.4E.18.300

Description: Pino Well is located in Pino Canyon on the northeast corner of the Sevilleta NWR. It is 18 feet deep and is powered by a solar panel. It was not sampled because the road was impassable. It became a solar well in 2004. It is functional.

Geologic & Hydrologic Setting and Water Source: The well is located on paleoproterozoic bedrock in the Los Piños Mountains. The principal water bearing layer is probably fractured bedrock. See Appendix B for Well Record.

9.3.6 Upper Montosa Well (UMW)

Location: Cerro Montoso 7.5 minute quadrangle, 34.34389, -106.55306, 1N.4E.5.411, NAD83

Description: Upper Montosa well is located on the eastern side of the Los Pinos mountains. It is 75 feet deep and is powered by a solar panel. It was out of commission during the sampling season. It became a solar well in 2004. It is currently out of order.

Geologic & Hydrologic Setting and Water Source: The well is located on paleoproterozoic bedrock in the Los Piños Mountains. The principal water bearing layer is probably fractured bedrock. The depth to water was 15 feet deep when drilled in 1950. See Appendix B for Well Record.

9.3.7 Richard Laing Oil and Gas Well (OGW)

Location: Scholle 7.5 minute quadrangle, 34.3829, -106.4942, 2N.4E.23.140, NAD83

Description: This is the only oil and gas well in the area, and did extend to 1182 feet deep. The well is now sealed and abandoned.

Geologic & Hydrologic Setting and Water Source: The well is located on the Pennsylvanian Madera limestone and the well record in Appendix B provides a record of the strata on the east side of the Los Pinos Mountains.

9.4 Additional Springs Not Sampled

The following springs were not sampled during this research. Presence or cessation of flow is noted for each spring where it is known. The Abo Pass springs (9.4.6-9.4.11) are located on the Scholle topographic quadrangle. There are other springs on that quadrangle not mentioned here (including Spencer Spring and several unmarked springs). Contacts for these privately owned springs were located through the following sources: Mark Matthews at the Socorro Bureau of Land Management office and Louis King at the Natural Resource Conservation Services. Identification codes (e.g. SC3, LJ1) found next to spring names are included if the site was previously visited by Rawling (*Rawling 2003*).

9.4.1 Tortola Spring (Dove Spring) (SC3)

Location: Silver Creek 7.5 minute quadrangle, 34.28696, -107.01749, NAD83

Description: Rawling (2003) reported that “this spring is marked on the Silver Creek quadrangle. It is located a few meters from the head of a small slot canyon in Cañada de la Tortola. The spring outlet is beneath the gravel bottom of the canyon; there are small pools of standing water with abundant algae and trickling surface flow. Damp sand extends for ~10 m downstream of the spring to an old concrete dam built across the mouth of the slot canyon. A pipe from this dam probably once led to a stock tank. The spring was flowing on July 11, 2002.” The name Dove Spring is derived from a map from the 1970’s of the Sevilleta Land Grant.

Geologic & Hydrologic Setting and Water Source: See Rawling 2003.

9.4.2 Los Alamos Spring (LJ1)

Location: La Joya 7.5 minute quadrangle, 34.30932, -106.7877, NAD83

Description: Rawling (2003) reported that "this spring is marked on the La Joya quadrangle, but there is no evidence of a spring on the ground. The marked location is within Arroyo los Alamos west of El Valle de la Joya and north of the Joyita Hills." Relics of previous development suggest that the spring was a reliable resource in the past.

Geologic & Hydrologic Setting and Water Source: See Rawling 2003

9.4.3 Gibbs Spring

Location: Becker SW 7.5 minute quadrangle, est. 34.269679, -106.716400, NAD83

Description: This spring is located on a map from the 1970s of the Sevilleta Land Grant, but is not located on the Becker SW quadrangle. It was not visited during the course of this study, thus its exact location is unknown.

Geologic & Hydrologic Setting and Water Source: Unknown. It is not known if this spring is still flowing.

9.4.4 Yeso/ Milagro Spring (SdC2)

Location: Sierra de la Cruz 7.5 minute quadrangle, est. 34.210478, -106.744474, NAD83

Description: It was not visited during the course of this study, thus its exact location is unknown.

Geologic & Hydrologic Setting and Water Source: See Rawling 2003.

9.4.5 Grapevine Spring

Location: Ladron Peak 7.5 minute quadrangle, est. 34.3537, -107.0528, NAD83

Description: It was not visited during the course of this study, thus its exact location is unknown.

Geologic & Hydrologic Setting and Water Source: Unknown.

9.4.6 Baca Spring

Location: Ladron Peak 7.5 minute quadrangle, est. 34.382673, -107.045519, NAD83

Description: It was not visited during the course of this study, thus its exact location is unknown.

Geologic & Hydrologic Setting and Water Source: Unknown.

9.4.7 Abo Spring

Location: Scholle 7.5 minute quadrangle, 34.431115, -106.432816, NAD83

Description: This spring is located in Abo Pass and on the Scholle topographic quadrangle. It is on private land. For contact information, see section 9.4.

Geologic & Hydrologic Setting and Water Source: Unknown.

9.4.8 Saladito Springs

Location: Scholle 7.5 minute quadrangle, 34.424242, -106.432628, NAD83

Description: This spring is located in Abo Pass and on the Scholle topographic quadrangle. It is on private land. For contact information, see section 9.4.

Geologic & Hydrologic Setting and Water Source: Unknown.

9.4.9 Indian Spring

Location: Scholle 7.5 minute quadrangle, 34.409300, -106.422113, NAD83

Description: This spring is located in Abo Pass and on the Scholle topographic quadrangle. It is on private land. For contact information, see section 9.4.

Geologic & Hydrologic Setting and Water Source: Unknown.

9.4.10 San Rafael Spring

Location: Scholle 7.5 minute quadrangle, 34.446231, -106.398599, NAD83

Description: This spring is located in Abo Pass and on the Scholle topographic quadrangle. It is on private land. For contact information, see section 9.4.

Geologic & Hydrologic Setting and Water Source: Unknown.

9.4.11 Coyote Springs

Location: Scholle 7.5 minute quadrangle, 34.449223, -106.441190, NAD83

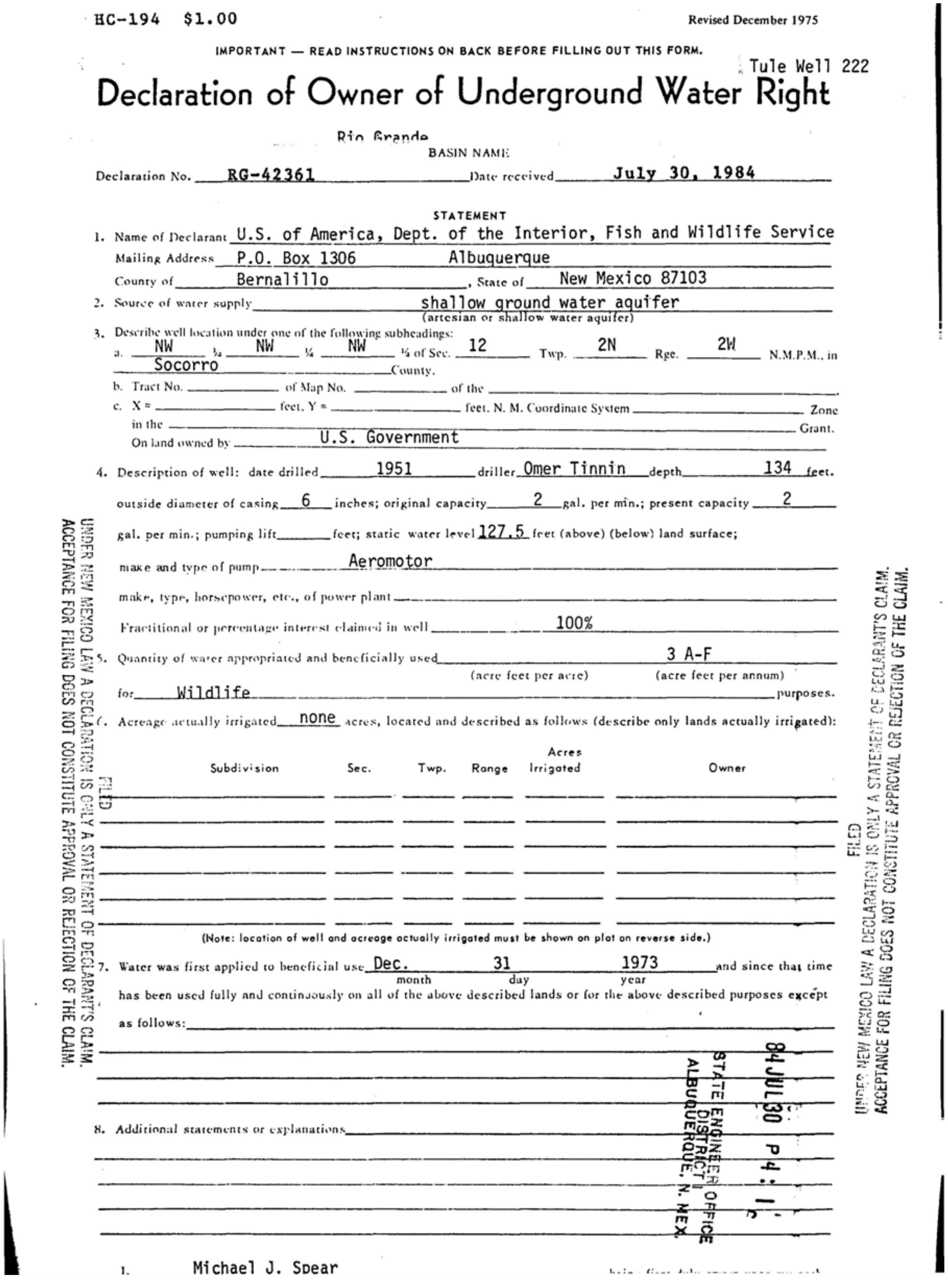
Description: This spring is located in Abo Pass and on the Scholle topographic quadrangle. It is on private land. For contact information, see section 9.4.

Geologic & Hydrologic Setting and Water Source: Unknown.

10 Appendix B – Well Records

Appendix B, Table 1. List of wells with an attached well declaration or well record and notation of private or Sevilleta NWR ownership. Records and declarations were located in the New Mexico State Engineer's Office. Additional well records of private wells not located on the Sevilleta NWR are available based on township and range at < http://iwaters.ose.state.nm.us:7001/iWATERS/>. Register, then choose POD/Surface Reports and Downloads.

Well	Well Declaration	Well Record	Private or Sevilleta owned
Tule 222 Well	Yes	No	Sevilleta
Bronco Well	Yes	No	Sevilleta
Canyon del Ojito Well	Yes	No	Sevilleta
Esquival Well	Yes	Yes	Sevilleta
FWS Field Station Well	Yes	Yes	Sevilleta
Gibbs Well	Yes	No	Sevilleta
Canyon Well	Yes	No	Sevilleta
Nunn Well	Yes	Yes	Sevilleta
Sepultura Flats/ Test Well	Yes	No	Sevilleta
Sepultura Canyon Well	Yes	No	Sevilleta
McKinsey Well	Yes	No	Sevilleta
Cottonwood Well	Yes	No	Sevilleta
Tomasino Well	Yes	No	Sevilleta
Oliver Lee Well	Yes	Yes	Private
Pino Well	Yes	No	Sevilleta
Upper Montosa Well	Yes	No	Sevilleta
Barella Well	Yes	Yes	Private
Richard Laing (Oil & Gas) Well	No	Yes	Private
San Acacia Well	No	Yes	Private



HC-194 $1.00

Revised December 1975

IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Tule Well 222

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42361 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico 87103

2. Source of water supply shallow ground water aquifer
(artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:
a. NW ¼ NW ¼ NW ¼ of Sec. 12 Twp. 2N Rge. 2W N.M.P.M., in Socorro County.
b. Tract No. ______ of Map No. ______ of the ______.
c. X = ______ feet, Y = ______ feet, N. M. Coordinate System ______ Zone in the ______ Grant.
On land owned by U.S. Government

4. Description of well: date drilled 1951 driller Omer Tinnin depth 134 feet.
outside diameter of casing 6 inches; original capacity 2 gal. per min.; present capacity 2 gal. per min.; pumping lift ______ feet; static water level 127.5 feet (above) (below) land surface;
make and type of pump Aeromotor
make, type, horsepower, etc., of power plant ______
Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used ______ (acre feet per acre) 3 A-F (acre feet per annum)
for Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows: ______

8. Additional statements or explanations ______

84 JUL 30 P 4: 1
STATE ENGINEER OFFICE
DISTRICT I
ALBUQUERQUE, N. MEX.

I. Michael J. Spear [illegible]

FILED
UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM.
ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

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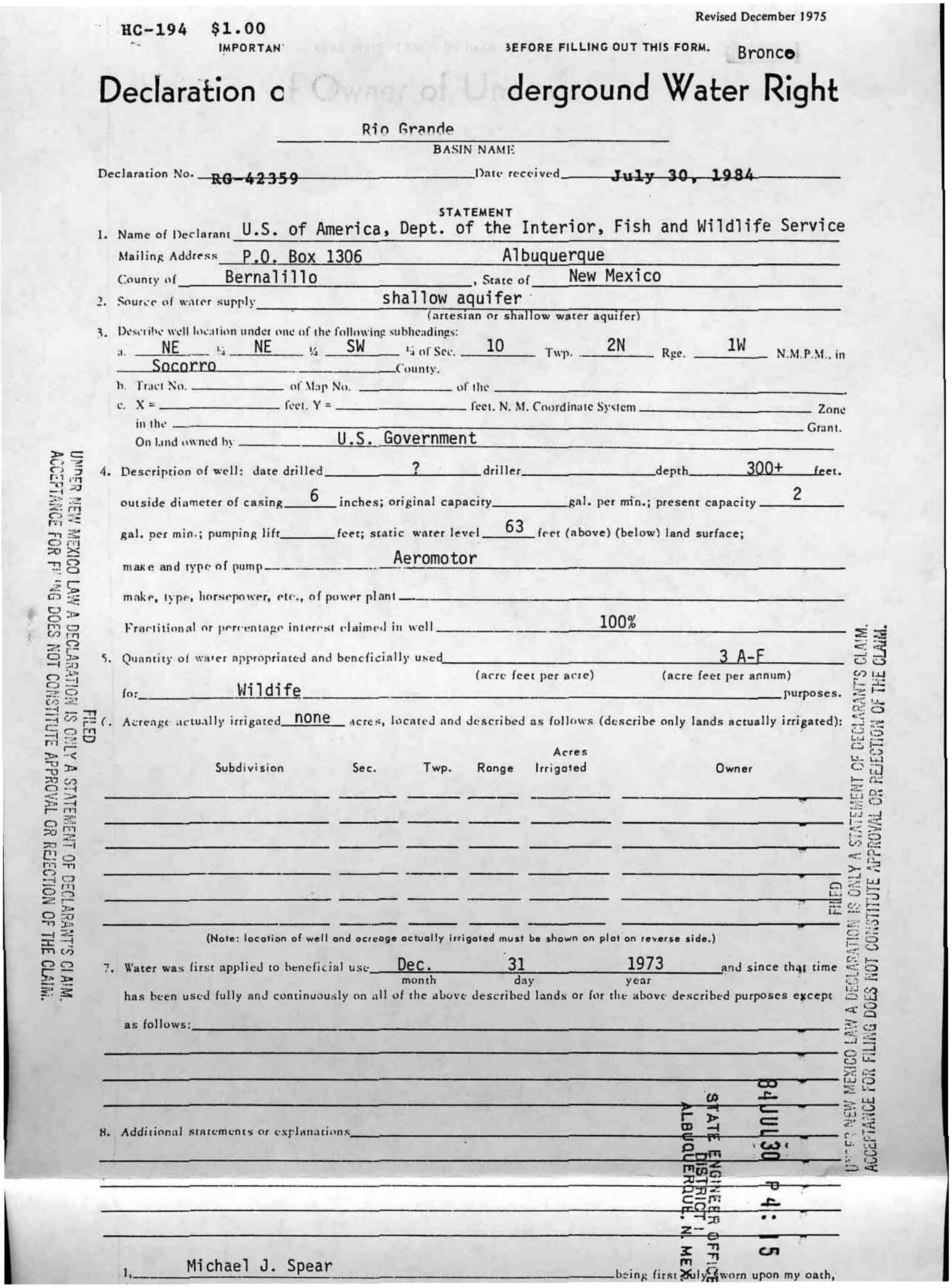
ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.



HC-194 $1.00 Revised December 1975

IMPORTANT [illegible] BEFORE FILLING OUT THIS FORM. Bronco

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. ~~RG-42359~~ Date received ~~July 30, 1984~~

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
   Mailing Address P.O. Box 1306 Albuquerque
   County of Bernalillo, State of New Mexico
2. Source of water supply shallow aquifer (artesian or shallow water aquifer)
3. Describe well location under one of the following subheadings:
   a. NE ¼ NE ¼ SW ¼ of Sec. 10 Twp. 2N Rge. 1W N.M.P.M., in Socorro County.
   b. Tract No. ____ of Map No. ____ of the ____.
   c. X = ____ feet, Y = ____ feet, N. M. Coordinate System ____ Zone in the ____ Grant.
   On land owned by U.S. Government
4. Description of well: date drilled ? driller ____ depth 300+ feet.
   outside diameter of casing 6 inches; original capacity ____ gal. per min.; present capacity 2 gal. per min.; pumping lift ____ feet; static water level 63 feet (above) (below) land surface;
   make and type of pump Aeromotor
   make, type, horsepower, etc., of power plant ____
   Fractitional or percentage interest claimed in well 100%
5. Quantity of water appropriated and beneficially used ____ (acre feet per acre) 3 A-F (acre feet per annum)
   for: Wildife purposes.
6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows: ____
8. Additional statements or explanations ____

I, Michael J. Spear being first duly sworn upon my oath,

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

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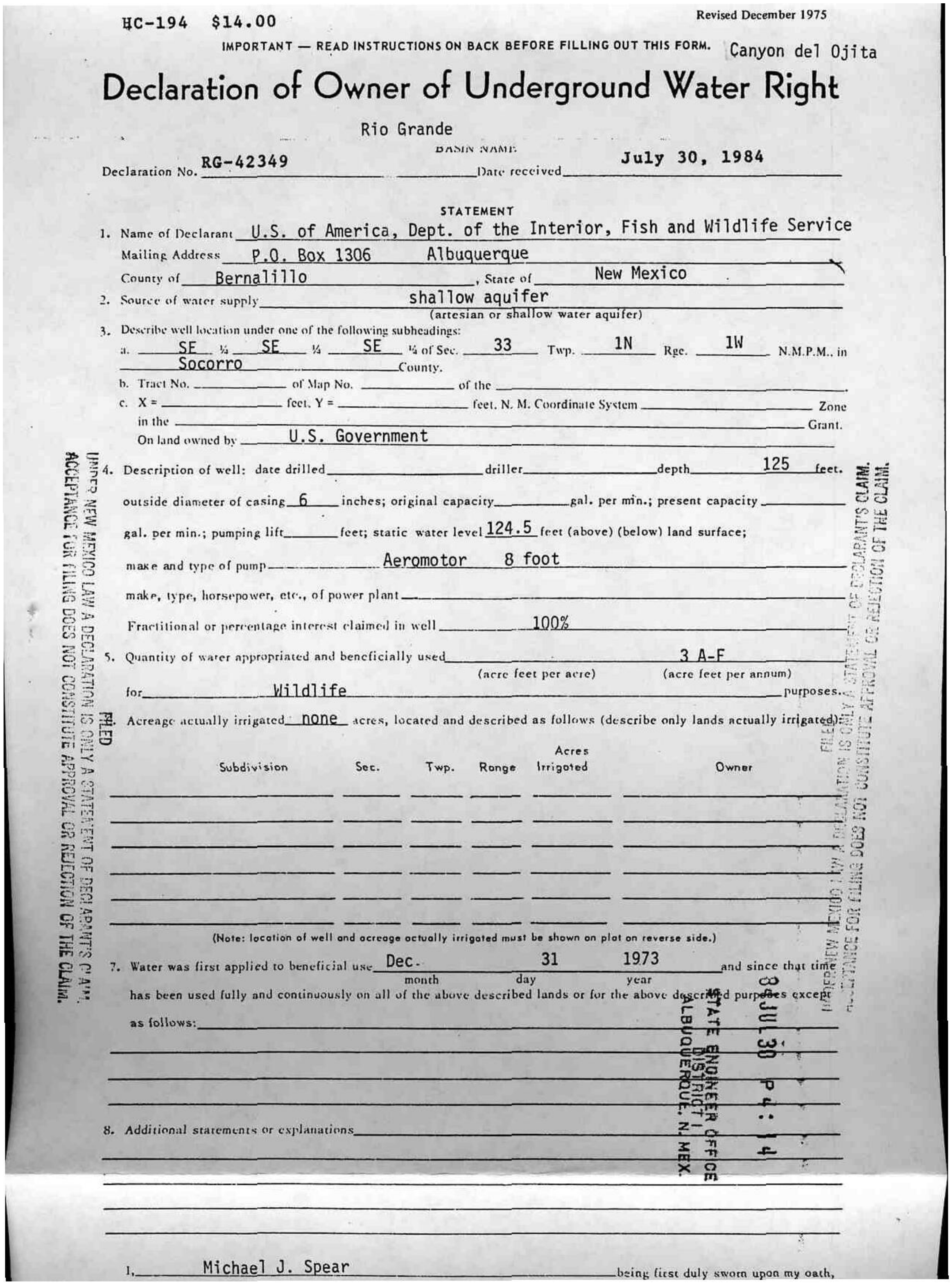

HC-194 $14.00

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Canyon del Ojita

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42349 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico

2. Source of water supply shallow aquifer
(artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:
a. SE ¼ SE ¼ SE ¼ of Sec. 33 Twp. 1N Rge. 1W N.M.P.M., in Socorro County.
b. Tract No. of Map No. of the
c. X = feet, Y = feet, N. M. Coordinate System Zone in the Grant.
On land owned by U.S. Government

4. Description of well: date drilled driller depth 125 feet.
outside diameter of casing 6 inches; original capacity gal. per min.; present capacity gal. per min.; pumping lift feet; static water level 124.5 feet (above) (below) land surface;
make and type of pump Aeromotor 8 foot
make, type, horsepower, etc., of power plant
Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used 3 A-F
(acre feet per acre) (acre feet per annum)
for Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. 31 1973 and since that time
month day year
has been used fully and continuously on all of the above described lands or for the above described purposes except as follows:

8. Additional statements or explanations

I, Michael J. Spear being first duly sworn upon my oath,

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

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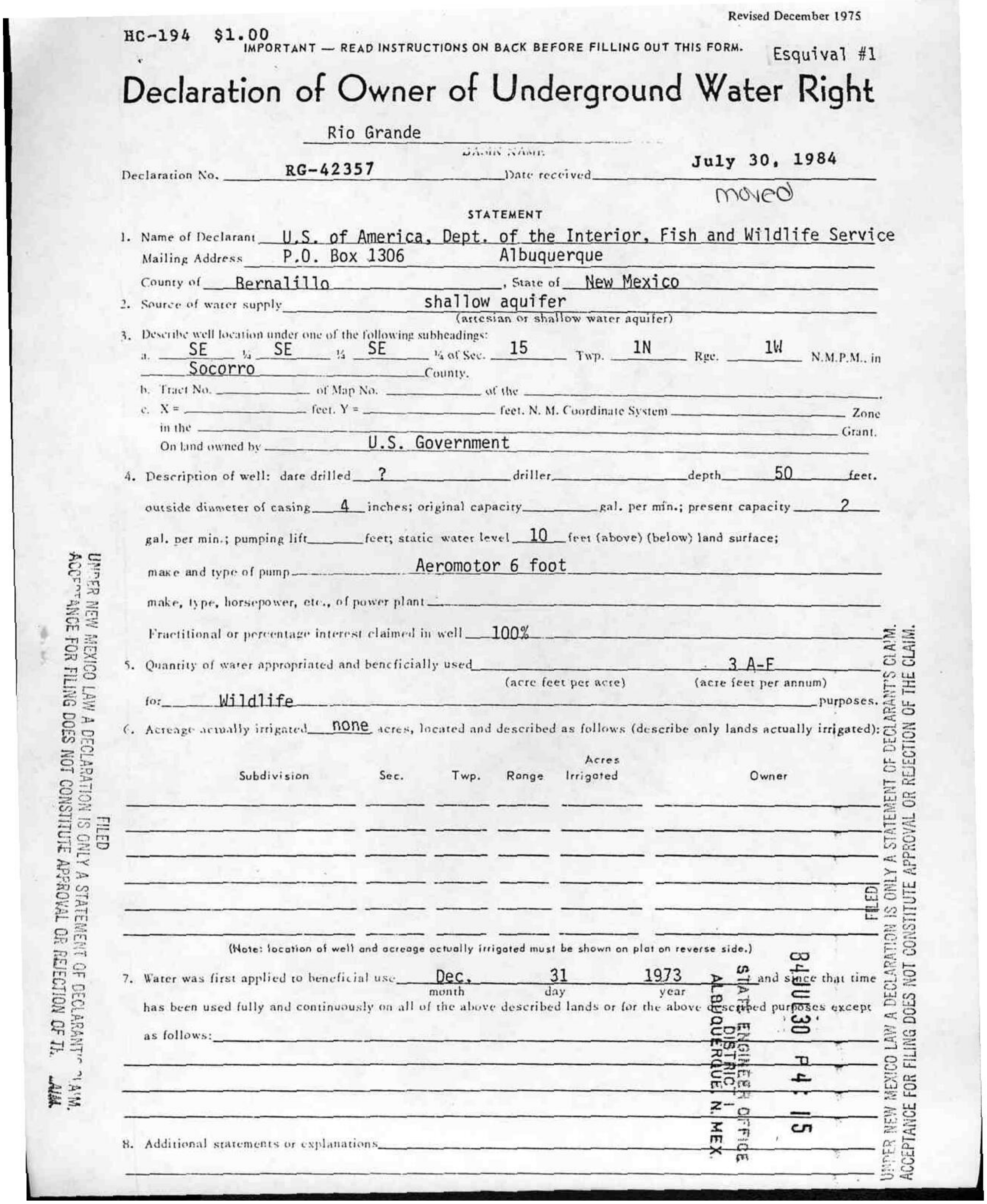

Revised December 1975

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Esquival #1

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42357 Date received July 30, 1984

moved

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico

2. Source of water supply shallow aquifer (artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:
a. SE ¼ SE ¼ SE ¼ of Sec. 15 Twp. 1N Rge. 1W N.M.P.M., in Socorro County.
b. Tract No. ___ of Map No. ___ of the ___
c. X = ___ feet, Y = ___ feet, N. M. Coordinate System ___ Zone in the ___ Grant.
On land owned by U.S. Government

4. Description of well: date drilled ? driller ___ depth 50 feet.
outside diameter of casing 4 inches; original capacity ___ gal. per min.; present capacity 2 gal. per min.; pumping lift ___ feet; static water level 10 feet (above) (below) land surface;
make and type of pump Aeromotor 6 foot
make, type, horsepower, etc., of power plant ___
Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used ___ (acre feet per acre) 3 A-F (acre feet per annum)
for Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows: ___

8. Additional statements or explanations ___

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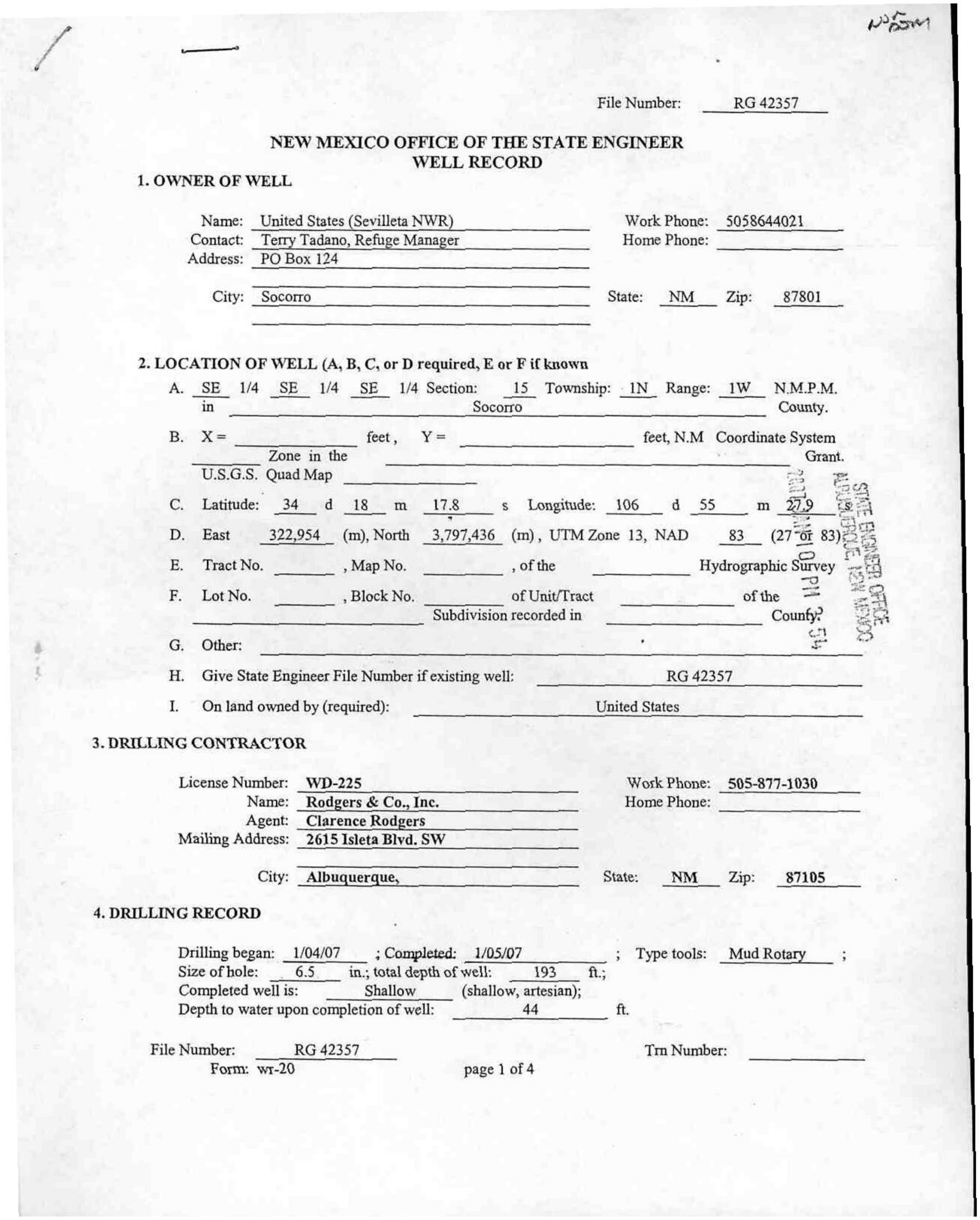


File Number: RG 42357

NEW MEXICO OFFICE OF THE STATE ENGINEER
WELL RECORD

1. OWNER OF WELL

Name: United States (Sevilleta NWR)
Work Phone: 5058644021
Contact: Terry Tadano, Refuge Manager
Home Phone:
Address: PO Box 124
City: Socorro
State: NM
Zip: 87801

2. LOCATION OF WELL (A, B, C, or D required, E or F if known

A. SE 1/4 SE 1/4 SE 1/4 Section: 15 Township: 1N Range: 1W N.M.P.M. in Socorro County.

B. X = ______ feet, Y = ______ feet, N.M Coordinate System ______ Zone in the ______ Grant. U.S.G.S. Quad Map ______

C. Latitude: 34 d 18 m 17.8 s Longitude: 106 d 55 m 27.9 s

D. East 322,954 (m), North 3,797,436 (m), UTM Zone 13, NAD 83 (27 or 83)

E. Tract No. ______, Map No. ______, of the ______ Hydrographic Survey

F. Lot No. ______, Block No. ______ of Unit/Tract ______ of the ______ Subdivision recorded in ______ County.

G. Other:

H. Give State Engineer File Number if existing well: RG 42357

I. On land owned by (required): United States

STATE ENGINEER OFFICE
ALBUQUERQUE, NEW MEXICO
2007 JAN 10 PM 3 54

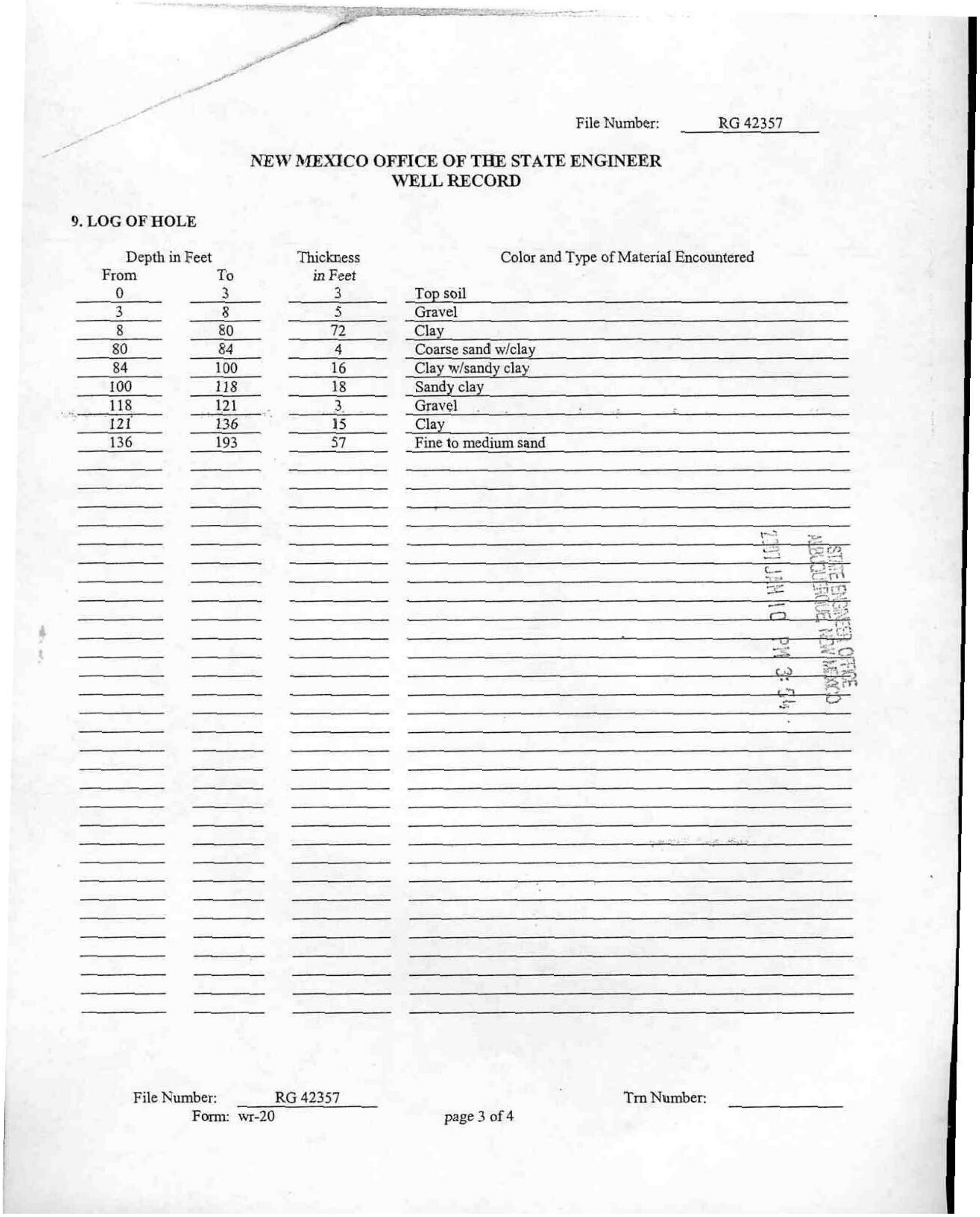
3. DRILLING CONTRACTOR

License Number: **WD-225**
Work Phone: **505-877-1030**
Name: **Rodgers & Co., Inc.**
Home Phone:
Agent: **Clarence Rodgers**
Mailing Address: **2615 Isleta Blvd. SW**
City: **Albuquerque,**
State: **NM**
Zip: **87105**

4. DRILLING RECORD

Drilling began: 1/04/07 ; Completed: 1/05/07 ; Type tools: Mud Rotary ;
Size of hole: 6.5 in.; total depth of well: 193 ft.;
Completed well is: Shallow (shallow, artesian);
Depth to water upon completion of well: 44 ft.

File Number: RG 42357
Trn Number:
Form: wr-20
page 1 of 4



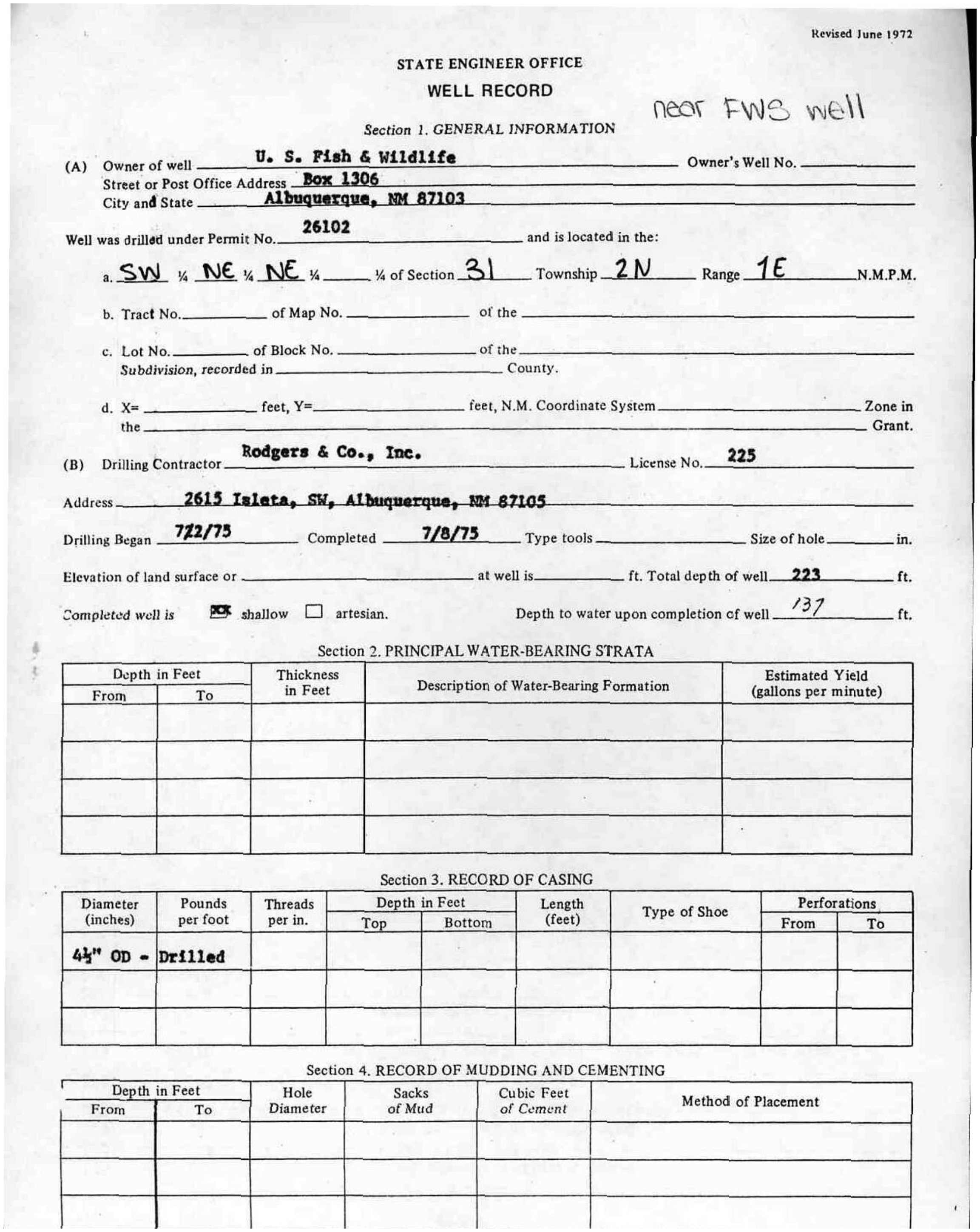
File Number: RG 42357

NEW MEXICO OFFICE OF THE STATE ENGINEER
WELL RECORD

9. LOG OF HOLE

Depth in Feet From	Depth in Feet To	Thickness *in Feet*	Color and Type of Material Encountered
0	3	3	Top soil
3	8	5	Gravel
8	80	72	Clay
80	84	4	Coarse sand w/clay
84	100	16	Clay w/sandy clay
100	118	18	Sandy clay
118	121	3	Gravel
121	136	15	Clay
136	193	57	Fine to medium sand

File Number: RG 42357
Form: wr-20
page 3 of 4
Trn Number:



Revised June 1972

STATE ENGINEER OFFICE

WELL RECORD

near FWS well

Section 1. GENERAL INFORMATION

(A) Owner of well U. S. Fish & Wildlife Owner's Well No. ____
Street or Post Office Address Box 1306
City and State Albuquerque, NM 87103

Well was drilled under Permit No. 26102 and is located in the:

a. SW ¼ NE ¼ NE ¼ ____ ¼ of Section 31 Township 2N Range 1E N.M.P.M.

b. Tract No. ____ of Map No. ____ of the ____

c. Lot No. ____ of Block No. ____ of the ____
Subdivision, recorded in ____ County.

d. X= ____ feet, Y= ____ feet, N.M. Coordinate System ____ Zone in the ____ Grant.

(B) Drilling Contractor Rodgers & Co., Inc. License No. 225

Address 2615 Isleta, SW, Albuquerque, NM 87105

Drilling Began 7/2/75 Completed 7/8/75 Type tools ____ Size of hole ____ in.

Elevation of land surface or ____ at well is ____ ft. Total depth of well 223 ft.

Completed well is ☒ shallow ☐ artesian. Depth to water upon completion of well 137 ft.

Section 2. PRINCIPAL WATER-BEARING STRATA

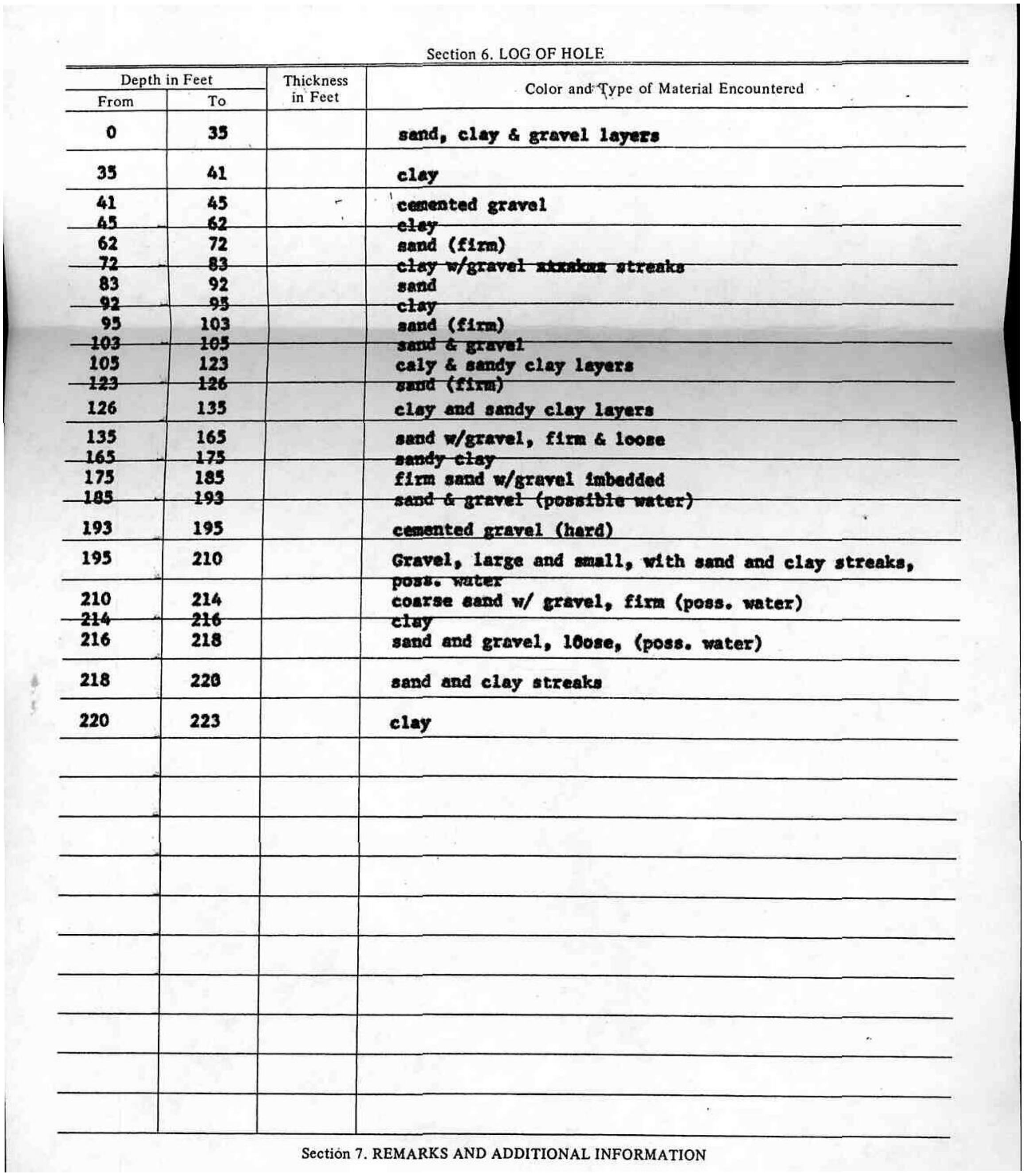
Depth in Feet		Thickness in Feet	Description of Water-Bearing Formation	Estimated Yield (gallons per minute)
From	To			

Section 3. RECORD OF CASING

Diameter (inches)	Pounds per foot	Threads per in.	Depth in Feet		Length (feet)	Type of Shoe	Perforations	
			Top	Bottom			From	To
4½" OD -	Drilled							

Section 4. RECORD OF MUDDING AND CEMENTING

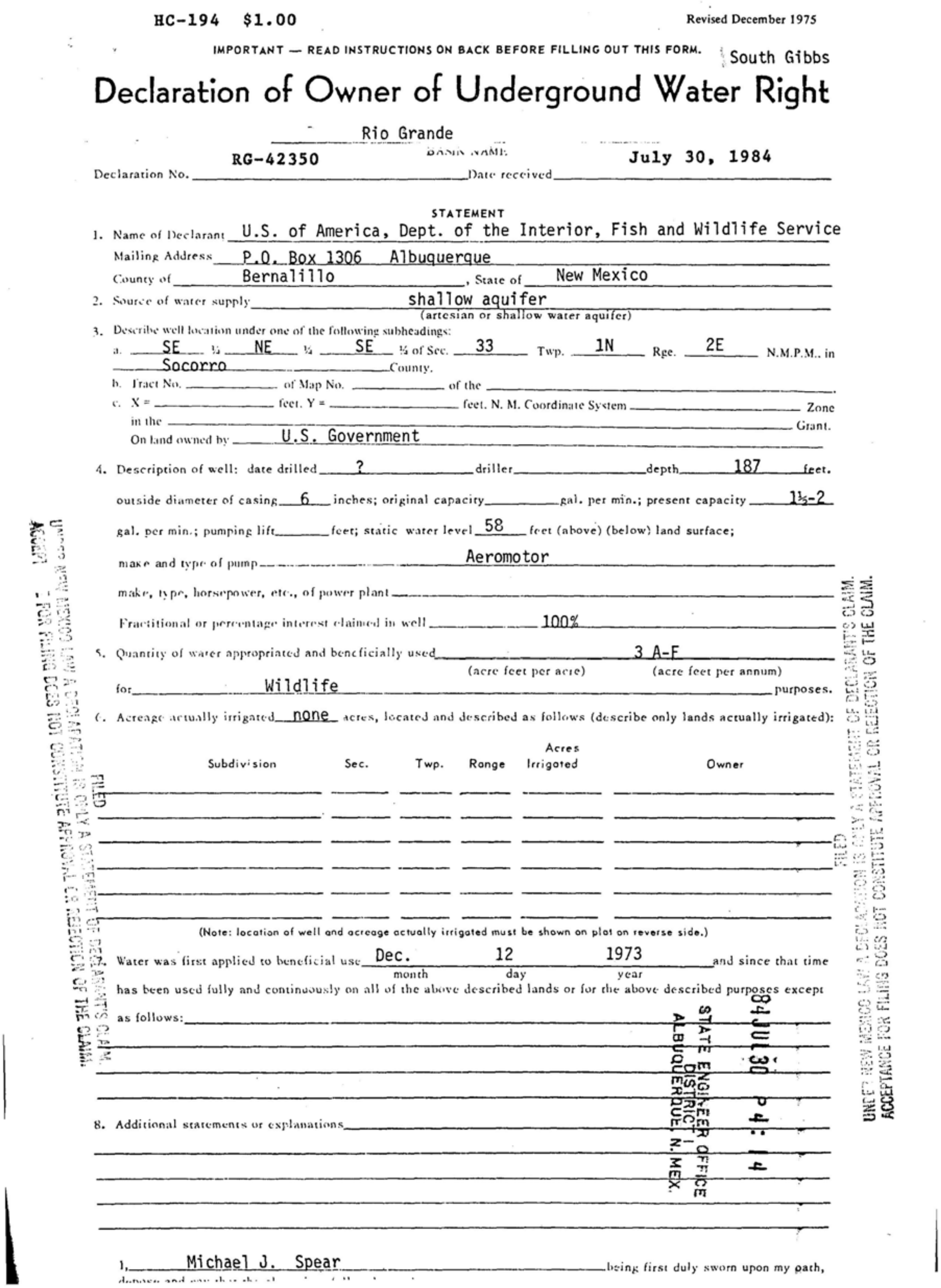
Depth in Feet		Hole Diameter	Sacks *of Mud*	Cubic Feet *of Cement*	Method of Placement
From	To				



Section 6. LOG OF HOLE

Depth in Feet		Thickness in Feet	Color and Type of Material Encountered
From	To		
0	35		sand, clay & gravel layers
35	41		clay
41	45		cemented gravel
45	62		clay
62	72		sand (firm)
72	83		clay w/gravel [illegible] streaks
83	92		sand
92	95		clay
95	103		sand (firm)
103	105		sand & gravel
105	123		caly & sandy clay layers
123	126		sand (firm)
126	135		clay and sandy clay layers
135	165		sand w/gravel, firm & loose
165	175		sandy clay
175	185		firm sand w/gravel imbedded
185	193		sand & gravel (possible water)
193	195		cemented gravel (hard)
195	210		Gravel, large and small, with sand and clay streaks, poss. water
210	214		coarse sand w/ gravel, firm (poss. water)
214	216		clay
216	218		sand and gravel, loose, (poss. water)
218	220		sand and clay streaks
220	223		clay

Section 7. REMARKS AND ADDITIONAL INFORMATION



HC-194 $1.00 Revised December 1975

IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

South Gibbs

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42350 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico

2. Source of water supply shallow aquifer (artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:
a. SE ¼ NE ¼ SE ¼ of Sec. 33 Twp. 1N Rge. 2E N.M.P.M., in Socorro County.
b. Tract No. ___ of Map No. ___ of the ___
c. X = ___ feet, Y = ___ feet, N. M. Coordinate System ___ Zone in the ___ Grant.
On land owned by U.S. Government

4. Description of well: date drilled ? driller ___ depth 187 feet.
outside diameter of casing 6 inches; original capacity ___ gal. per min.; present capacity 1½-2 gal. per min.; pumping lift ___ feet; static water level 58 feet (above) (below) land surface;
make and type of pump Aeromotor
make, type, horsepower, etc., of power plant ___
Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used ___ (acre feet per acre) 3 A-F (acre feet per annum)
for Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 12 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows:

8. Additional statements or explanations

84 JUL 30 P 4: 14
STATE ENGINEER OFFICE
DISTRICT I
ALBUQUERQUE, N. MEX.

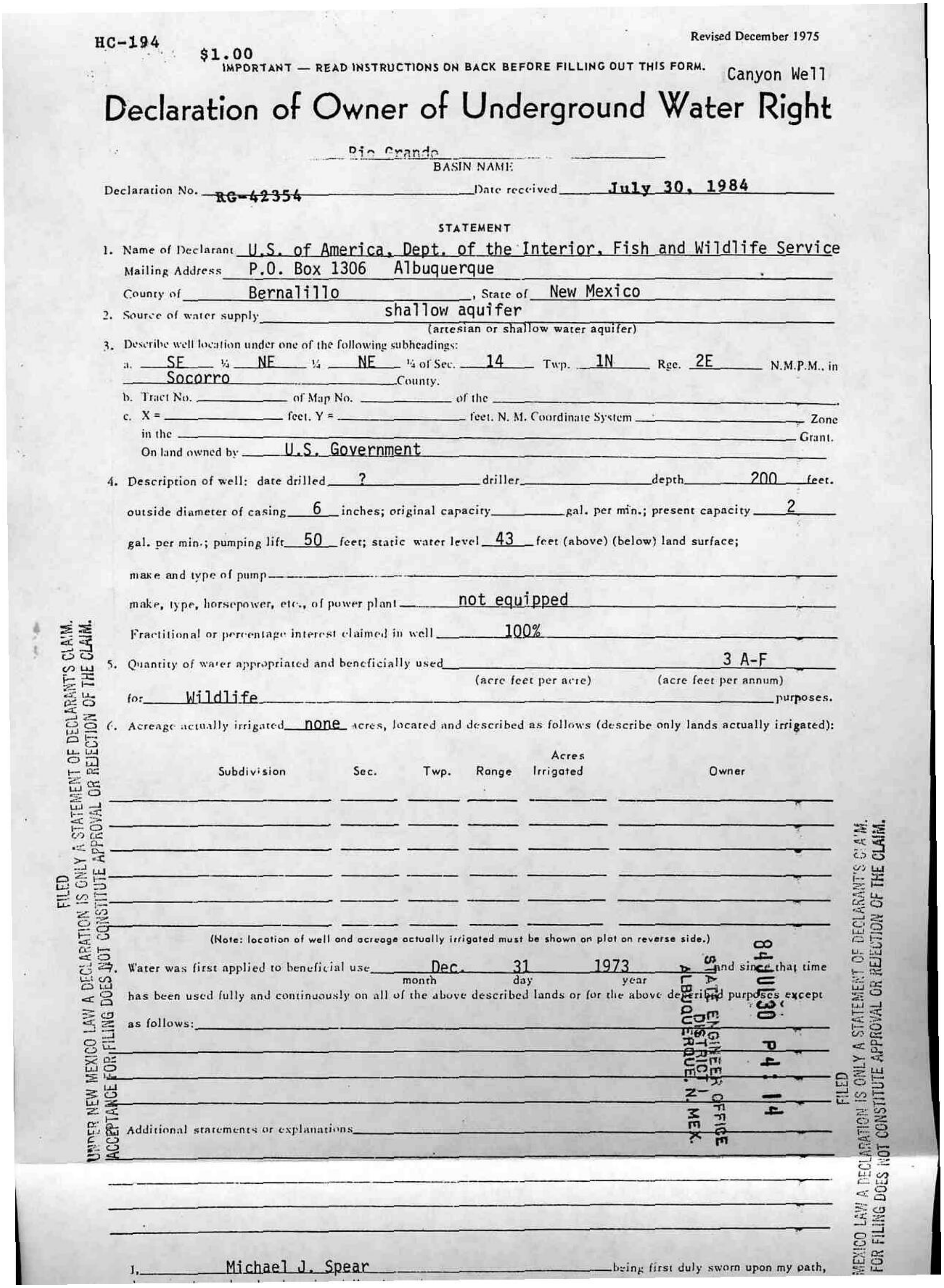
FILED

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

FILED

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

I, Michael J. Spear being first duly sworn upon my oath,



HC-194 $1.00

Revised December 1975

IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Canyon Well

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42354 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico
2. Source of water supply shallow aquifer (artesian or shallow water aquifer)
3. Describe well location under one of the following subheadings:
a. SE ¼ NE ¼ NE ¼ of Sec. 14 Twp. 1N Rge. 2E N.M.P.M., in Socorro County.
b. Tract No. of Map No. of the
c. X = feet, Y = feet, N. M. Coordinate System Zone in the Grant.
On land owned by U.S. Government
4. Description of well: date drilled ? driller depth 200 feet.
outside diameter of casing 6 inches; original capacity gal. per min.; present capacity 2 gal. per min.; pumping lift 50 feet; static water level 43 feet (above) (below) land surface;
make and type of pump
make, type, horsepower, etc., of power plant not equipped
Fractitional or percentage interest claimed in well 100%
5. Quantity of water appropriated and beneficially used 3 A-F (acre feet per acre) (acre feet per annum) for Wildlife purposes.
6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. 31 1973 (month day year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows:

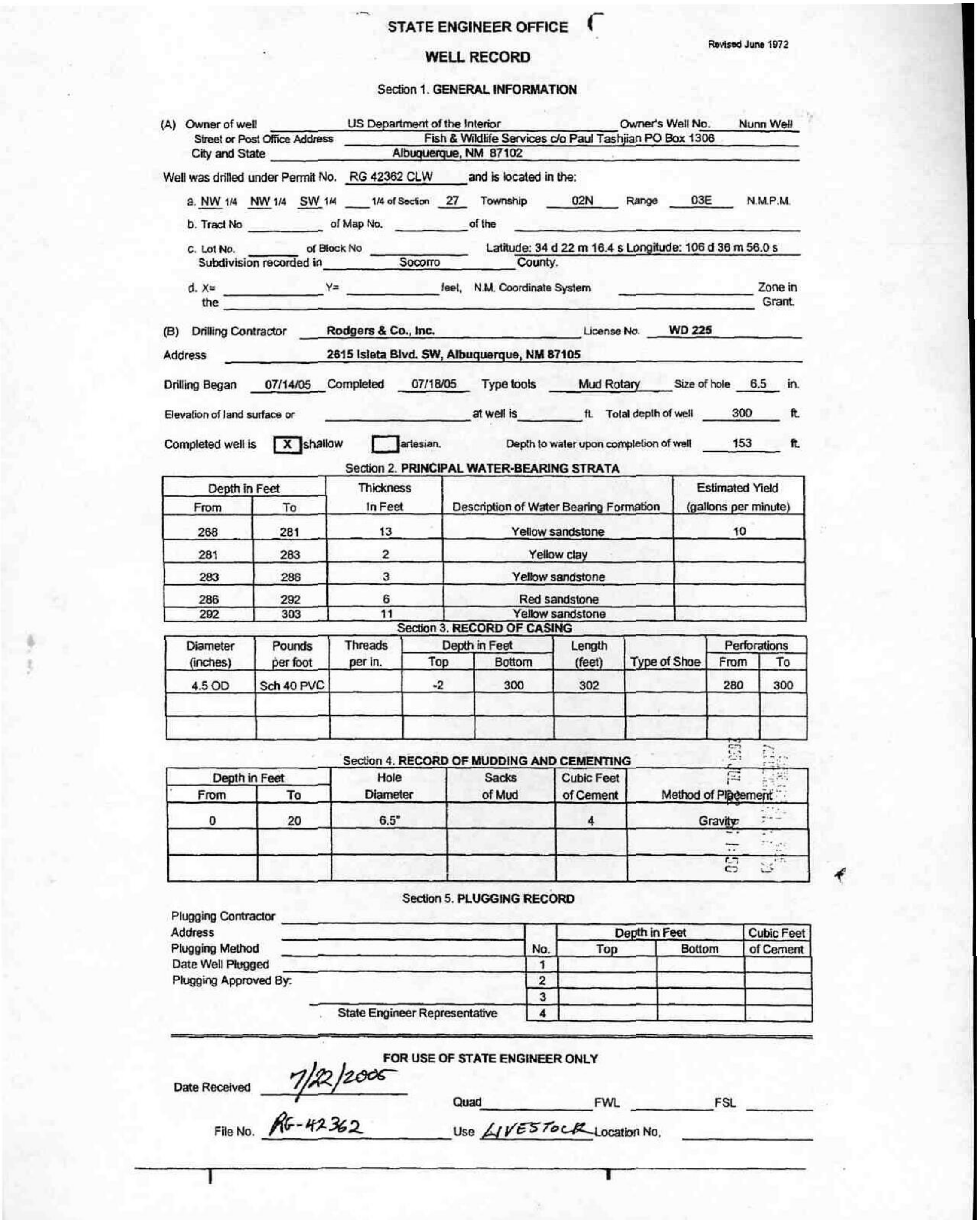
Additional statements or explanations

84 JUL 30 P4:14
STATE ENGINEER OFFICE
DISTRICT 1
ALBUQUERQUE, N. MEX.

FILED
UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM.
ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

FILED
MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM.
FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

I, Michael J. Spear being first duly sworn upon my oath,



STATE ENGINEER OFFICE

Revised June 1972

WELL RECORD

Section 1. GENERAL INFORMATION

(A) Owner of well US Department of the Interior Owner's Well No. Nunn Well
Street or Post Office Address Fish & Wildlife Services c/o Paul Tashjian PO Box 1306
City and State Albuquerque, NM 87102

Well was drilled under Permit No. RG 42362 CLW and is located in the:

a. NW 1/4 NW 1/4 SW 1/4 ___ 1/4 of Section 27 Township 02N Range 03E N.M.P.M.
b. Tract No ______ of Map No. ______ of the ______
c. Lot No. ______ of Block No ______ Latitude: 34 d 22 m 16.4 s Longitude: 106 d 36 m 56.0 s
Subdivision recorded in Socorro County.
d. X= ______ Y= ______ feet, N.M. Coordinate System ______ Zone in the ______ Grant.

(B) Drilling Contractor **Rodgers & Co., Inc.** License No. **WD 225**
Address **2615 Isleta Blvd. SW, Albuquerque, NM 87105**

Drilling Began 07/14/05 Completed 07/18/05 Type tools Mud Rotary Size of hole 6.5 in.

Elevation of land surface or ______ at well is ______ ft. Total depth of well 300 ft.

Completed well is ☒ shallow ☐ artesian. Depth to water upon completion of well 153 ft.

Section 2. PRINCIPAL WATER-BEARING STRATA

Depth in Feet		Thickness		Estimated Yield
From	To	In Feet	Description of Water Bearing Formation	(gallons per minute)
268	281	13	Yellow sandstone	10
281	283	2	Yellow clay	
283	286	3	Yellow sandstone	
286	292	6	Red sandstone	
292	303	11	Yellow sandstone	

Section 3. RECORD OF CASING

Diameter	Pounds	Threads	Depth in Feet		Length		Perforations	
(inches)	per foot	per in.	Top	Bottom	(feet)	Type of Shoe	From	To
4.5 OD	Sch 40 PVC		-2	300	302		280	300

Section 4. RECORD OF MUDDING AND CEMENTING

Depth in Feet		Hole	Sacks	Cubic Feet	
From	To	Diameter	of Mud	of Cement	Method of Placement
0	20	6.5"		4	Gravity

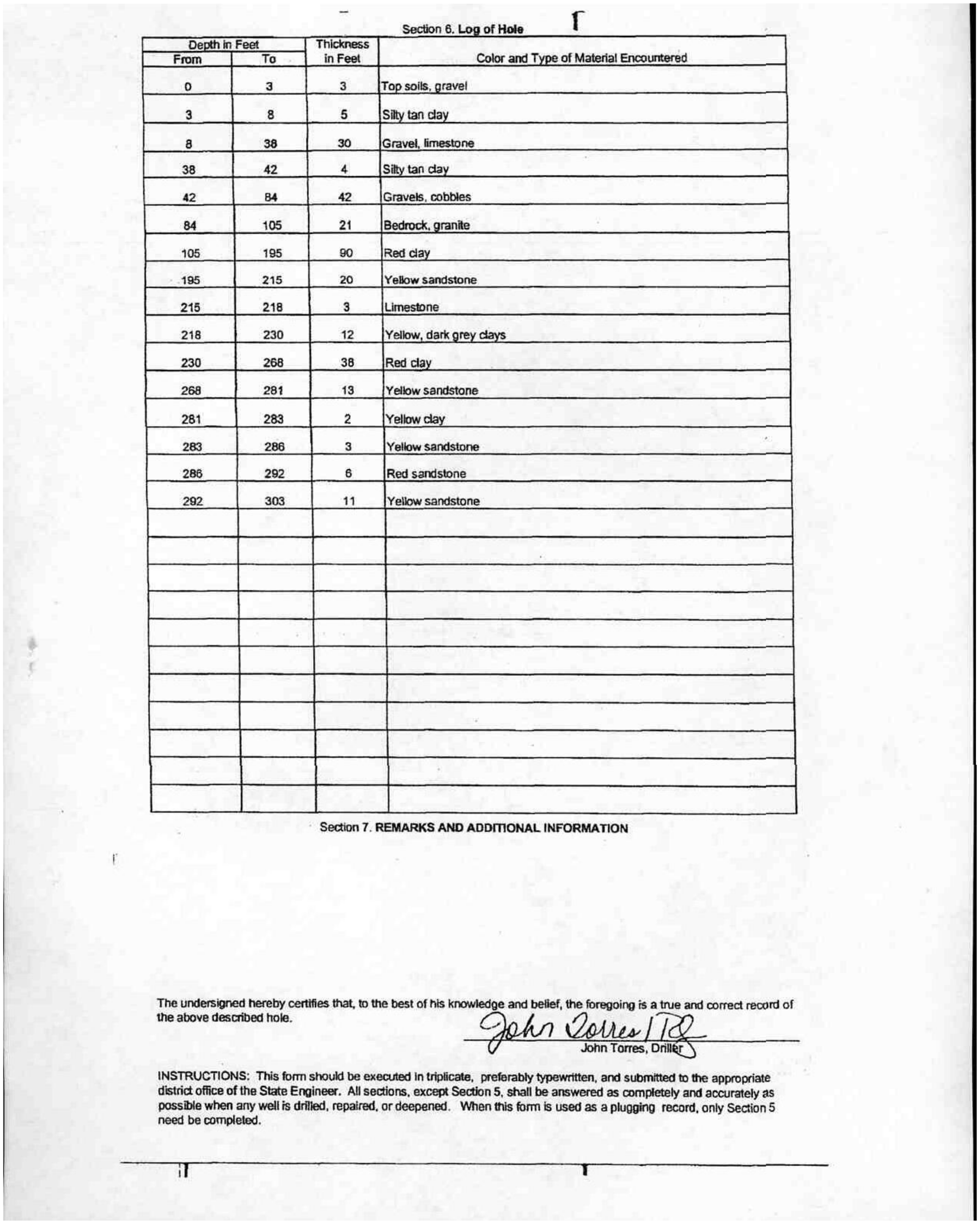
Section 5. PLUGGING RECORD

Plugging Contractor ______
Address ______
Plugging Method ______
Date Well Plugged ______
Plugging Approved By:
______ State Engineer Representative

	Depth in Feet		Cubic Feet
No.	Top	Bottom	of Cement
1			
2			
3			
4			

FOR USE OF STATE ENGINEER ONLY

Date Received 7/22/2005
Quad ______ FWL ______ FSL ______
File No. RG-42362 Use LIVESTOCK Location No. ______



Section 6. **Log of Hole**

Depth in Feet		Thickness in Feet	Color and Type of Material Encountered
From	To		
0	3	3	Top soils, gravel
3	8	5	Silty tan clay
8	38	30	Gravel, limestone
38	42	4	Silty tan clay
42	84	42	Gravels, cobbles
84	105	21	Bedrock, granite
105	195	90	Red clay
195	215	20	Yellow sandstone
215	218	3	Limestone
218	230	12	Yellow, dark grey clays
230	268	38	Red clay
268	281	13	Yellow sandstone
281	283	2	Yellow clay
283	286	3	Yellow sandstone
286	292	6	Red sandstone
292	303	11	Yellow sandstone

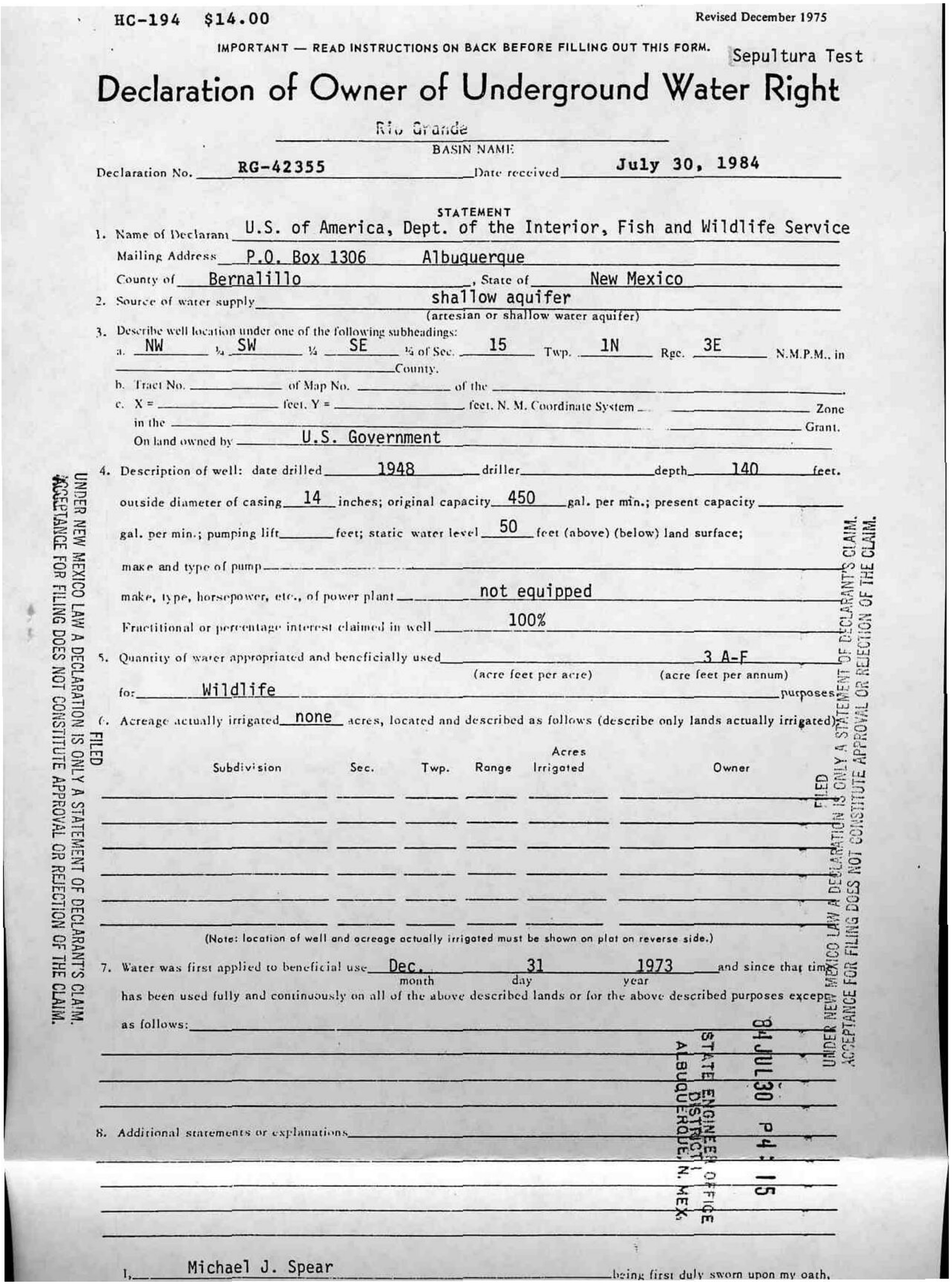
Section 7. **REMARKS AND ADDITIONAL INFORMATION**

The undersigned hereby certifies that, to the best of his knowledge and belief, the foregoing is a true and correct record of the above described hole.

John Torres

John Torres, Driller

INSTRUCTIONS: This form should be executed in triplicate, preferably typewritten, and submitted to the appropriate district office of the State Engineer. All sections, except Section 5, shall be answered as completely and accurately as possible when any well is drilled, repaired, or deepened. When this form is used as a plugging record, only Section 5 need be completed.



HC-194 $14.00

Revised December 1975

IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Sepultura Test

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42355 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service

Mailing Address P.O. Box 1306 Albuquerque

County of Bernalillo, State of New Mexico

2. Source of water supply shallow aquifer
(artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:

a. NW ¼ SW ¼ SE ¼ of Sec. 15 Twp. 1N Rge. 3E N.M.P.M., in ____ County.

b. Tract No. ____ of Map No. ____ of the ____

c. X = ____ feet, Y = ____ feet, N. M. Coordinate System ____ Zone in the ____ Grant.

On land owned by U.S. Government

4. Description of well: date drilled 1948 driller ____ depth 140 feet.

outside diameter of casing 14 inches; original capacity 450 gal. per min.; present capacity ____ gal. per min.; pumping lift ____ feet; static water level 50 feet (above) (below) land surface;

make and type of pump ____

make, type, horsepower, etc., of power plant not equipped

Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used ____ (acre feet per acre) 3 A-F (acre feet per annum)

for: Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated)

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows:

8. Additional statements or explanations

I, Michael J. Spear being first duly sworn upon my oath,

FILED

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

FILED

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

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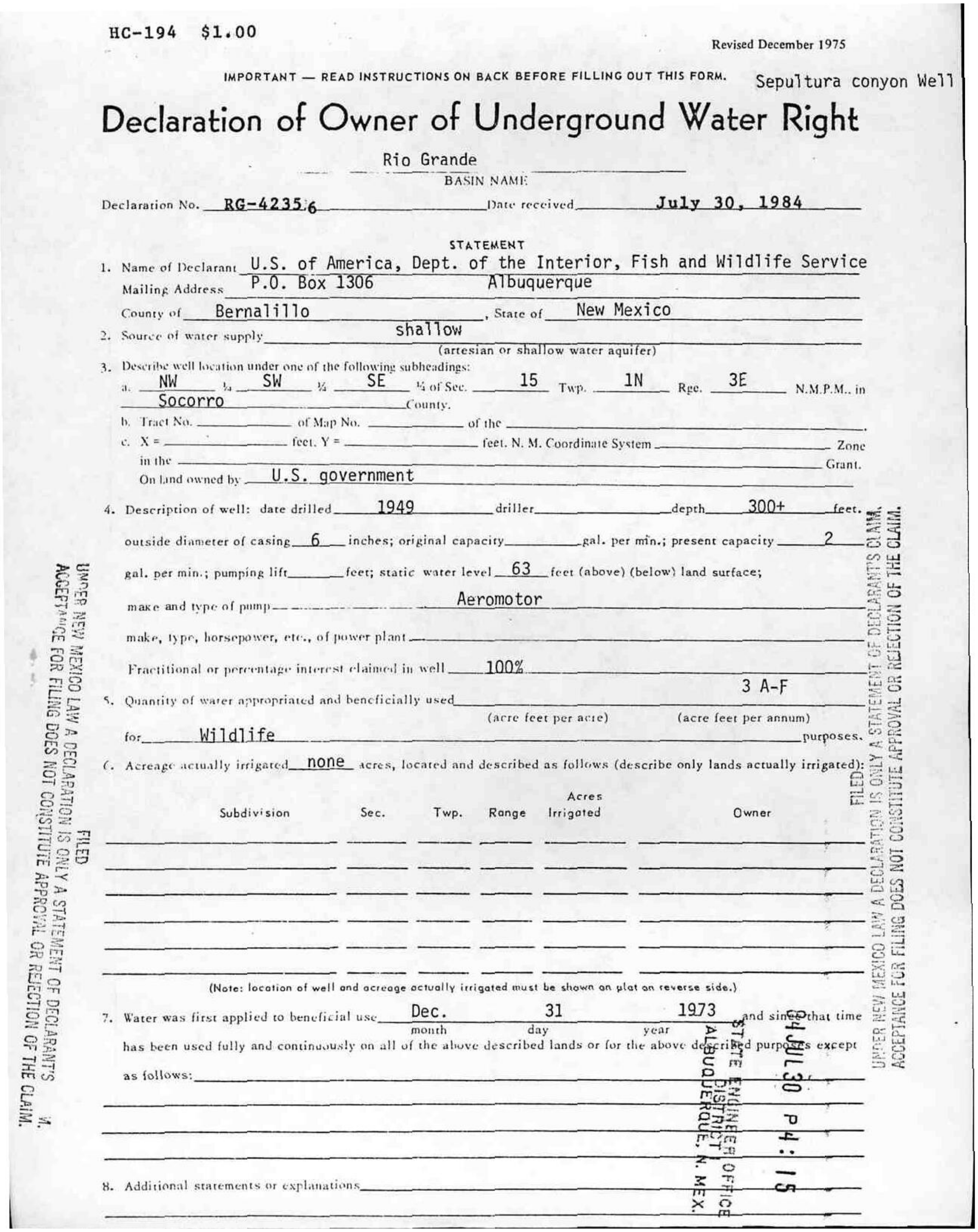
STATE ENGINEER OFFICE
DISTRICT I
ALBUQUERQUE, N. MEX.



HC-194 $1.00

Revised December 1975

IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Sepultura conyon Well

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42356 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico
2. Source of water supply shallow
(artesian or shallow water aquifer)
3. Describe well location under one of the following subheadings:
a. NW ¼ SW ¼ SE ¼ of Sec. 15 Twp. 1N Rge. 3E N.M.P.M., in Socorro County.
b. Tract No. ___ of Map No. ___ of the ___.
c. X = ___ feet, Y = ___ feet, N. M. Coordinate System ___ Zone in the ___ Grant.
On land owned by U.S. government
4. Description of well: date drilled 1949 driller ___ depth 300+ feet.
outside diameter of casing 6 inches; original capacity ___ gal. per min.; present capacity 2
gal. per min.; pumping lift ___ feet; static water level 63 feet (above) (below) land surface;
make and type of pump Aeromotor
make, type, horsepower, etc., of power plant ___
Fractitional or percentage interest claimed in well 100%
5. Quantity of water appropriated and beneficially used ___ 3 A-F
(acre feet per acre) (acre feet per annum)
for Wildlife purposes.
6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

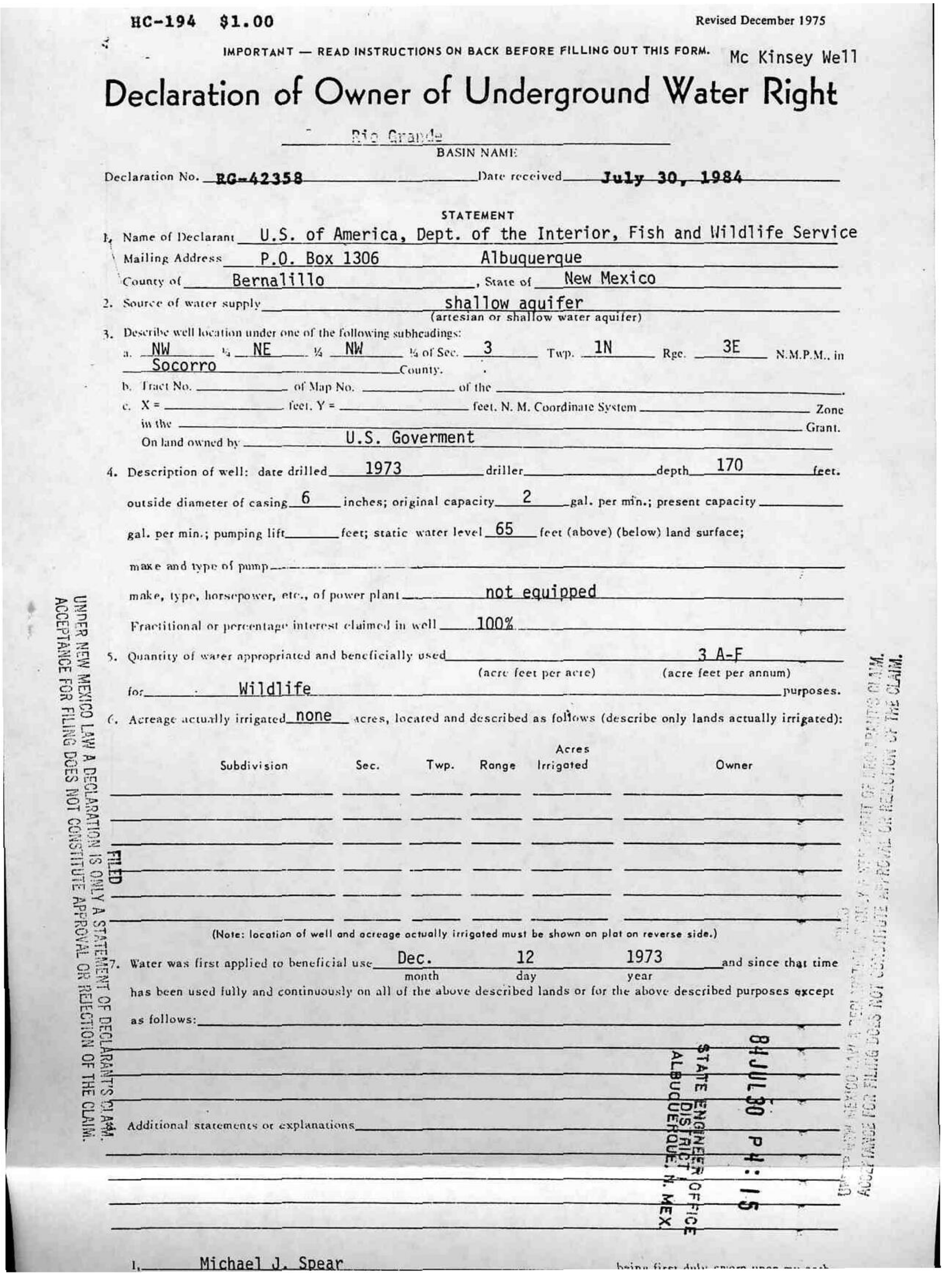
7. Water was first applied to beneficial use Dec. 31 1973 and since that time
month day year
has been used fully and continuously on all of the above described lands or for the above described purposes except as follows:

8. Additional statements or explanations

FILED
UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANTS
ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

FILED: UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM.
ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

84 JUL 30 P4:15
STATE ENGINEER
DISTRICT I OFFICE
ALBUQUERQUE, N. MEX.



HC-194 $1.00 Revised December 1975

IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Mc Kinsey Well

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. **RG-42358** Date received **July 30, 1984**

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico

2. Source of water supply shallow aquifer
(artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:
a. NW ¼ NE ¼ NW ¼ of Sec. 3 Twp. 1N Rge. 3E N.M.P.M., in Socorro County.
b. Tract No. ____ of Map No. ____ of the ____
c. X = ____ feet, Y = ____ feet, N. M. Coordinate System ____ Zone in the ____ Grant.
On land owned by U.S. Goverment

4. Description of well: date drilled 1973 driller ____ depth 170 feet.
outside diameter of casing 6 inches; original capacity 2 gal. per min.; present capacity ____ gal. per min.; pumping lift ____ feet; static water level 65 feet (above) (below) land surface;
make and type of pump ____
make, type, horsepower, etc., of power plant not equipped
Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used ____ (acre feet per acre) 3 A-F (acre feet per annum)
for Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 12 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows:

Additional statements or explanations

I, Michael J. Spear being first duly sworn upon my oath

FILED

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANTS CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

84 JUL 30 P 4:15
STATE ENGINEER OFFICE
DISTRICT 1
ALBUQUERQUE, N. MEX.

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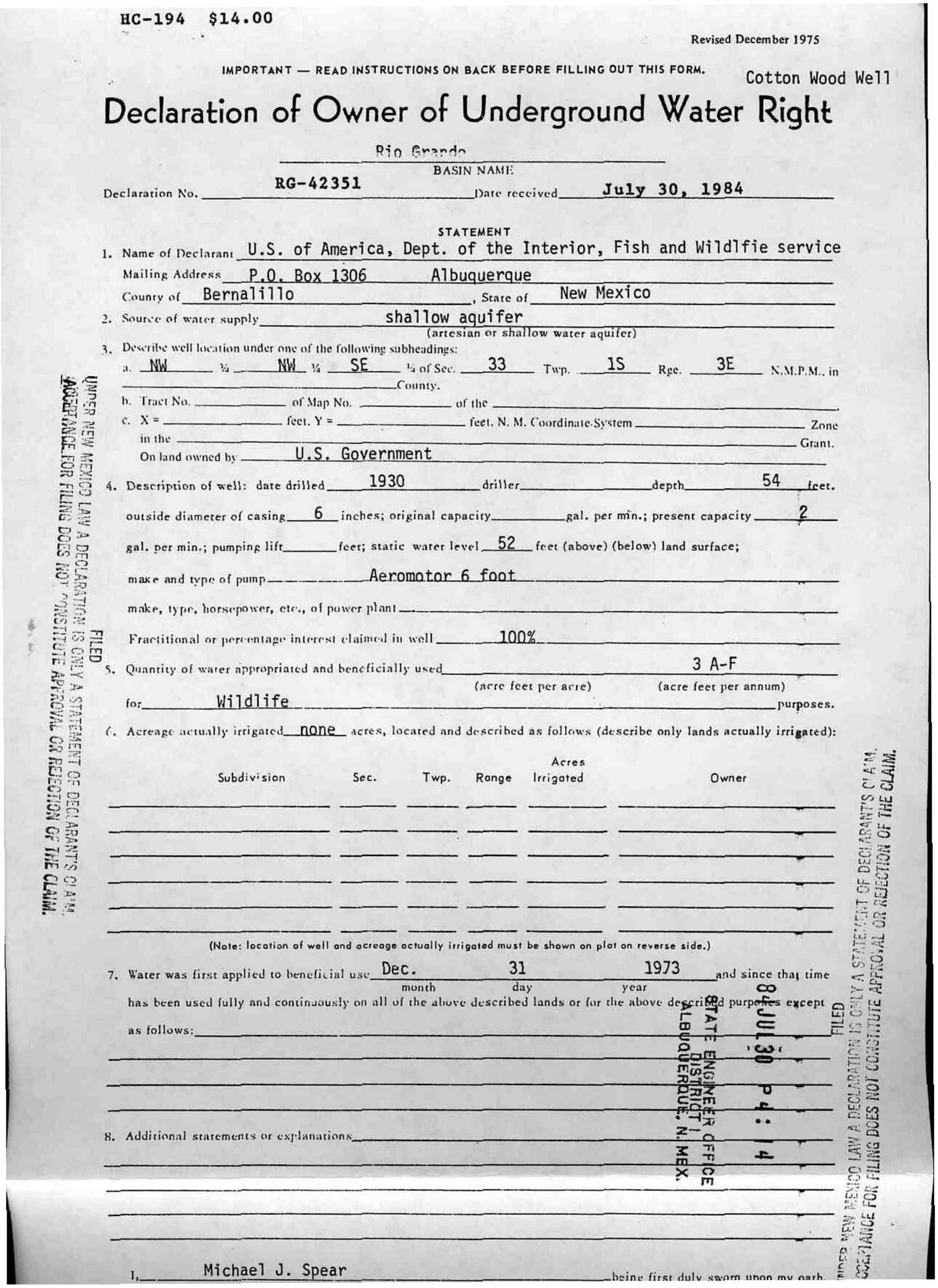

HC-194 $14.00

Revised December 1975

IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Cotton Wood Well

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42351 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlfie service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico

2. Source of water supply shallow aquifer (artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:
a. NW ¼ NW ¼ SE ¼ of Sec. 33 Twp. 1S Rge. 3E N.M.P.M., in ______ County.
b. Tract No. ______ of Map No. ______ of the ______
c. X = ______ feet, Y = ______ feet, N. M. Coordinate System ______ Zone in the ______ Grant.
On land owned by U.S. Government

4. Description of well: date drilled 1930 driller ______ depth 54 feet.
outside diameter of casing 6 inches; original capacity ______ gal. per min.; present capacity 2 gal. per min.; pumping lift ______ feet; static water level 52 feet (above) (below) land surface;
make and type of pump Aeromotor 6 foot
make, type, horsepower, etc., of power plant ______
Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used ______ (acre feet per acre) 3 A-F (acre feet per annum) for Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows:

8. Additional statements or explanations

I, Michael J. Spear being first duly sworn upon my oath,

FILED

UNDER NEW MEXICO LAW A DECLARATION IS ONLY A STATEMENT OF DECLARANT'S CLAIM. ACCEPTANCE FOR FILING DOES NOT CONSTITUTE APPROVAL OR REJECTION OF THE CLAIM.

84 JUL 30 P 4:14

STATE ENGINEER OFFICE
DISTRICT I
ALBUQUERQUE, N. MEX.

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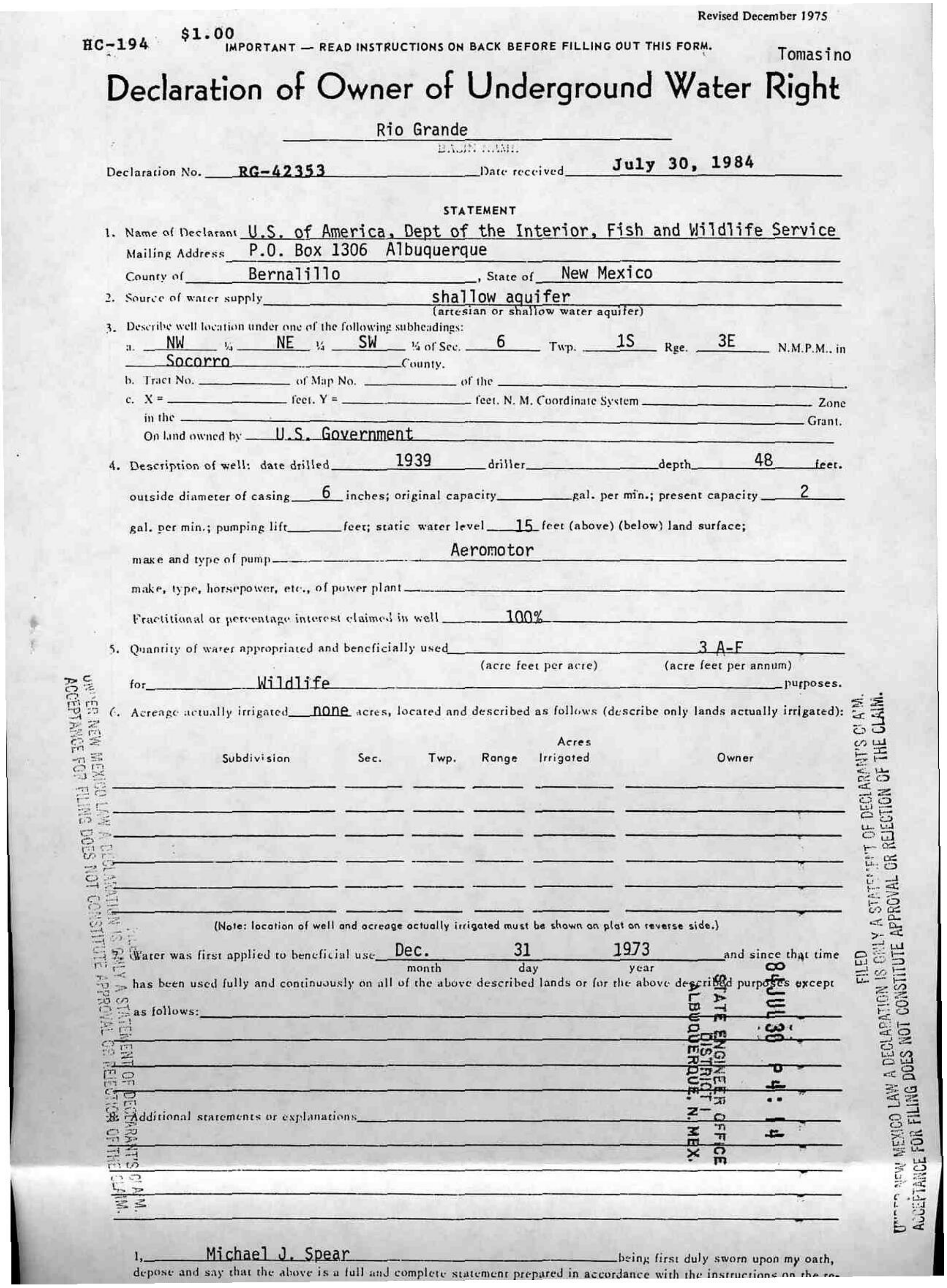

Revised December 1975

HC-194 $1.00 IMPORTANT — READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Tomasino

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42353 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico

2. Source of water supply shallow aquifer
(artesian or shallow water aquifer)

3. Describe well location under one of the following subheadings:
a. NW ¼ NE ¼ SW ¼ of Sec. 6 Twp. 1S Rge. 3E N.M.P.M., in Socorro County.
b. Tract No. ______ of Map No. ______ of the ______
c. X = ______ feet, Y = ______ feet, N. M. Coordinate System ______ Zone in the ______ Grant.
On land owned by U.S. Government

4. Description of well: date drilled 1939 driller ______ depth 48 feet.
outside diameter of casing 6 inches; original capacity ______ gal. per min.; present capacity 2 gal. per min.; pumping lift ______ feet; static water level 15 feet (above) (below) land surface;
make and type of pump Aeromotor
make, type, horsepower, etc., of power plant ______
Fractitional or percentage interest claimed in well 100%

5. Quantity of water appropriated and beneficially used ______ (acre feet per acre) 3 A-F (acre feet per annum)
for Wildlife purposes.

6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows: ______

8. Additional statements or explanations ______

I, Michael J. Spear being first duly sworn upon my oath, depose and say that the above is a full and complete statement prepared in accordance with the instructions on the re-

STATE ENGINEER OFFICE
DISTRICT I
ALBUQUERQUE, N. MEX.

84 JUL 30 P 4:14

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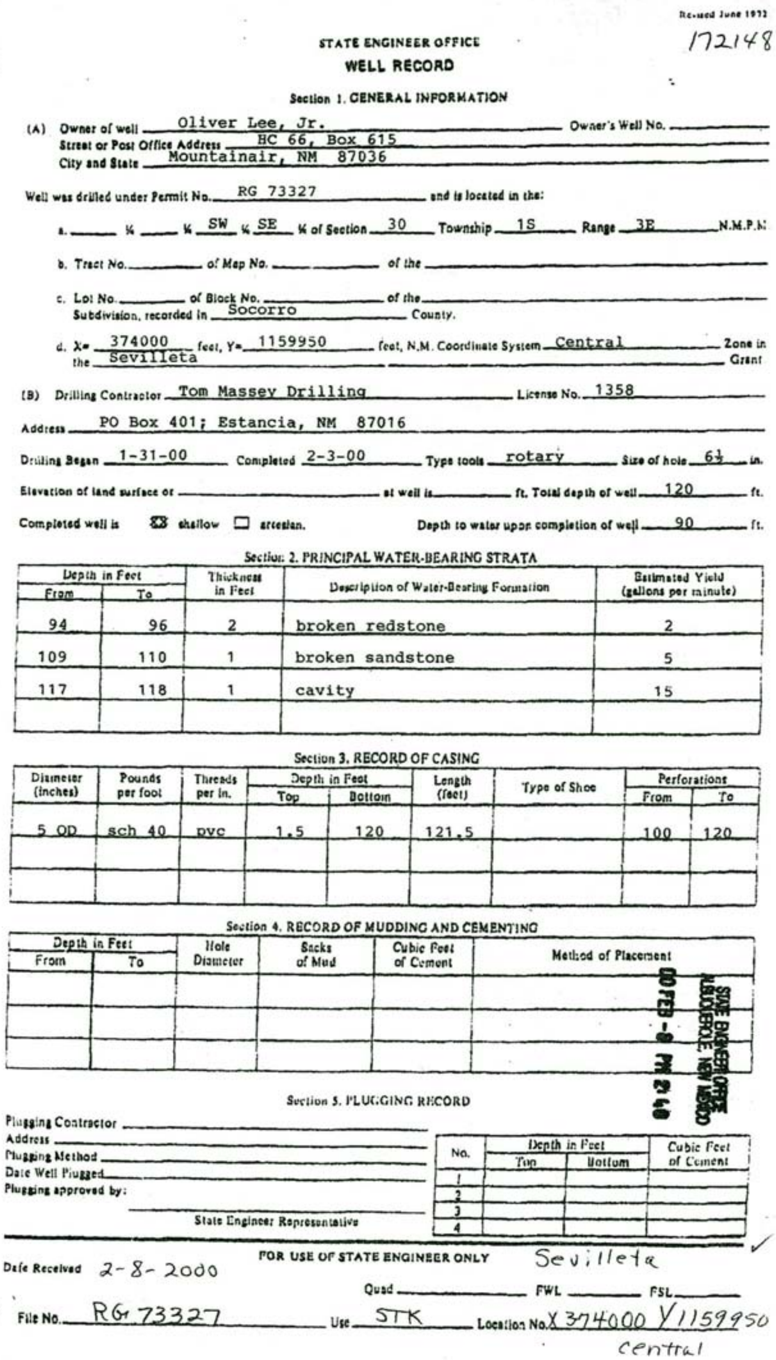

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Revised June 1972

172148

STATE ENGINEER OFFICE

WELL RECORD

Section 1. GENERAL INFORMATION

(A) Owner of well Oliver Lee, Jr. Owner's Well No. ____
Street or Post Office Address HC 66, Box 615
City and State Mountainair, NM 87036

Well was drilled under Permit No. RG 73327 and is located in the:

a. ____ ¼ ____ ¼ SW ¼ SE ¼ of Section 30 Township 1S Range 3E N.M.P.M.

b. Tract No. ____ of Map No. ____ of the ____

c. Lot No. ____ of Block No. ____ of the ____
Subdivision, recorded in Socorro County.

d. X= 374000 feet, Y= 1159950 feet, N.M. Coordinate System Central Zone in the Sevilleta Grant

(B) Drilling Contractor Tom Massey Drilling License No. 1358

Address PO Box 401; Estancia, NM 87016

Drilling Began 1-31-00 Completed 2-3-00 Type tools rotary Size of hole 6½ in.

Elevation of land surface or ____ at well is ____ ft. Total depth of well 120 ft.

Completed well is ☒ shallow ☐ artesian. Depth to water upon completion of well 90 ft.

Section 2. PRINCIPAL WATER-BEARING STRATA

Depth in Feet		Thickness in Feet	Description of Water-Bearing Formation	Estimated Yield (gallons per minute)
From	To			
94	96	2	broken redstone	2
109	110	1	broken sandstone	5
117	118	1	cavity	15

Section 3. RECORD OF CASING

Diameter (inches)	Pounds per foot	Threads per in.	Depth in Feet		Length (feet)	Type of Shoe	Perforations	
			Top	Bottom			From	To
5 OD	sch 40	pvc	1.5	120	121.5		100	120

Section 4. RECORD OF MUDDING AND CEMENTING

Depth in Feet		Hole Diameter	Sacks of Mud	Cubic Feet of Cement	Method of Placement
From	To				

STATE ENGINEER OFFICE
ALBUQUERQUE, NEW MEXICO
00 FEB -8 PM 2:40

Section 5. PLUGGING RECORD

Plugging Contractor ____
Address ____
Plugging Method ____
Date Well Plugged ____
Plugging approved by:
____
State Engineer Representative

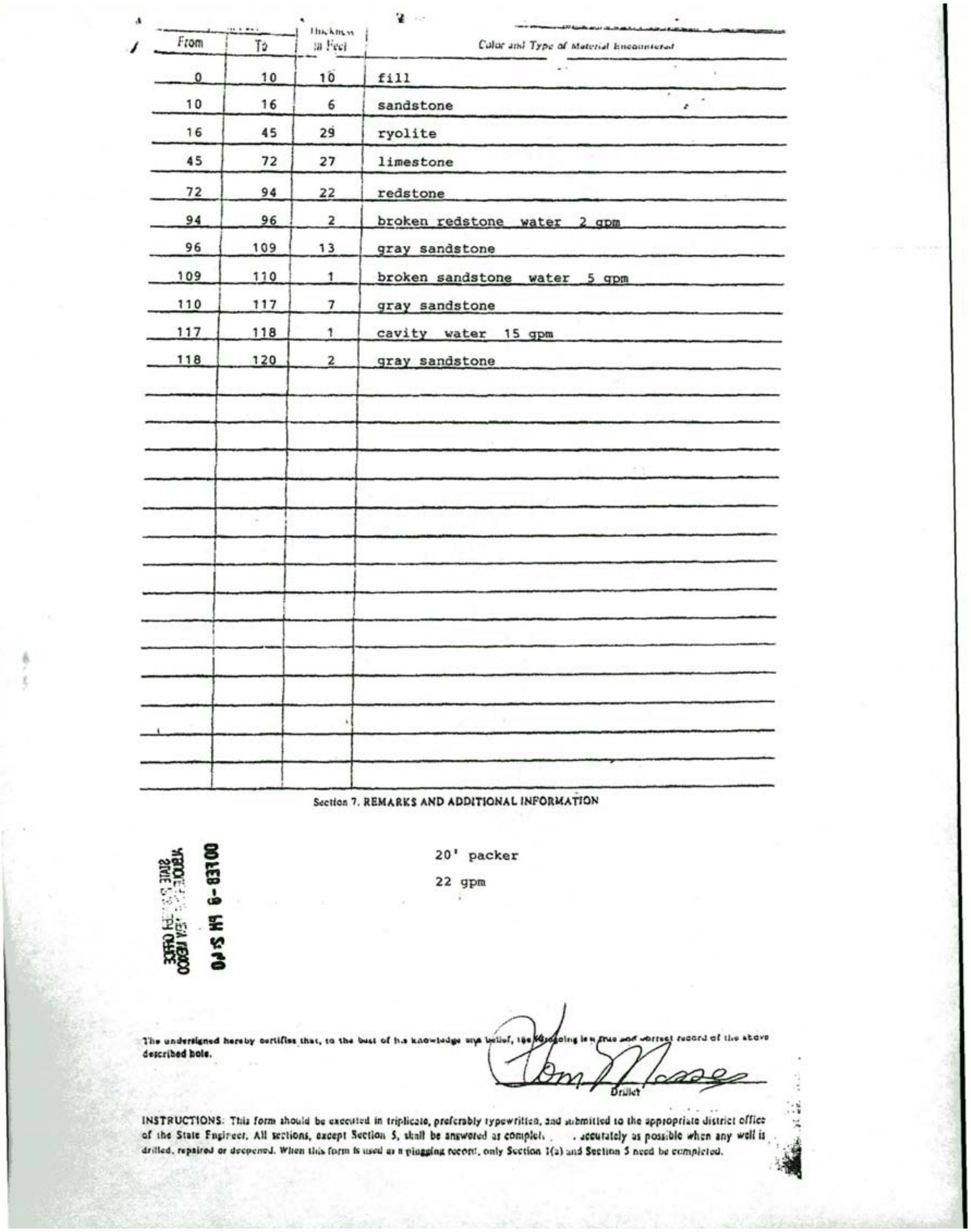
No.	Depth in Feet		Cubic Feet of Cement
	Top	Bottom	
1			
2			
3			
4			

FOR USE OF STATE ENGINEER ONLY

Date Received 2-8-2000 Sevilleta

Quad ____ FWL ____ FSL ____

File No. RG 73327 Use STK Location No. X 374000 Y 1159950
central



From	To	Thickness in Feet	Color and Type of Material Encountered
0	10	10	fill
10	16	6	sandstone
16	45	29	ryolite
45	72	27	limestone
72	94	22	redstone
94	96	2	broken redstone water 2 gpm
96	109	13	gray sandstone
109	110	1	broken sandstone water 5 gpm
110	117	7	gray sandstone
117	118	1	cavity water 15 gpm
118	120	2	gray sandstone

Section 7. REMARKS AND ADDITIONAL INFORMATION

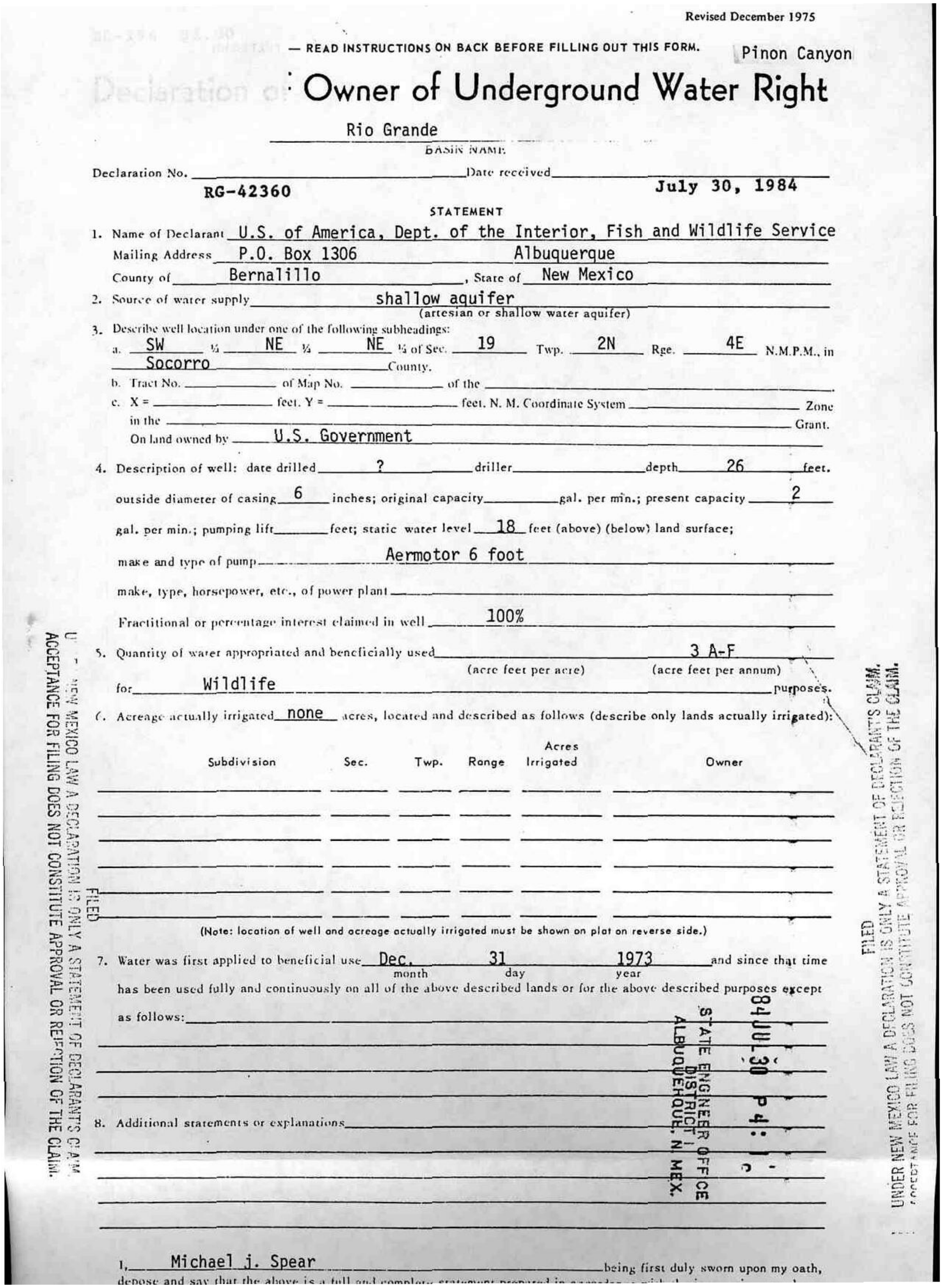
20' packer

22 gpm

The undersigned hereby certifies that, to the best of his knowledge and belief, the foregoing is a true and correct record of the above described hole.

Driller

INSTRUCTIONS: This form should be executed in triplicate, preferably typewritten, and submitted to the appropriate district office of the State Engineer. All sections, except Section 5, shall be answered as complet[illegible] accurately as possible when any well is drilled, repaired or deepened. When this form is used as a plugging record, only Section 1(a) and Section 5 need be completed.



Revised December 1975

— READ INSTRUCTIONS ON BACK BEFORE FILLING OUT THIS FORM.

Pinon Canyon

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42360 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico
2. Source of water supply shallow aquifer (artesian or shallow water aquifer)
3. Describe well location under one of the following subheadings:
a. SW ¼ NE ¼ NE ¼ of Sec. 19 Twp. 2N Rge. 4E N.M.P.M., in Socorro County.
b. Tract No. ______ of Map No. ______ of the ______
c. X = ______ feet, Y = ______ feet, N. M. Coordinate System ______ Zone in the ______ Grant.
On land owned by U.S. Government
4. Description of well: date drilled ? driller ______ depth 26 feet.
outside diameter of casing 6 inches; original capacity ______ gal. per min.; present capacity 2 gal. per min.; pumping lift ______ feet; static water level 18 feet (above) (below) land surface;
make and type of pump Aermotor 6 foot
make, type, horsepower, etc., of power plant ______
Fractitional or percentage interest claimed in well 100%
5. Quantity of water appropriated and beneficially used ______ (acre feet per acre) 3 A-F (acre feet per annum) for Wildlife purposes.
6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows: ______
8. Additional statements or explanations ______

I, Michael j. Spear being first duly sworn upon my oath, depose and say that the above is a full and complete

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84 JUL 30 P 4: 1
STATE ENGINEER OFFICE
DISTRICT I
ALBUQUERQUE, N. MEX.

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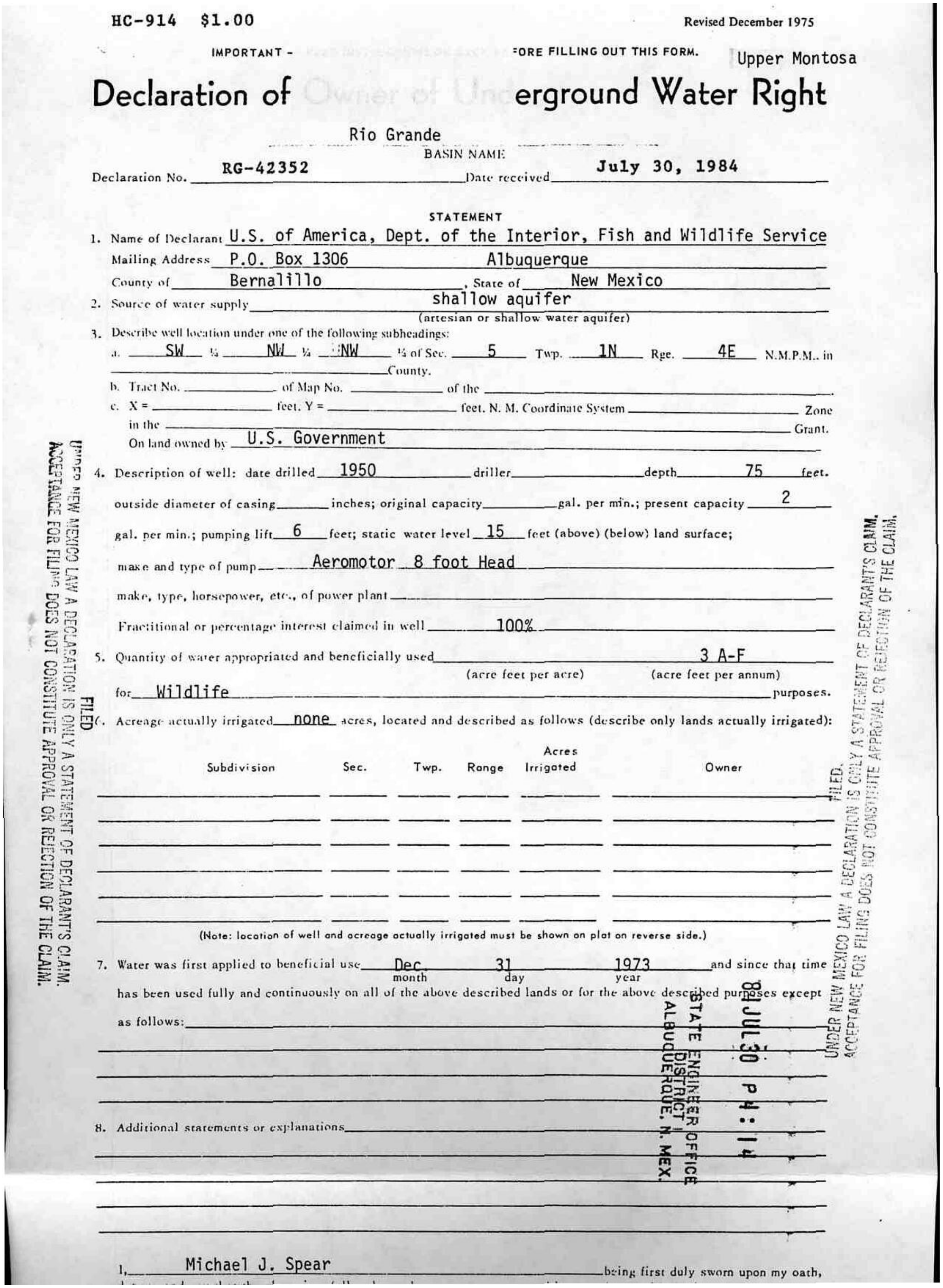

HC-914 $1.00

Revised December 1975

IMPORTANT - [illegible] FORE FILLING OUT THIS FORM.

Upper Montosa

Declaration of Owner of Underground Water Right

Rio Grande
BASIN NAME

Declaration No. RG-42352 Date received July 30, 1984

STATEMENT

1. Name of Declarant U.S. of America, Dept. of the Interior, Fish and Wildlife Service
Mailing Address P.O. Box 1306 Albuquerque
County of Bernalillo, State of New Mexico
2. Source of water supply shallow aquifer
(artesian or shallow water aquifer)
3. Describe well location under one of the following subheadings:
a. SW ¼ NW ¼ NW ¼ of Sec. 5 Twp. 1N Rge. 4E N.M.P.M., in ________ County.
b. Tract No. ________ of Map No. ________ of the ________.
c. X = ________ feet, Y = ________ feet, N. M. Coordinate System ________ Zone in the ________ Grant.
On land owned by U.S. Government
4. Description of well: date drilled 1950 driller ________ depth 75 feet.
outside diameter of casing ________ inches; original capacity ________ gal. per min.; present capacity 2
gal. per min.; pumping lift 6 feet; static water level 15 feet (above) (below) land surface;
make and type of pump Aeromotor 8 foot Head
make, type, horsepower, etc., of power plant ________
Fractitional or percentage interest claimed in well 100%
5. Quantity of water appropriated and beneficially used ________ (acre feet per acre) 3 A-F (acre feet per annum)
for Wildlife purposes.
6. Acreage actually irrigated none acres, located and described as follows (describe only lands actually irrigated):

Subdivision	Sec.	Twp.	Range	Acres Irrigated	Owner

(Note: location of well and acreage actually irrigated must be shown on plat on reverse side.)

7. Water was first applied to beneficial use Dec. (month) 31 (day) 1973 (year) and since that time has been used fully and continuously on all of the above described lands or for the above described purposes except as follows: ________

8. Additional statements or explanations ________

I, Michael J. Spear being first duly sworn upon my oath,

FILED

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84 JUL 30 P4:14

STATE ENGINEER OFFICE
DISTRICT 1
ALBUQUERQUE, N. MEX.

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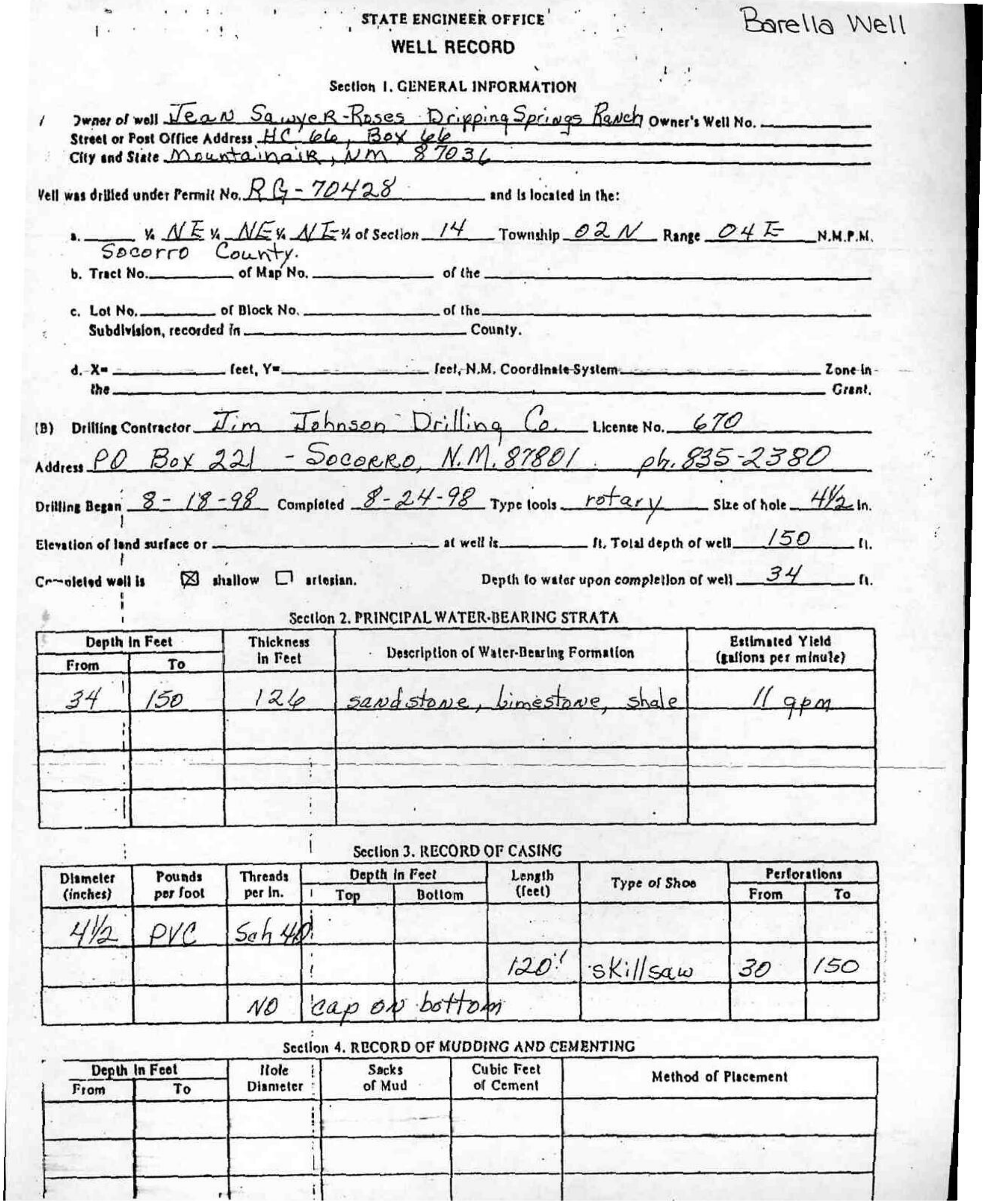


Barella Well

STATE ENGINEER OFFICE

WELL RECORD

Section 1. GENERAL INFORMATION

Owner of well Jean Sawyer-Roses Dripping Springs Ranch Owner's Well No. ______
Street or Post Office Address HC 66, Box 66
City and State Mountainair, NM 87036

Well was drilled under Permit No. RG-70428 and is located in the:

a. ____ ¼ NE ¼ NE ¼ NE ¼ of Section 14 Township 02 N Range 04 E N.M.P.M.
Socorro County.
b. Tract No. ______ of Map No. ______ of the ______
c. Lot No. ______ of Block No. ______ of the ______
Subdivision, recorded in ______ County.
d. X= ______ feet, Y= ______ feet, N.M. Coordinate System ______ Zone in the ______ Grant.

(B) Drilling Contractor Jim Johnson Drilling Co. License No. 670
Address PO Box 221 - Socorro, N.M. 87801 ph. 835-2380
Drilling Began 8-18-98 Completed 8-24-98 Type tools rotary Size of hole 4½ in.
Elevation of land surface or ______ at well is ______ ft. Total depth of well 150 ft.
Completed well is ☒ shallow ☐ artesian. Depth to water upon completion of well 34 ft.

Section 2. PRINCIPAL WATER-BEARING STRATA

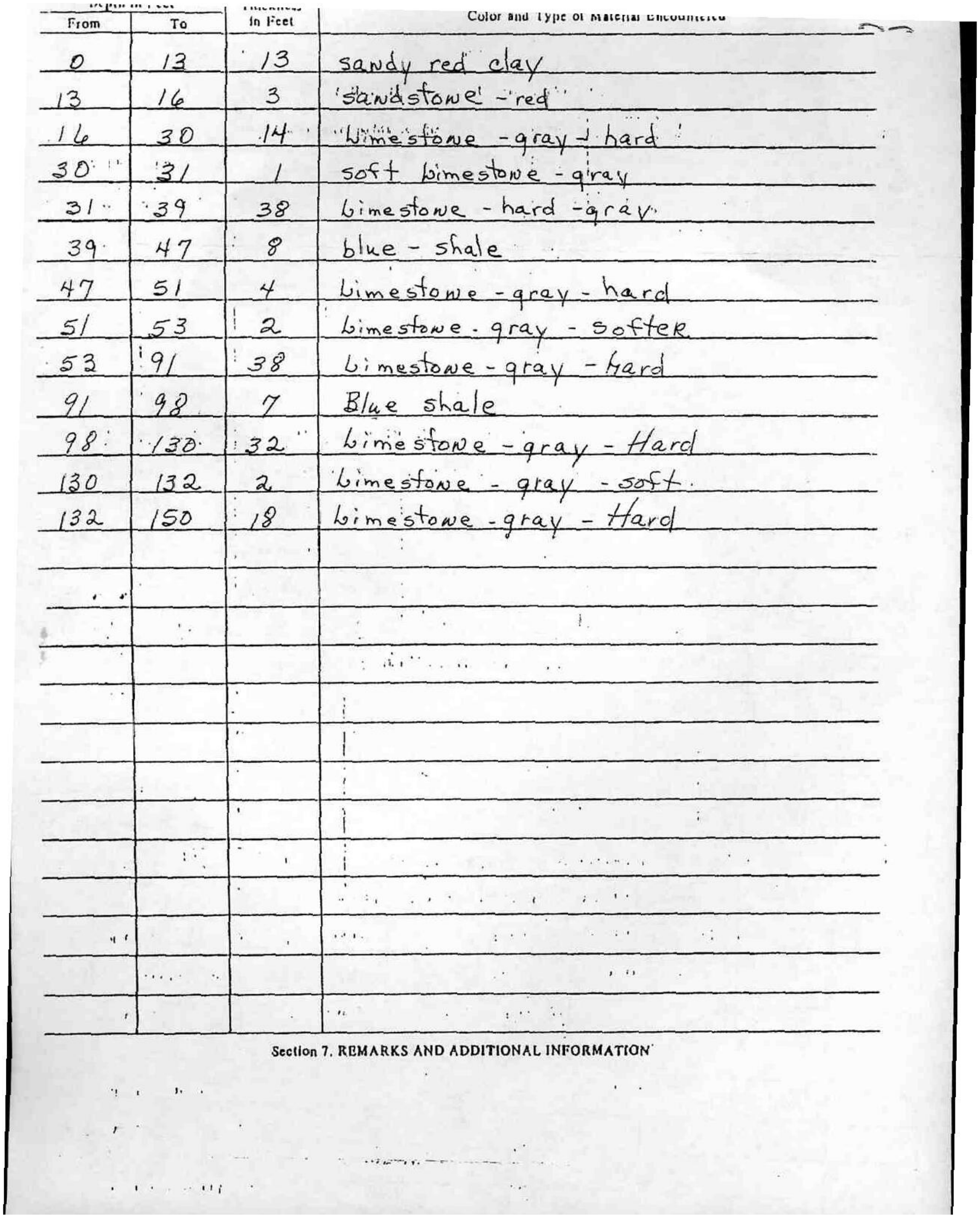
Depth in Feet		Thickness in Feet	Description of Water-Bearing Formation	Estimated Yield (gallons per minute)
From	To			
34	150	126	sandstone, limestone, shale	11 gpm

Section 3. RECORD OF CASING

Diameter (inches)	Pounds per foot	Threads per in.	Depth in Feet		Length (feet)	Type of Shoe	Perforations	
			Top	Bottom			From	To
4½	PVC	Sch 40						
					120'	skillsaw	30	150
		NO	cap on bottom					

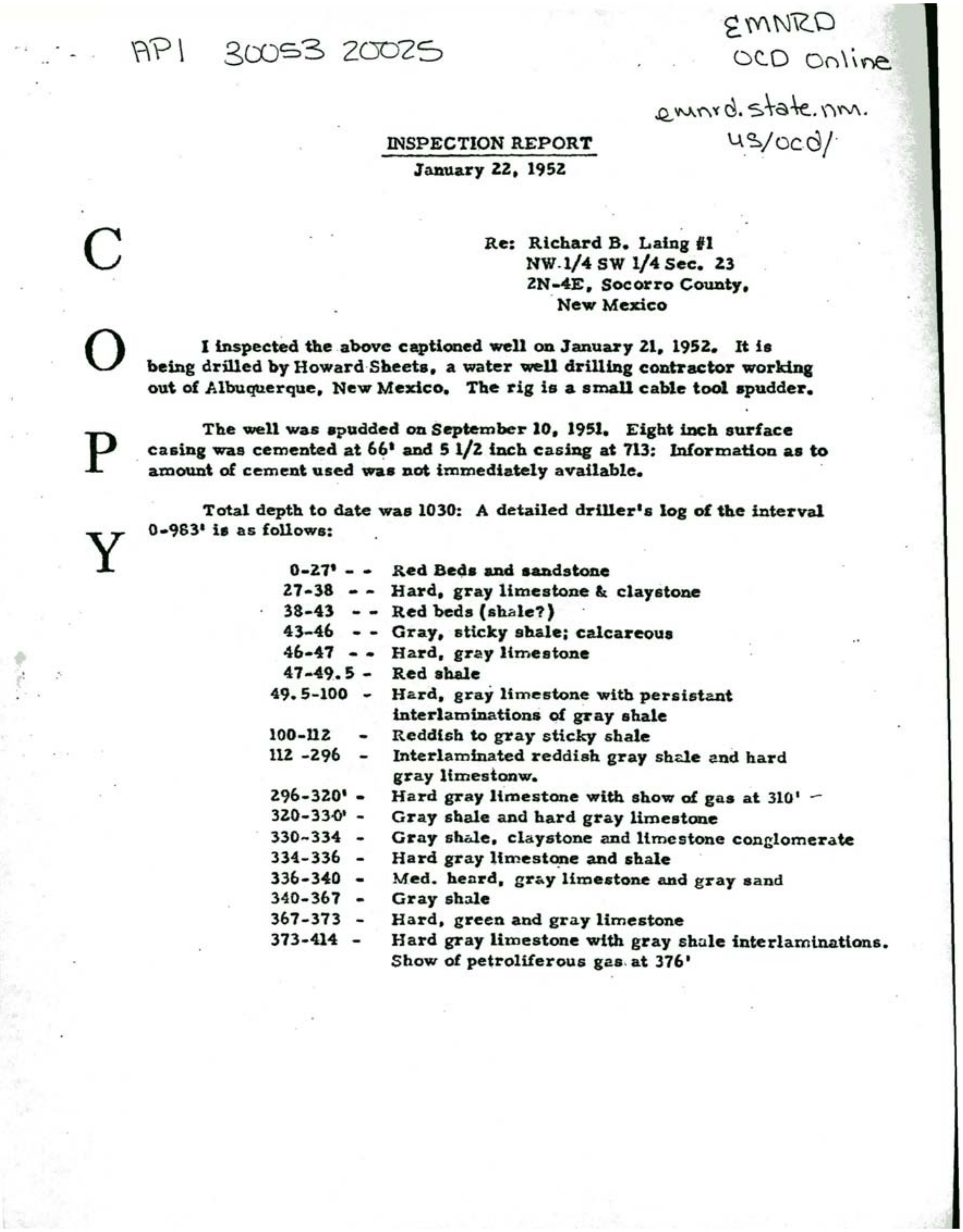
Section 4. RECORD OF MUDDING AND CEMENTING

Depth in Feet		Hole Diameter	Sacks of Mud	Cubic Feet of Cement	Method of Placement
From	To				



From	To	In Feet	Color and Type of Material Encountered
0	13	13	sandy red clay
13	16	3	sandstone - red
16	30	14	limestone - gray - hard
30	31	1	soft limestone - gray
31	39	38	limestone - hard - gray
39	47	8	blue - shale
47	51	4	limestone - gray - hard
51	53	2	limestone - gray - softer
53	91	38	limestone - gray - hard
91	98	7	Blue shale
98	130	32	limestone - gray - Hard
130	132	2	limestone - gray - soft
132	150	18	limestone - gray - Hard

Section 7. REMARKS AND ADDITIONAL INFORMATION



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OCD Online

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INSPECTION REPORT

January 22, 1952

Re: Richard B. Laing #1
NW 1/4 SW 1/4 Sec. 23
2N-4E, Socorro County,
New Mexico

I inspected the above captioned well on January 21, 1952. It is being drilled by Howard Sheets, a water well drilling contractor working out of Albuquerque, New Mexico. The rig is a small cable tool spudder.

The well was spudded on September 10, 1951. Eight inch surface casing was cemented at 66' and 5 1/2 inch casing at 713: Information as to amount of cement used was not immediately available.

Total depth to date was 1030: A detailed driller's log of the interval 0-983' is as follows:

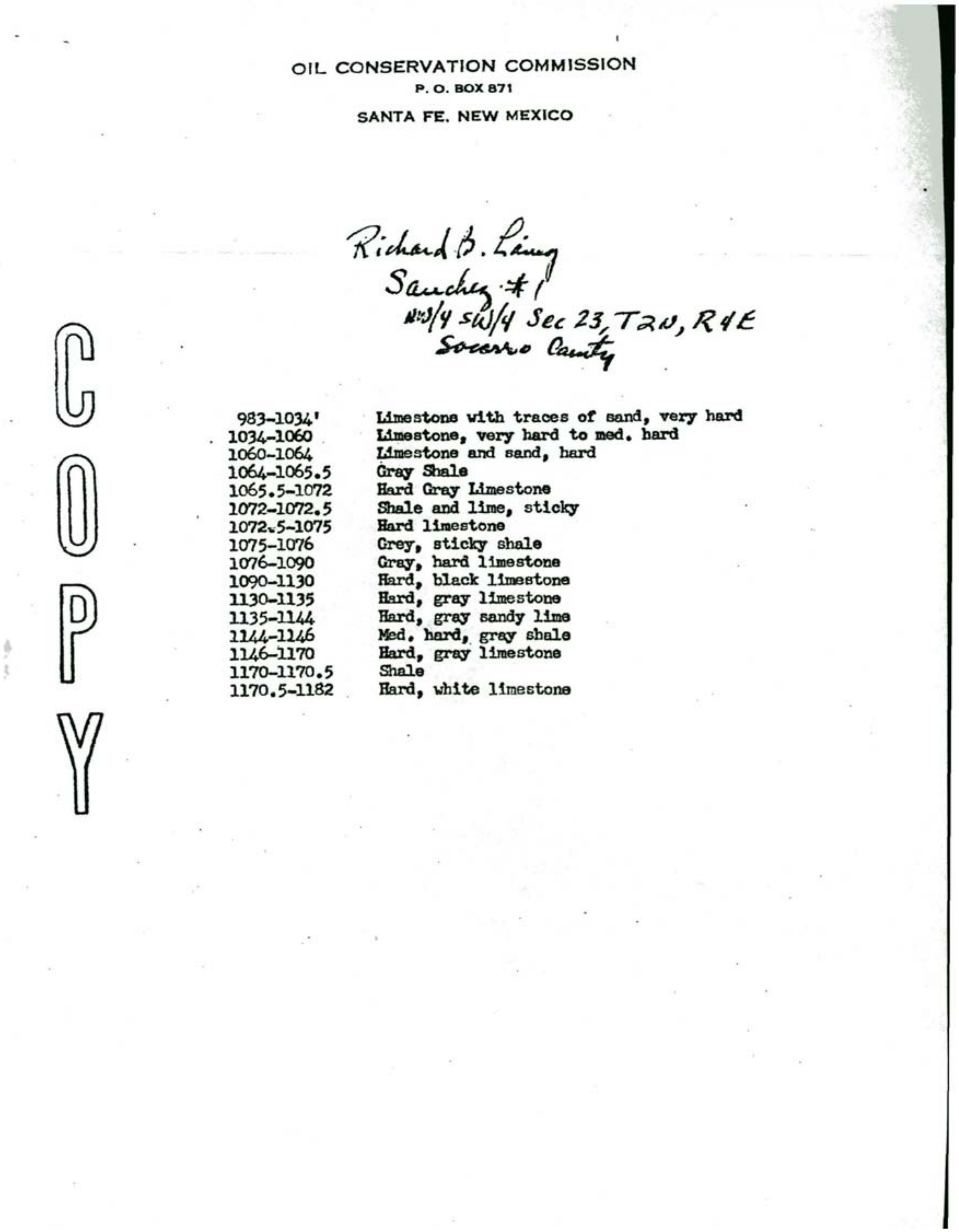
0-27' - -	Red Beds and sandstone
27-38 - -	Hard, gray limestone & claystone
38-43 - -	Red beds (shale?)
43-46 - -	Gray, sticky shale; calcareous
46-47 - -	Hard, gray limestone
47-49.5 -	Red shale
49.5-100 -	Hard, gray limestone with persistant interlaminations of gray shale
100-112 -	Reddish to gray sticky shale
112 -296 -	Interlaminated reddish gray shale and hard gray limestonw.
296-320' -	Hard gray limestone with show of gas at 310' —
320-330' -	Gray shale and hard gray limestone
330-334 -	Gray shale, claystone and limestone conglomerate
334-336 -	Hard gray limestone and shale
336-340 -	Med. heard, gray limestone and gray sand
340-367 -	Gray shale
367-373 -	Hard, green and gray limestone
373-414 -	Hard gray limestone with gray shale interlaminations. Show of petroliferous gas at 376'

414-443- Grayish black med. hard limestone
443-450- Hard gray limestone
450-468- Gray shale and limestone. Trace of oil
468-508- Hard gray limestone and med. hard shales
508-510- Hard gray limestone and some black sand
510-575- Gray to black sands and shales; Med. hard
575-594- Gray, med. hard sandstone. Show of oil at 590'
594-630- Gray shales, hard gray limestone and hard gray quartzitic sandstone
630-710- Hard gray quartzitic sands w/sporadic med. hard shale interbedding
710-720- Gray to black hard limestone and med. hard shale
720-741- Hard, black, finegrained sandstone, slightly calcareous
741-746- Black, finegrained sand, trace of shale
746-779- Gray and black coarse grained sandstone
779-798- Hard gray finegrained sand, little lime
798-806- Reddish brown, med. hard shale
806-810- Hard, gray, f.g. quartzitic sandstone
810-834- Hard gray limestone, traces of sand
834-842- Med. coarse, gray calcareous sandstone with strong petroliferous odor
842-847- Finegrained, gray calcareous sand
847-854- Finegrained, gray sandstone, med. hard
854-865- Gray limestone, sandy, med. hard
865-876- Gray sandy siltstone
876-892- Gray lime and finegrained sandstone, hard
892-910- Med. hard quartzitic, sandstone
910-920- Finegrained gray sand and limestone, hard
920-934- Sandy, black siltstone
934-941- Hard gray calcareous sandstone
941-951- Med. hard, gray shale
951-966- Hard, gray sand
966-971- Sticky shale and some lime conglomerate
971-983- Hard, gray limestone and sticky shale - traces of sand toward bottom.

The well is presently making some gas at approximate pressures of 30-40 lbs. This gas is shut in and controlled.

Eugene A. Chavez
EUGENE A. CHAVEZ,
Geologist

ir

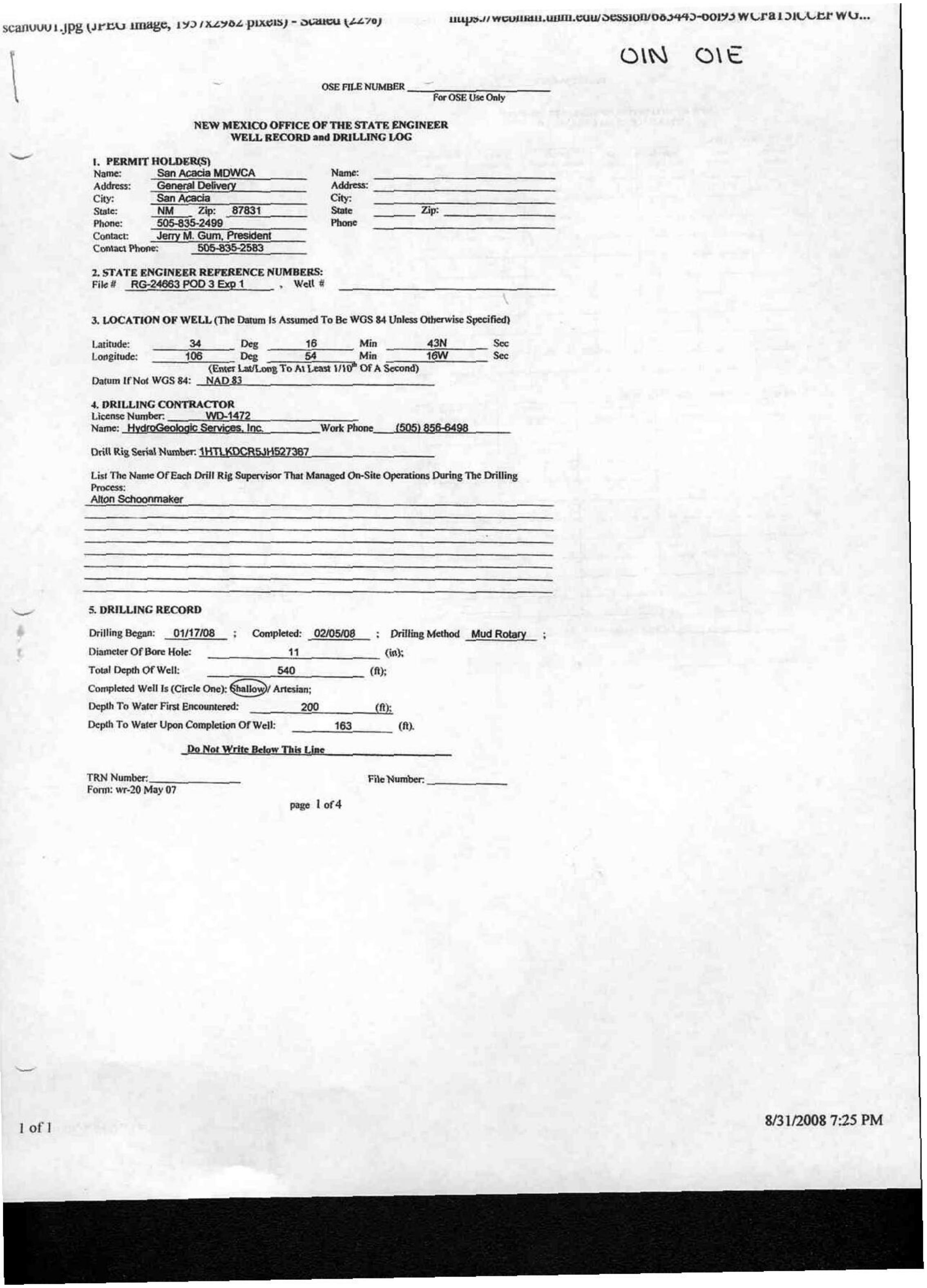


OIL CONSERVATION COMMISSION
P. O. BOX 871
SANTA FE, NEW MEXICO

Richard B. Laing
Sanchez #1
NW/4 SW/4 Sec 23, T2N, R4E
Socorro County

COPY

983-1034'	Limestone with traces of sand, very hard
1034-1060	Limestone, very hard to med. hard
1060-1064	Limestone and sand, hard
1064-1065.5	Gray Shale
1065.5-1072	Hard Gray Limestone
1072-1072.5	Shale and lime, sticky
1072.5-1075	Hard limestone
1075-1076	Grey, sticky shale
1076-1090	Gray, hard limestone
1090-1130	Hard, black limestone
1130-1135	Hard, gray limestone
1135-1144	Hard, gray sandy lime
1144-1146	Med. hard, gray shale
1146-1170	Hard, gray limestone
1170-1170.5	Shale
1170.5-1182	Hard, white limestone



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NEW MEXICO OFFICE OF THE STATE ENGINEER
WELL RECORD and DRILLING LOG

1. PERMIT HOLDER(S)

Name:	San Acacia MDWCA	Name:	
Address:	General Delivery	Address:	
City:	San Acacia	City:	
State:	NM Zip: 87831	State	Zip:
Phone:	505-835-2499	Phone	
Contact:	Jerry M. Gum, President		
Contact Phone:	505-835-2583		

2. STATE ENGINEER REFERENCE NUMBERS:
File # RG-24663 POD 3 Exp 1 , Well # ____________

3. LOCATION OF WELL (The Datum Is Assumed To Be WGS 84 Unless Otherwise Specified)

Latitude:	34	Deg	16	Min	43N	Sec
Longitude:	106	Deg	54	Min	16W	Sec

(Enter Lat/Long To At Least 1/10th Of A Second)
Datum If Not WGS 84: NAD 83

4. DRILLING CONTRACTOR
License Number: WD-1472
Name: HydroGeologic Services, Inc. Work Phone (505) 856-6498

Drill Rig Serial Number: 1HTLKDCR5JH527367

List The Name Of Each Drill Rig Supervisor That Managed On-Site Operations During The Drilling Process:
Alton Schoonmaker

5. DRILLING RECORD

Drilling Began: 01/17/08 ; Completed: 02/05/08 ; Drilling Method Mud Rotary ;
Diameter Of Bore Hole: 11 (in);
Total Depth Of Well: 540 (ft);
Completed Well Is (Circle One): [✓ Shallow]/ Artesian;
Depth To Water First Encountered: 200 (ft);
Depth To Water Upon Completion Of Well: 163 (ft).

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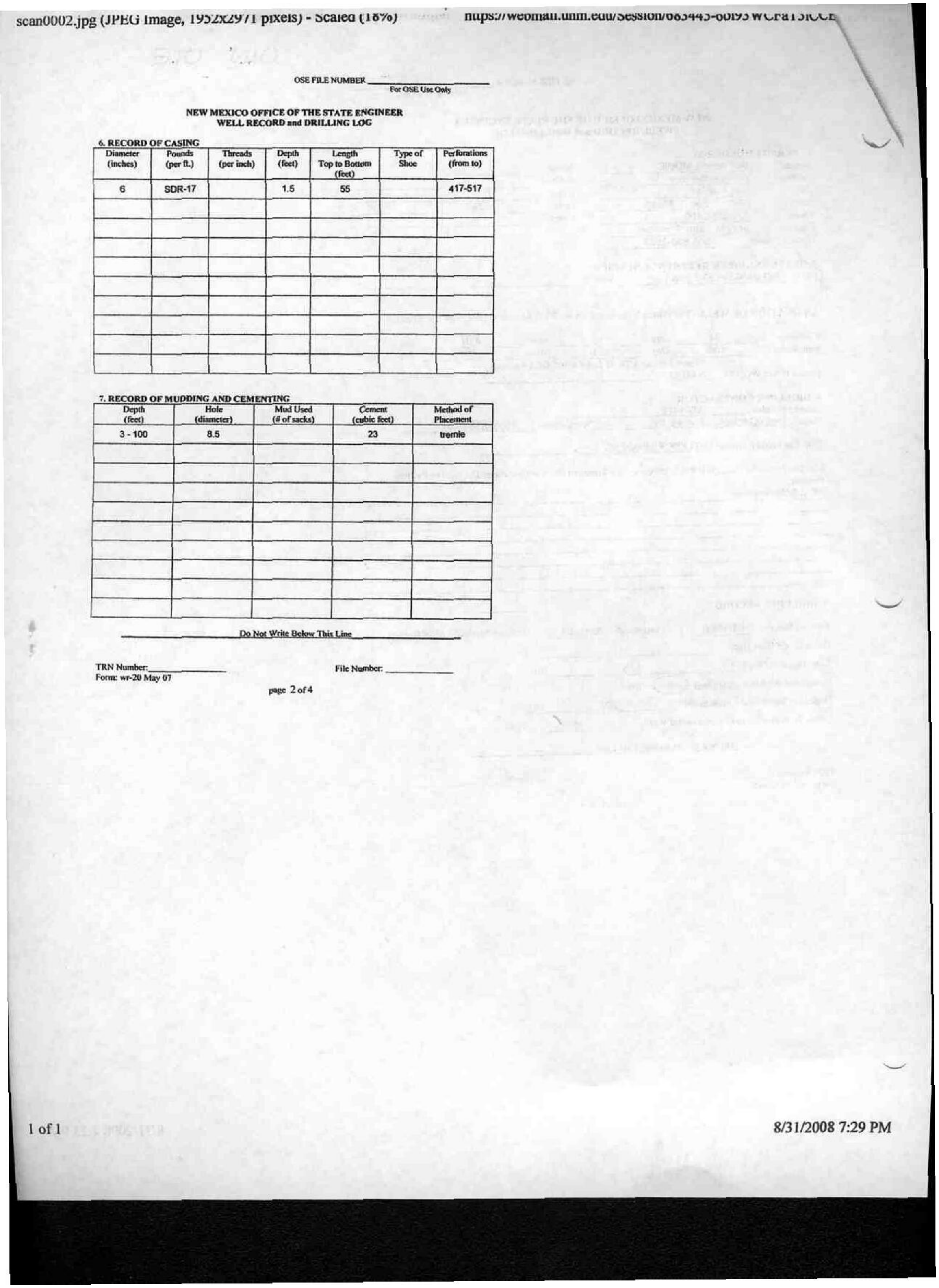
TRN Number: ____________ File Number: ____________
Form: wr-20 May 07

page 1 of 4

1 of 1 8/31/2008 7:25 PM



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NEW MEXICO OFFICE OF THE STATE ENGINEER
WELL RECORD and DRILLING LOG

6. RECORD OF CASING

Diameter (inches)	Pounds (per ft.)	Threads (per inch)	Depth (feet)	Length Top to Bottom (feet)	Type of Shoe	Perforations (from to)
6	SDR-17		1.5	55		417-517

7. RECORD OF MUDDING AND CEMENTING

Depth (feet)	Hole (diameter)	Mud Used (# of sacks)	Cement (cubic feet)	Method of Placement
3 - 100	8.5		23	tremie

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File Number: ____________

page 2 of 4

1 of 1

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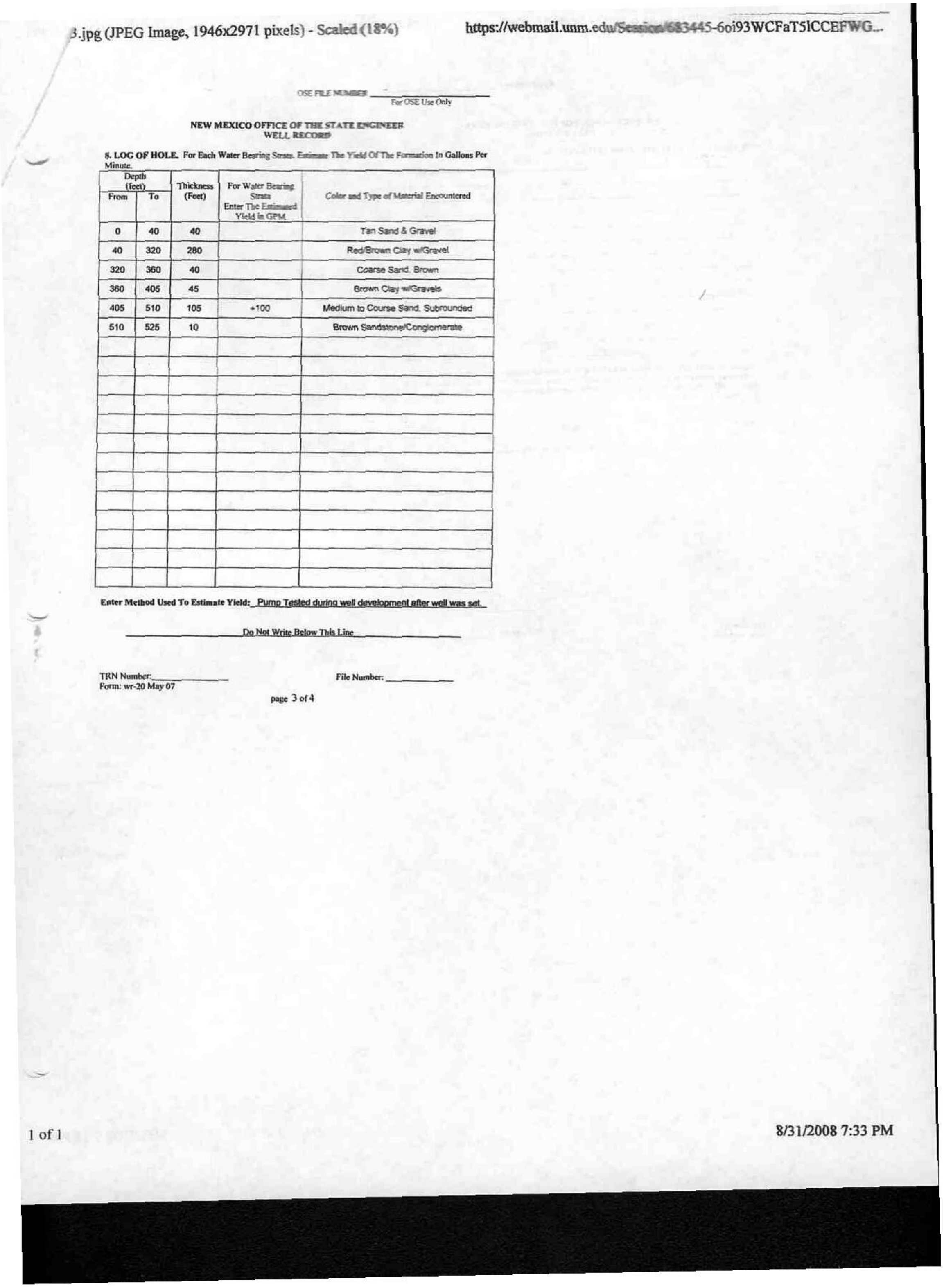

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NEW MEXICO OFFICE OF THE STATE ENGINEER
WELL RECORD

8. LOG OF HOLE. For Each Water Bearing Strata. Estimate The Yield Of The Formation In Gallons Per Minute.

Depth (feet)		Thickness (Feet)	For Water Bearing Strata Enter The Estimated Yield in GPM	Color and Type of Material Encountered
From	To			
0	40	40		Tan Sand & Gravel
40	320	280		Red/Brown Clay w/Gravel
320	360	40		Coarse Sand, Brown
360	405	45		Brown Clay w/Gravels
405	510	105	+100	Medium to Course Sand, Subrounded
510	525	10		Brown Sandstone/Conglomerate

Enter Method Used To Estimate Yield: Pump Tested during well development after well was set.

Do Not Write Below This Line

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Form: wr-20 May 07

File Number: ____________

page 3 of 4

1 of 1

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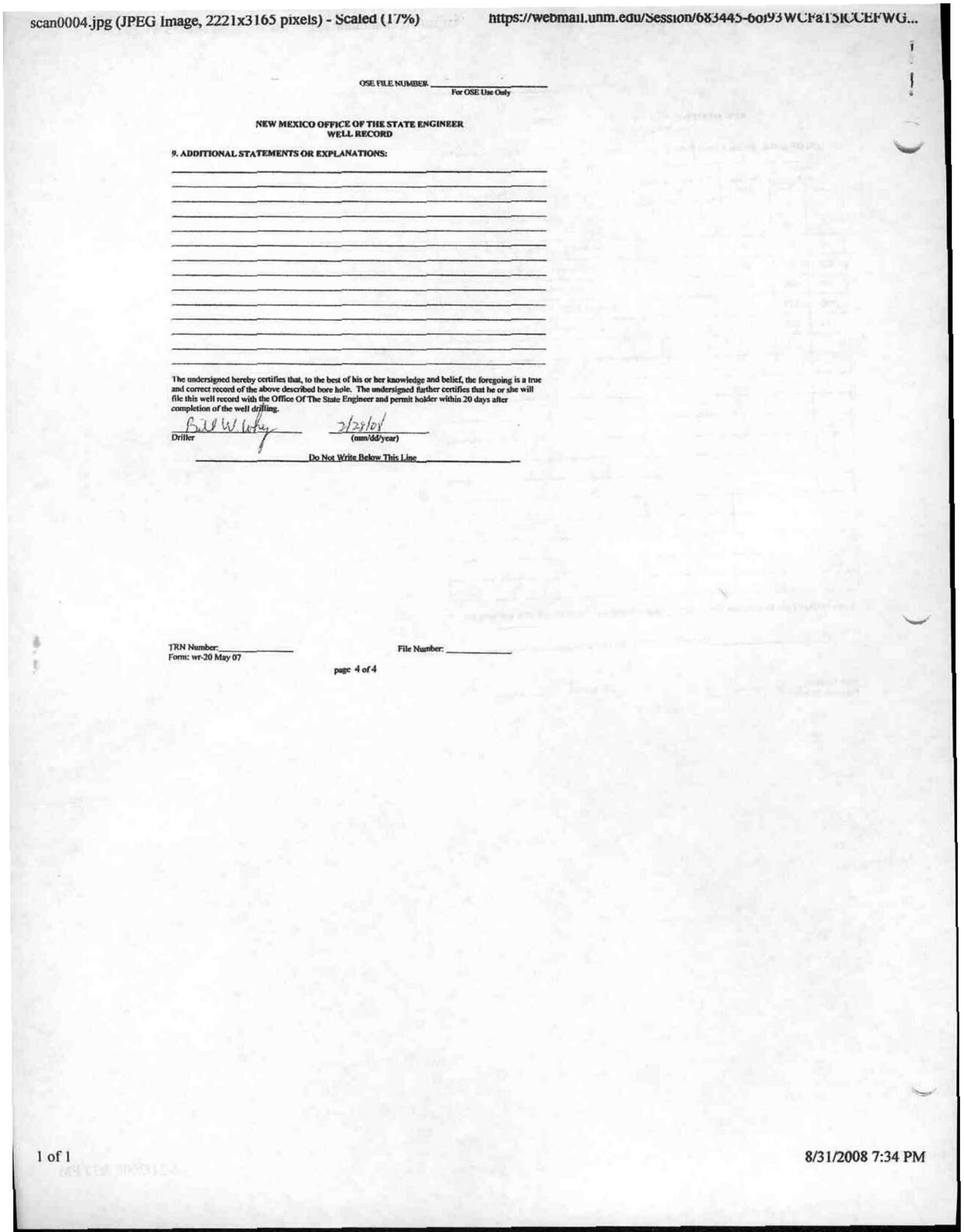

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For OSE Use Only

NEW MEXICO OFFICE OF THE STATE ENGINEER
WELL RECORD

9. ADDITIONAL STATEMENTS OR EXPLANATIONS:

The undersigned hereby certifies that, to the best of his or her knowledge and belief, the foregoing is a true and correct record of the above described bore hole. The undersigned further certifies that he or she will file this well record with the Office Of The State Engineer and permit holder within 20 days after completion of the well drilling.

Bill W [illegible] 2/28/08
Driller (mm/dd/year)

Do Not Write Below This Line

TRN Number:____________ File Number: ____________
Form: wr-20 May 07

page 4 of 4

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11 Appendix C – Directions

Directions to these sites were in most cases written from first-hand accounts by the author. They contain suggestions to the successful navigation of sometimes rough and often changing terrain. Within the Sevilleta NWR, the eastern side is generally well groomed, with the exception of the southern portion of Tomasino road. Most ‘roads’ on the western side are arroyos, with groomed roads appearing occasionally. A digitized map of the Sevilleta NWR roads is presented at the end of this section. This map is modified from the FWS map available in the FWS field station. Solid lines indicate either present roads or are not confirmed by the author as abandoned. Dashed lines are confirmed by the author as impassible. The author does not guarantee safe or continuous passage with the use of this map.

11.1 RSB Rio Salado Box Springs

Take San Acacia exit right, then straight, bear to left onto residential road. On the right will be a Sevilleta Gate (Alamillo Gate) next to house with several little dogs. You will drive through this guy’s yard. Two gates later, pass the Powerline road and continue in sand to Alamillo Road (left turn). At the first semi-fork, bear left. At highline road, bear right but don’t get on the highline road. You will pass a cross on the right. Take a right at the T where Alamillo continues to the right. Silver Creek road will be a ways down on the right. Follow it to the Rio Salado. Go up the Salado (west-northwest) and cross the Sevilleta boundary[***Permission required to drive up the Rio Salado***]. Continue straight. The springs are just outside and in the eastern most part of the Rio Salado box. RSB12 issues from the southern wall, RSB11 is in the arroyo.

11.2 SLS1, 3, 4 San Lorenzo Springs 1,3,4

Gate to Spring 45 minutes

Enter Alamillo Gate. Two gates later, pass the Powerline road and continue in sand to Alamillo Road (left turn). At the first semi-fork, bear left. At highline road, bear right but don't get on the highline road. You will pass a cross on the right. Take a left at the T where Alamillo continues to the right. The road will be quite rough. The spring is several tens of meters on the left before the barbwire Sevilleta fence that blocks the road. For SLS3 and 4, cross the barbwire fence (not in your car) and walk up the arroyo 130 meters to SLS3 and 530 meters to SLS4. One-way trip takes ~ 45 minutes. Sand is very hard to drive in.

11.3 SLS2 San Lorenzo Springs 2

Take San Acacia exit right to Frontage Road (make a left). Go under I 25 (left). Turn right onto next paved road that goes under I 25. Go W (mostly straight). Turn right into San Lorenzo Canyon (at sign and cattle guard). Continue straight-ish down canyon. You will pass a large unconformity of Santa Fe Group on the right. In the canyon, enter just west of grove of trees at the white spiral marker on the face of the rocks in the distance. Spring is just west of the spiral and is marked by several large trees (only ones nearby). Spring is just over the Sevilleta fence.

11.4 SC1 Silver Creek Seeps

Enter Alamillo Gate. Two gates later, pass the Powerline road and continue in sand to Alamillo Road (left turn). At the first semi-fork, bear left. At highline road, bear right but don't get on the highline road. You will pass a cross on the right. Take a right at the T where Alamillo continues to the right. Silver Creek road will be a ways down on the right. Follow that road to non-descript canyon pullover on right near SC1 coordinates [34.29063, -107.03484]. John Dewitt, Sevilleta LTER field station caretaker, knows the exact location. I would recommend having him drive you down there.

11.5 RS1 Rio Salado at Silver Creek

Enter Alamillo Gate. Two gates later, pass the Powerline road and continue in sand to Alamillo Road (left turn). At the first semi-fork, bear left. At highline road, bear right but don't get on the highline road. You will pass a cross on the right. Take a right at the T where Alamillo continues to the right. Silver Creek road will be a ways down on the right. Follow it to the Rio Salado.

11.6 SA1 Canyon del Ojito Spring

Gate to Parking ~15 minutes **Parking to Spring ~30 minutes**

Enter Alamillo Gate. Two gates later, pass the Powerline road and continue in sand to Alamillo Road (left turn). You will pass a Met station (tiltmeter and solar panel) on the right. Look for a place to pull over soon after that, you'll want to be on the west side of the station to walk to the canyon mouth. Walk north/northeast toward the canyon. In 10-15 minutes, you'll come to a topographic "bowl" visible on the topo map. Descend in and go west (to the left) into the canyon. It becomes narrow and tall and 15 minutes after entering the canyon, you'll come to a slot canyon. Up the shoot, you'll find a small pool (the spring) with an active source 1-2cm long, which stirs up the sand where it's entering the pool.

11.7 SanA (-S) San Acacia Pools

Highway Exit to Pool ~7 minutes

Take I-25 to San Acacia exit east. Take residential road straight. At T junction (drainage will be in front of you) take a left. Go straight past a cemetery on the left and through a white gate, past a trailer on the left that backs up to Indian Hill. The road curves right next to the railroad tracks follow it around and over the tracks at the RR x-ing sign. Make an immediate left and pass the dam on the right. The road forks right after the dam. Take the left one, *right* next to the railroad tracks on the east side. Follow the road until you reach a clearing on the other side of the tracks. Right at the beginning of the brine pool, the barbwire fence is down. Cross the tracks, going west, and the pool will be on the other side. To get out, drive up a bit to the gravel and execute a 10-point turn, or follow the road to Rio Salado (another 7 minutes from the brine pool) and turn around there (the NWR gate is down there as well). For the upper pool, walk north up the railroad tracks to the northernmost extent of the pool.

11.8 SdC1 Cibola Springs

Gate to Spring ~33 minutes

Take highway 60E. Enter at gate right after Black Butte (go south). Take either side of diamond to Tomasino Road. Spring is east down arroyo a little after Tomasino well and old structure on right.

11.9 SdC3 Milagro Seep

Enter at Black Butte Gate. Go straight down Five Points Road, follow straight onto Palo Duro Road. Follow straight onto Beacon Forks Road. At intersection, take a left onto Tomasino Road. Follow until road ends in arroyo. Walk up arroyo, past Milagro Wells, to water filled depression in arroyo, surrounded by salts.

11.10 WMW West Mesa Well

Gate to Well ~1 hour

Enter Alamillo Gate. Two gates later, pass the Powerline road and continue in sand to Alamillo Road (left turn). At the first semi-fork, bear left. At highline road, bear right but don't get on the highline road. You will pass a cross on the right. Take a right at the T where Alamillo continues to the right. Pass Silver Creek Road on right, continue straight at West Mesa Road (it's a circle). Right before you reach the western fence, the well is on the left.

11.11 BW Bronco Well

Gate to Well 12 minutes

Take I-25 to Highway 60 exit west. Take the interstate entrance ramp loop, turn right at the RV Park and Horse Motel (no joke) before reentering I-25. Continue straight across Rio Puerco Bridge and past a paved county road heading west. The Sevilleta gate will be directly in front of you. The A.T.T. road is the first right. Continue straight towards Ladron Peak, passing under several powerlines. Soon after you pass Bronco Road, the well will be on the left.

11.12 TUW Tule Well

Enter Sevilleta NWR as you would for Bronco Well. Pass BW and continue on A.T.T. road. The 222 road will appear on the right. Turn down 222 road; you will pass the Hanta Virus site (Biohazard). Continue several minutes down the road. The well is on the left.

11.13 EW Esquival Well

Gate to Well ~10 minutes

Take I-25 to San Acacia exit, turn west (right). Take the immediate right to a frontage road that goes north (parallel to I-25). The frontage road will dead end into the Sevilleta gate. Go through, and take the dirt road on the left (Esquival Road). Keep going straight. Fork to the right at the first fork. Drive straight through the 4-way intersection (head towards the Esquival sign). Once you come down from the mesa, you will cross under the power lines. Keep going straight. At the next fork, take the left, do not take the road heading for the power lines. At the next fork, take the right road and continue on the right towards the well.

11.14 CW Canyon Well

Take Black Butte Gate. Go straight onto Five Points Road and straight onto Palo Duro Road. There is a sign on the right for Canyon Well. The well is down that road on the right.

11.15 GW Gibbs Well

Gate to Well ~33 minutes

Take Black Butte Gate. Go straight onto Five Points Road, straight onto Palo Duro Road, then straight onto Beacon Forks Road. The well is off the road on the left.

11.16 TW Tomasino Well

Gate to Well ~27 minutes

Take Black Butte Gate. Take either side of diamond to Tomasino Road. Well is to the right of the road after old structure.

11.17 MW McKensie Well

Take Black Butte Gate. Turn left after Sev gate onto McKensie North. The well is at the corner of McKensie North and Test Well Road.

11.18 NW Nunn Well

Take Black Butte Gate. Turn left after Sevilleta gate and Firebreak road onto McKensie North. There will be a turn on the left to go north on Nunn road. The well is on the right on another unnamed right-bearing road a ways up.

11.19 GDW Goat Draw Well

Gate to Well 8 minutes

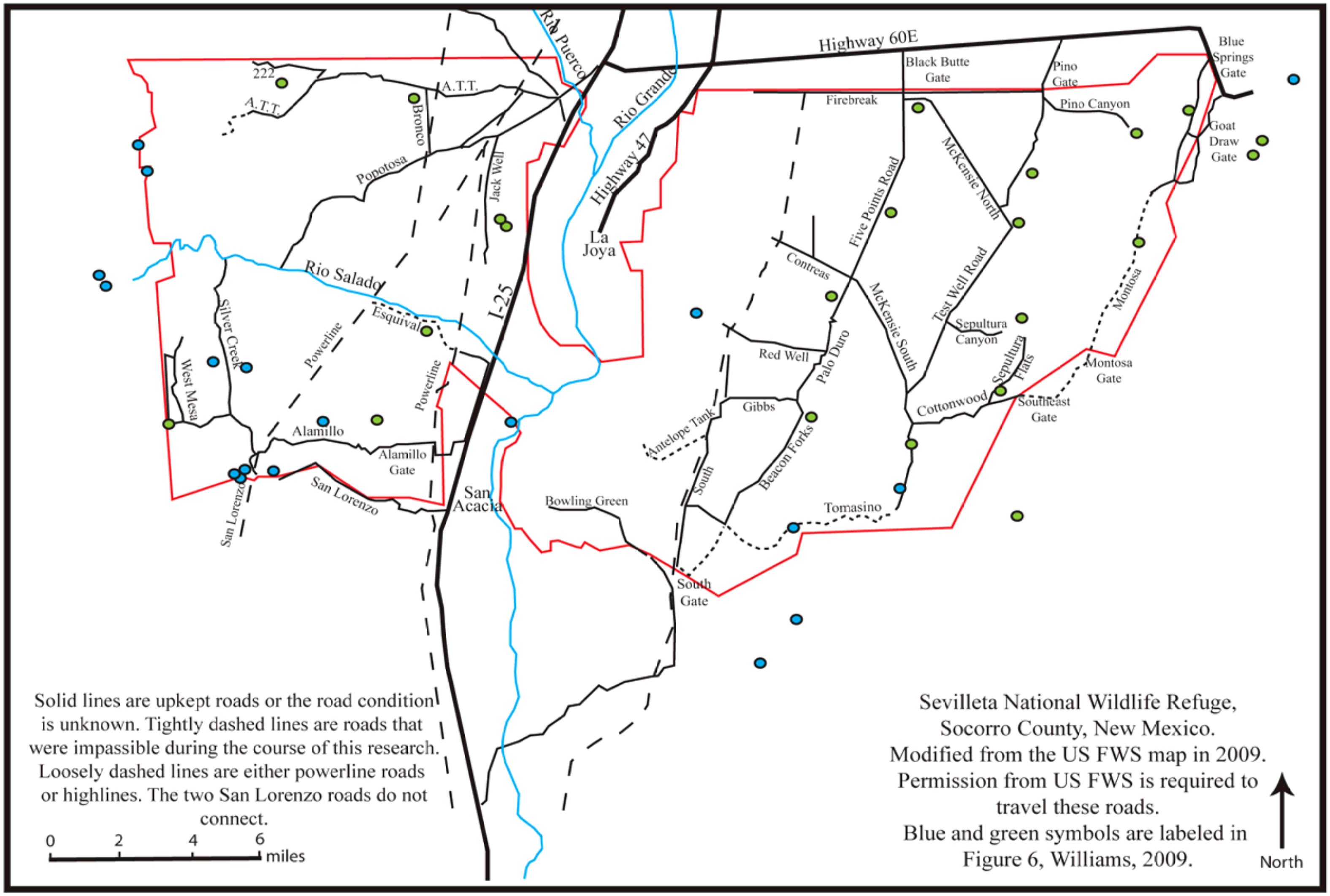
Take Highway 60E. Take the Blue Springs gate to Montoso Road (second gravel road on right- there is a Sevilleta sign on the gate). Go down arroyo ~2km. The well is on the right.

11.20 JS/BWS Jump Spring/ "Baca Well" Spring

These springs are located on the private ranch of Jay Santillanes. For contact information, please email the author.

11.21 DS/ BRW Dripping Springs/ Barella Well

This spring and well are located on the private land of Jean Sawyer-Rosas. For contact information, please email the author.



Solid lines are upkept roads or the road condition is unknown. Tightly dashed lines are roads that were impassible during the course of this research. Loosely dashed lines are either powerline roads or highlines. The two San Lorenzo roads do not connect.

Sevilleta National Wildlife Refuge, Socorro County, New Mexico. Modified from the US FWS map in 2009. Permission from US FWS is required to travel these roads. Blue and green symbols are labeled in Figure 6, Williams, 2009.