DIGITAL HYDROGEOLOGIC FRAMEWORK MODEL OF THE RINCON VALLEY AND ADJACENT AREAS OF DONA ANA, SIERRA AND LUNA COUNTIES, NM

John W. Hawley[1], John F. Kennedy[2], Marquita Ortiz[3], and Sean Carrasco[3]

[1]Senior Hydrogeologist, [2]Hydrogeologist/GIS Specialist, and [3]Student Assistants
New Mexico Water Resources Research Institute
New Mexico State University

For the: Lower Rio Grande Water Users Organization

Account Number 01-4-23914

June 2005

ADDENDUM TO:

CREATION OF A DIGITAL HYDROGEOLOGIC FRAMEWORK MODEL OF THE MESILLA BASIN AND SOUTHERN JORNADA DEL MUERTO BASIN

For the: Lower Rio Grande Water Users Organization

TECHNICAL COMPLETION REPORT NO. 332

Account Number 01-4-23987b

June 2004

INTRODUCTION

This CD-ROM *addendum* extends the area covered in our report on “Creation of a digital hydrogeologic framework model” of the Mesilla and southern Jornada del Muerto Basins (NMWRRI TCR#332; red rectangle on map *insert*-p. xviii) to the northern end of Rincon Valley (Caballo Dam) and adjacent parts of the southern Palomas Basin (Fig. 1-1 [P]; blue rectangle on map *insert*). The expanded study area includes the valley of the Rio Grande between Caballo Reservoir and Leasburg Dam, and the Uvas Valley at the southern end of the Palomas Basin southwest of Hatch. The latter locality is also part of the “Nutt-Hockett *basin*,” a New Mexico Office of the State Engineer *closed* groundwater-basin administrative unit. In addition, note that we arbitrarily place the boundary between the “middle” and “southern” Jornada Basins in the general area of the Sierra-Doña Ana County Line and Point of Rocks northeast of the Rincon Hills. As in the main body of the report text, our characterization of this complex intermontane-basin and river-valley geohydrologic system emphasizes the lithofacies composition (**LFA**s) and structural framework of basin-fill and contiguous bedrock hydrostratigraphic units (**HSU**s, Figs. 3-3, 3-4).

The expanded digital model of the Rincon Valley study area includes surficial hydrogeologic and well-location maps (Plates R1 and R2), a structure-contour map showing the general topography of bedrock units beneath Santa Fe Group basin fill (Plate R3), and seven hydrogeologic cross sections. The latter schematic diagrams (base elevation—1,000 ft asl, 10x vertical exaggeration) comprise six transverse-basin/valley sections (Plate R4: RA-RA’, RB-RB’, RC-RC’, RD-RD’, RE-RE’, and RF-A-A’) and one down-valley (longitudinal) section (Plate R5: CD-LD-LC) that extends from Caballo Dam to Las Cruces (via Leasburg Dam). Section CD-LD-LC connects with Section O-O’, which continues down the Mesilla Valley to the International Boundary zone of the southern Mesilla Basin between El Paso del Norte and Santa Teresa (Plate 5c). In addition, section CD-LD-LC forms fence-diagram connections with transverse-basin sections RF-A-A’, B-B’, C-C’, and D-D’ in the Selden Canyon-southern Jornada Basin-northern Mesilla Valley area (Plates 1 to 3, 7, R1 to R5).

The CD-ROM *addendum* also contains updated versions of Tables A1 to A4 (341 well-control points) and a new subsurface data-base (Table A5) with records of 78 reference wells in the Rincon Valley area of Doña Ana, Sierra and Luna Counties (Plate R2). With this addition, our hydrogeologic-data compilation now includes aquifer-specific and more general information on basin-fill/bedrock hydrostratigraphy and geohydrology for 419 wells in the Mesilla-Jornada-Palomas Basin region. The hydrogeologic and bedrock-topography maps (Plates 1, 7, R1, R3) and cross sections (Plates 3 to 6, R3, R5) are based on published research and our own interpretations of the best-available geological, geophysical and geochemical information in cited publications (Tables A1 to A5; *Addendum* Selected References). They illustrate not only current progress in digital hydrogeologic-model development, but also many areas where a variety of more-detailed subsurface investigations are still needed.

Reviews of this document by Scott Anderholm, U.S. Geological Survey; John Shomaker, John Shomaker & Associates; Nabil Shafik and John Gillentine, New Mexico Interstate Stream Commission/New Mexico Office of the State Engineer; and Francis West, retired New Mexico Office of the State Engineer are greatly appreciated.

HYDROGEOLOGIC SETTING OF THE RINCON VALLEY AREA

OVERVIEW

The following discussions emphasize the hydrogeologic framework of the Rincon Valley and Selden Canyon of the Rio Grande as well as adjacent parts of the southern Palomas and Jornada (structural) basins of the Rio Grande rift tectonic province (Fig, 1-1, map *insert*-p. xviii, Plates R1-R5). As in other intermontane basins of the rift region, the primary basin-fill unit is the Santa Fe Group, with Upper and Middle Santa Fe HSUs (USF/MSF) forming the bulk of exposed deposits (Hawley and Kernodle 2000, Connell et al. 2005). Major features of the southern Jornada Basin east of the Rincon Valley and Selden Canyon are described in the report text (p. 8, 9, 33-36, 39, 40, 45, 53, 54, 65-68, 75, 76, 80, 81, 86). However, the CD-ROM *Addendum* now also includes an additional brief synopsis of basin hydrogeology in the south-central part of the Jornada structural depression near Flat Lake playa and the Point of Rocks-Upham Hills volcanic uplands (Plates R1, R3, R4e, R4f). This part of the Basin is topographically *closed*; but, in terms of groundwater flow it is a *drained basin* that discharges to the lower Rincon Valley reach (Section 7.3.2).

Geologic studies of the Palomas Basin-Rincon Valley area date back to the 1930's (see Kelley and Silver 1952, Hawley 1978), but the publications cited herein are limited to those with direct application to development of our digital hydrogeologic model (e.g. Clemons 1979, Clemons and Seager 1973, Conover 1954, Davie and Spiegel 1967, Hawley et al. 1969, King et al. 1971, Lozinsky and Hawley 1986, Mack and Seager 1990, Ross and Witcher 1998, Seager 1975, 1981, Seager and Hawley 1973, Seager and Mack 1991, 2003, Seager et al. 1971, 1975, 1982, 1987, Wilson et al. 1981, Witcher 1991, 1998, Witcher et al. 2003).

As noted in Section 1.3.4, the Rio Grande is the only significant surface-water resource in the region. The river and associated shallow alluvial deposits of its inner valley also served as the ultimate discharge zone for pre-development groundwater flow from adjacent basins and uplands (Conover 1954, King et al. 1971, Wilson et al. 1981). Drainage basin area of the river above Caballo Dam is about 27,700 mi^2. Rincon Valley is about 32 miles long and maximum valley-floor width (floodplain and lowest river terraces) ranges from one to two miles. Floodplain elevation is about 4,160 ft at Caballo Dam and 4,100 ft at the lower end of the Valley near San Diego Mountain (Tonuco uplift). The Rincon and Mesilla Valleys are linked by Selden Canyon (Plate R5), a narrow meandering-valley reach that is deeply entrenched in Tertiary volcanic and sedimentary rocks of the Selden Hills uplift. The "Canyon" is about six miles long and ends at Leasburg Dam (Radium Springs-Fort Selden area), where floodplain elevation is about 4,060 ft.

The most striking hydrogeologic difference between the eastern Mesilla Basin and the Rincon Valley-Selden Canyon area, including adjacent parts of the southern Palomas and Jornada Basins (Plates R1 and R3), is the very limited extent of major aquifer zones in Santa Fe HSUs north of the Doña Ana and Robledo Mountains, and Sierra de las Uvas. The only large area of productive aquifers is located in the west-central part of the Palomas Basin between the Animas uplift and upper Rincon Valley. There, stream-channel lithofacies assemblages (LFAs 5-7) are major constituents of Upper and Middle Santa Fe HSUs (USF1/USFc/MSF1). See Davie and Spiegel (1967), Wilson and others (1981, p. 28-30), Seager and others (1982), and Plate 4a (section RA-RA'). Also, unlike the eastern Mesilla Basin, the Rincon Valley study area is structurally higher and Upper

Santa Fe Gp ancestral-river facies (USF2; LFAs 1-3) are thinner; so most basin-fill units with high hydraulic-conductivity potential are in the vadose zone.

On the plus side of the groundwater-resource *equation* is the well-documented occurrence of productive bedrock-aquifer units (initially *artesian*) in basaltic to silicic volcanic and volcaniclastic rocks beneath fine-grained basin fill of the Uvas Valley (Nutt-Hockett *basin*) area (Clemons 1979). The inferred extent and structure of these units (Tba, Tmr, Tmrs, Tmrp) is shown on Plates 4a to 4f as well as in the general vicinity of *zones* where these cross sections intersect buried bedrock surfaces illustrated on Plate R3. However, this is clearly still an area of hydrogeologic *speculation* on our part because *modern* groundwater exploration outside the Nutt-Hockett *basin* has been limited to only a few test wells in the 500 to 1,200-ft depth range (Wilson et al. 1981). The following comments illustrate hydrogeologic features that define specific parts of the study area.

SOUTHERN PALOMAS BASIN AND RINCON VALLEY

With respect to its Rio Grande rift tectonic setting, the Palomas Basin is an east-tilted half-graben to full-graben (fault-block) depression located between the Black Range and Mimbres Mountains (west) and the Caballo-Red Hills-Derry Hills uplift (map *insert*-p. xviii; Plates R1, R3, R4a-d). Uvas Valley, at the southwestern end of the Basin, is formed by a north-plunging syncline between the Good Sight Mountains (west) and the Sierra de las Uvas (east). The major landforms of the southern Palomas Basin comprise deeply entrenched valleys of the Rio Grande (Rincon Valley) and a few large tributary streams with headwaters in Black Range and Mimbres Mountains. The watershed of the three major streams in the latter area (Trujillo, Tierra Blanca and Berrenda Creeks) is about 280 mi^2; and highest elevations of the Rio Grande-Mimbres River drainage divide range from 7,934 (Thompson Cone) to 9,669 feet (Sawyers Peak).

Broad interfluve-tablelands (mesas) are the dominant landscape features of the west-central part of the Palomas Basin. They are remnants of piedmont slopes graded to ancestral-Rio Grande base levels as much as 400-500 ft above the present Rincon Valley floor (Hawley and Kottlowski 1969). Most valleys are cut in Upper Santa Fe Group basin fill (Palomas Fm of Lozinsky and Hawley 1986); and the only large area where constructional surfaces on ancient basin-floor deposits are well preserved is in the Uvas Valley southwest of Hatch (map *insert*-p. xviii). There, the Upper Santa Fe hydrostratigraphic unit (Camp Rice Fm of Hawley et al. 1969) is undissected and is buried by playa-lake and eolian sediments in a large *closed* depression (15 mi^2; 4,445-4,500 ft elev.) that was formerly inundated by Lake Goodsight during Late Quaternary glacial-pluvial intervals (Plate R1; Hawley 1965, 1993, Hawley and Kottlowski 1969, Clemons 1979, Hawley et al. 2000).

The basic hydrogeologic framework of the Rincon Valley *corridor*, is illustrated by cross sections RA-RA' to RF-A-A' (Plates R4a-R4f); and down-valley perspective from Caballo Dam to Selden Canyon is provided by the northwestern part of section CD-LD-LC (Plate R5 to section RF-A-A'). The essential hydrogeologic characteristic of this part of the study area is the absence of any significant basin-fill aquifer unit beneath the thin (<100 ft) alluvial fill of the inner river valley (HSU RA, LFA a; Table A5). Test drilling near Percha Dam (16.5W.36.344; USGS-1,200 ft) and Rincon (19.2W.17.431; USGS-500 ft), and the Hatch cotton-gin site (19.3W.9.411; ~2,000 ft) document the presence of a very thick sequence of fine-grained basin-floor sediments (mostly playa-lake) of the Middle Santa Fe HSU (LFAs 9, 10, 3) below the inner-valley fill (King et al. 1971, Wilson et al. 1981). However, as noted in the preceding Overview, Santa Fe Group deposits throughout this part of the Palomas Basin are immediately underlain by volcanic and volcaniclastic rocks with significant aquifer potential (Tba, Tmr, Tmrs, Tmrv; e.g. Uvas basaltic andesite, Bell Top Fm, Thurman Fm, and Kneeling Nun rhyolite). Our maximum depth-of-burial estimates for these confined-aquifer units is only about 2,500 ft (Plate R5); and piezometric *heads* should be near or locally above land surface in many parts of the Valley.

SELDEN CANYON

Selden Canyon of the Rio Grande extends from the southern Tonuco uplift (San Diego Mountain) to Leasburg Dam (near Radium Springs and Fort Selden; map *insert*-p. xviii). Cross section CD-LD-LC (Plate 5) between sections RF-A-A' (Plates 4a, R4f) and B-B' (Plate 4b) and the updated bedrock-topography map (Plate R3) illustrate the abrupt thinning to complete erosion of Santa Fe Gp deposits in the inner Canyon area. Moreover, the basaltic to silicic volcanic rocks with significant aquifer potential in the Rincon Valley-Palomas Basin area have also been almost completely removed during Pleistocene episodes of river-valley incision. Since underlying Lower Tertiary volcaniclastic and sedimentary rocks (Tlvs/Tls) have a fine-grained, well-indurated matrix, these very thick bedrock sequences (e.g. Palm Park/Love Ranch Fms) form major aquicludes rather than aquifers (King et al.1971; Seager 1975, Seager et al. 1975, Wilson et al. 1981). As already noted (Sections 7.3.2, 8.2.7), effects of the abrupt termination of the deeply circulating regional groundwater-flow system in the Rincon to Radium Springs reach of lower Rincon Valley and Selden Canyon, and resulting occurrence of significant local geothermal groundwater resources were not investigated in the present study (see Ross and Witcher 1998, Witcher 1988, 1991, 1995, 1998, Witcher et al. 2003).

JORNADA DEL MUERTO BASIN

In the south-central part of the Jornada structural depression near the Doña Ana-Sierra County Line (map *inset*-p. xviii), cross sections RE-RE' and RF-A-A' (Plates R4e, f), and our new bedrock-topography map (Plate R3) document the abrupt thinning and fine-grained texture (LFAs 9,3) of Santa Fe Group HSUs (mainly MSF2). Deeper wells in the vicinity of Flat Lake playa, Jornada Draw, Point of Rocks, and the Upham-Prisor Hills (Plates R1 and R2, Table A5, 17.1E.30.142) probably produce from localized aquifers in Middle and Lower Santa Fe HSUs as well as fracture zones in shallowly buried volcanic and volcaniclastic rocks of mid-Tertiary age (Tba/Tmrs—Uvas basaltic andesite and Bell Top Fm of Seager et al. 1987).

The combined watersheds of the two main tributaries to Flat Lake playa (elev. 4,345-4,350 ft), Jornada Draw and Gilmore Draw, have an area of about 690 mi^2. Gypsum, however, is a significant component of the bedrock and basin-fill terranes that contribute to surface and subsurface flow systems; and groundwater reservoirs throughout this part of the Jornada Basin are therefore slightly saline at best. As noted in Sections 7.1 and 7.3.2 (p. 67, 75), the relatively small component of groundwater-underflow discharge from the entire central and southern Jornada Basin area that does contribute to the lower Rincon Valley flow system enters the Rio Grande Valley through the "structural gap between the Tonuco uplift (San Diego Mountain) and the Rincon Hills" (Plate R3, near section RE-RE' [Plate 4e]). The only large surface- and subsurface-flow system in the south-central part of the Jornada Basin that discharges *directly* to the Rio Grande Valley is the one associated with Rincon Arroyo. It has a watershed of about 110 mi^2 and heads in the southeastern Caballo Mountains and western Point of Rocks.

The deepest exploration well in the study area, the 11,650-ft Exxon No. 1-Prisor oil test (Plate R2, Table A5, 16.1E.29.124) is also adjacent to the Upham-Prisor Hills uplift about 8 mi east of Upham railroad siding (map *inset*-p. xviii). Here, basin fill is only 250 ft thick; and it is underlain by a 4,650-ft (*aquiclude*) sequence of mostly fine-grained volcaniclastic rocks of Early Tertiary to Late Cretaceous age (Tlvs/Tls/K—Palm Park, Love Ranch and McRae Fms, Seager et al. 1987-well 25). However, it is important to note that a thick (>1,000 ft) section of middle Pennsylvanian carbonate rocks with zones of cavernous porosity probably occurs at depths of 5,000 to 6,000 ft below land surface near Upham. Since *brackish* geothermal groundwater in this very deep aquifer system may be moderately saline locally (e.g., <5,000 mg/L) and under high artesian pressure, it could ultimately prove to be a significant water resource. These very speculative comments are inserted at the conclusion of this *addendum*, primarily because the Upham area is the designated site of the future National Spaceport (King et al. 1996).

SELECTED REFERENCES

Clemons, R.E. 1979. *Geology of Good Sight Mountains and Uvas Valley, southwest New Mexico*. New Mexico Bureau of Mines and Mineral Resources, Circular 169. 32 p.

Clemons, R.E. and W.R. Seager. 1973. *Geology of Souse Springs Quadrangle, Doña Ana County, New Mexico*. New Mexico Bureau of Mines and Mineral Resources, Bulletin 100. 31 p.

Connell, S.D., J.W. Hawley, and D.W. Love. 2005. Late Cenozoic drainage development in the southeastern basin and range of New Mexico, southeasternmost Arizona, and western Texas. In *New Mexico's Ice Ages.* Edited by S.G. Lucas, G.S. Morgan, and K.E. Zeigler. New Mexico Museum of Natural History and Science, Bulletin 28. 125-150.

Conover, C.S. 1954. *Ground-water conditions in the Rincon and Mesilla Valleys and adjacent areas in New Mexico.* U.S. Geological Survey Water-Supply Paper 1230. 200 p.

Davie, C.H. and Z. Spiegel. 1967. *Geology and water resources of the Rincon and Las Animas Creek and vicinity, Sierra County, New Mexico.* New Mexico State Engineer Hydrographic Survey Report. 44 p.

Hawley, J.W. 1965. Geomorphology surfaces along the Rio Grande Valley from El Paso, Texas to Caballo Reservoir, New Mexico. *New Mexico Geological Society, 16th Annual Field Conference Guidebook*. 188-198.

Hawley, J.W. (compiler). 1978. *Guidebook to the Rio Grande Rift in New Mexico and Colorado*. New Mexico Bureau of Mines and Mineral Resources, Circular 163. 241 p.

Hawley, J.W. 1993. Geomorphologic Setting and Late Quaternary History of Pluvial-lake Basins in the Southwestern New Mexico Region. New Mexico Bureau of Mines and Mineral Resources Open File Report 391. 28 p.

Hawley, J.W., B.J. Hibbs, J.F. Kennedy, B.J. Creel, M.D. Remmenga, M. Johnson, M. Lee, and P. Dinterman. 2000. Trans-International Boundary aquifers in southwestern New Mexico. New Mexico Water Resources Research Institute, New Mexico State University, prepared for U.S. Environmental Protection Agency-Region 6 and International Boundary and Water Commission; Technical Completion Report-Interagency Contract X-996350-01-3. 126 p.

Hawley, J.W. 2005. Five million years of landscape evolution in New Mexico: An overview based on two centuries of geomorphic conceptual-model development. In *New Mexico's Ice Ages.* Edited by S.G. Lucas, G.S. Morgan, and K.E. Zeigler. New Mexico Museum of Natural History and Science, Bulletin 28. 9-93.

Hawley, J.W. and J.M. Kernodle. 2000. Overview of the hydrogeology and geohydrology of the northern Rio Grande basin – Colorado, New Mexico, and Texas. In *Proceedings of the 44th Annual New Mexico Water Conference: The Rio Grande Compact: It's the Law.* Edited by C.T. Ortega Klett. New Mexico Water Resources Research Institute Report No. 310. 46-38.

Hawley, J.W. and F.E. Kottlowski. 1969. Quaternary geology of the south-central New Mexico border region. In *Border Stratigraphy Symposium*. New Mexico Bureau of Mines and Mineral Resources, Circular 104. 89-115.

Hawley, J.W., F.E. Kottlowski, W.S. Strain, W.R. Seager, W.E. King, and D.V. LeMone. 1969. The Santa Fe Group in the south-central New Mexico border region. In *Border Stratigraphy Symposium*. New Mexico Bureau of Mines and Mineral Resources, Circular 104. 52-76.

Kelley, V.C. and C. Silver. 1952. *Geology of the Caballo Mountains.* University of New Mexico, Publications in Geology, No. 5, 286 p.

King, J.P., A.S. Bawazir, and M.W. Wentzel. 1996. *Water supply preliminary evaluation: New Mexico Spaceport*. New Mexico Water Resources Institute, Special Contract Completion Report, New Mexico State University, Las Cruces.

King, W.E., J.W. Hawley, A.M. Taylor, and R.P. Wilson. 1971. *Geology and Ground-water Resources of Central and Western Doña Ana County, New Mexico*. New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 1. 64 p.

Leeder, M.R., G.H. Mack, and S.L. Salyards. 1996. Axial—transverse fluvial interactions in half-graben: Plio-Pleistocene Palomas Basin, southern Rio Grande Rift, New Mexico, USA. *Basin Research.* 12: 225-241.

Leeder, M.R., G.H. Mack, J. Peakall, and S.L. Salyards. 1996. First quantitative test of alluvial stratigraphic models: Southern Rio Grande rift, New Mexico. *Geology.* 24. 1: 87-90.

Lozinsky, R.P. and J.W. Hawley. 1986. The Palomas Formation of south-central New Mexico—a formal definition. *New Mexico Geology.* 8:4:73-82.

Mack, G.H. and W.R. Seager. 1990. Tectonic controls on facies distribution of the Camp Rice and Palomas Formations (Pliocene-Pleistocene) in the southern Rio Grande rift. *Geological Society of America Bulletin.* 102: 45-53.

Mack, G.H., G.S. Austin, and J.M. Barker (editors). 1998, Las Cruces Country II. *New Mexico Geological Society, 49th Field Conference Guidebook*. 325p.

Mack, G.H., F.E. Kottlowski, and W.R. Seager. 1998. The stratigraphy of south-central New Mexico. *New Mexico Geological Society, 49th Field Conference Guidebook*. 135-153.

Mack, G.H., S.L. Salyards, and W.C. James. 1993. Magnetostratigraphy of the Plio-Pleistocene Camp Rice and Palomas formations in the Rio Grande rift of southern New Mexico. *American Journal of Science.* 293: 49-77.

Mack, G.H., S.L. Salyards, W.C. McIntosh, and M.R. Leeder. 1998. Reversal magnetostratigraphy and radioisotopic geochronology of the Plio-Pleistocene Camp Rice and Palomas Formations, southern Rio Grande rift. *New Mexico Geological Society, 49th Annual Field Conference Guidebook.* 229-236.

O'Neill, J.M. (editor). 2002. *Geologic investigations in the Lake Valley area, Sierra County, New Mexico*. U.S. Geological Survey, Professional Paper 1644, 4 Chapters, 1 plate, 78 p.

Ross, H.P. and J.C. Witcher. 1998. Self-potential surveys of three geothermal areas in the southern Rio Grande rift, New Mexico. *New Mexico Geological Society, 49th Annual Field Conference Guidebook.* 93-100.

Seager, W.R. 1975. *Geologic map of the southern half of San Diego Mountain fifteen-minute quadrangle* [*Doña Ana County*], *New Mexico.* New Mexico Bureau of Mines and Mineral Resources Geologic Map GM-35, scale 1:24,000.

Seager, W.R. 1981. *Geology of the Organ Mountains and southern San Andres Mountains, New Mexico*. New Mexico Bureau of Mines and Mineral Resources, Memoir 36. 97 p.

Seager, W.R. and J.W. Hawley. 1973. *Geology of Rincon quadrangle, New Mexico.* New Mexico Bureau of Mines and Mineral Resources, Bulletin 102. 56 p.

Seager, W.R. and G.H. Mack. 1991. *Geology of the Garfield quadrangle, Sierra and Doña Ana Counties, New Mexico*. New Mexico Bureau of Mines and Mineral Resources, Bulletin 128. 24 p.

Seager, W.R. and G.H. Mack. 2003. *Geology of the Caballo Mountains, New Mexico*. New Mexico Bureau of Mines and Mineral Resources, Memoir 49. 136 p.

Seager, W.R., R.E. Clemons and J.W. Hawley. 1975. *Geology of Sierra Alta Quadrangle, Doña Ana County, New Mexico.* New Mexico Bureau of Mines and Mineral Resources, Bulletin 102. 56 p.

Seager, W.R., J.W. Hawley, and R.E. Clemons. 1971. *Geology of San Diego Mountain area, Doña Ana County, New Mexico.* New Mexico Bureau of Mines and Mineral Resources, Bulletin 97. 38 p.

Seager, W.R., R.E. Clemons, J.W. Hawley, and R.E. Kelley. 1982. *Geology of northwest part of Las Cruces 1º x 2º sheet, New Mexico, New Mexico*. NM Bureau of Mines and Mineral Resources Geologic Map GM-53, scale 1:125,000.

Seager, W.R., J.W. Hawley, F.E. Kottlowski, and S.A. Kelley. 1987. *Geology of the east half of Las Cruces and northeast El Paso 1º x 2º sheets, New Mexico*. New Mexico Bureau of Mines and Mineral Resources Geologic Map GM-57, scale 1:125,000.

Wilson, C.A., R.R. White, R.B. Orr, and R.G. Roybal. 1981. *Water Resources of the Rincon and Mesilla Valleys and Adjacent Areas.* New Mexico State Engineer Technical Report 43. 514 p.

Witcher, J.C. 1988. Geothermal resources of southwestern New Mexico. *New Mexico Geological Society, 39th Annual Field Conference Guidebook.* 191-197.

Witcher, J.C. 1991. *The Rincon geothermal system, southern Rio Grande rift, New Mexico; a preliminary report on a recent discovery*. Transactions, Geothermal Resources Council. 15: 205-212.

Witcher, J.C. 1995. *A geothermal resource database of New Mexico*. Southwest Technology Development Institute, New Mexico State University, Las Cruces, 28 p.

Witcher, J.C. 1998. The Rincon SLH 1 discovery well. *New Mexico Geological Society, 49th Annual Field Conference Guidebook.* 93-100.

Witcher, J.C., J.P. King, J.W. Hawley, J.F. Kennedy, J. Williams, M. Cleary, and L. Bothern. 2003. *Sources of Salinity in the Rio Grande and Mesilla Basin Groundwater*. New Mexico Water Resources Institute, Technical Completion Report No. 330, New Mexico State University, Las Cruces, 168 p., 9 plates, 3 appendices.