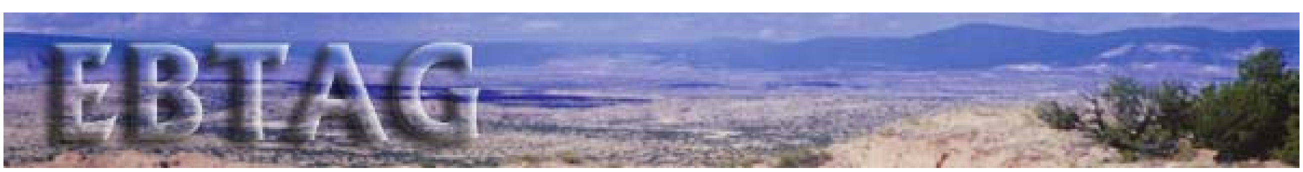
Geology and Hydrology of the Española Basin -- Proceedings of the 7th Annual Española Basin Workshop, Santa Fe, New Mexico, March 6, 2008

Ardyth Simmons, editor

New Mexico Bureau of Geology and Mineral Resources

Open-File Report 513

February, 2009



A product of the Española Basin Technical Advisory Group (EBTAG)

7th Annual Española Basin Workshop

Geology and Hydrology of the Española Basin

March 6, 2008 Santa Fe, NM
Santa Fe Community College

In Memory of Zane Spiegel (1926 – 2008)

PROGRAM AND PRELIMINARY ABSTRACTS

Hosted by EBTAG (Española Basin Technical Advisory Group)

An ad hoc group of technical people who represent government and academic organizations conducting geologic, geophysical, and hydrogeologic studies related to understanding of the Española groundwater basin.

City of Santa Fe

Jemez Y Sangre Water Planning Council

Los Alamos National Laboratory

New Mexico Bureau of Geology and Mineral Resources

New Mexico Office of State Engineer

New Mexico Environment Department

Santa Fe County

Española Basin Regional Planning Issues Forum (EBRPIF)

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Geology and Hydrology of the Española Basin
7th Annual Española Basin Workshop

Thursday, March 6, 2008
Jemez Room, Santa Fe Community College, Santa Fe, New Mexico

PROGRAM

Registration
7:30-8:30 am Pick up badges, programs and sign in; poster set up and viewing

Introductory Remarks
8:30-8:40 am ***Welcome and Introduction to EB Workshop and the Española Basin Technical Advisory Committee (EBTAG):*** Claudia Borchert, EBTAG chair

Tribute to Zane Spiegel, Father of Santa Fe Area Geology
8:40-8:50 am Born November 6, 1926, died , February 25th, 2008

Invited Presentations

8:50-9:15 am ***Updated 3D Model of the Geological and Geophysical Framework of the Southern Española Basin near Santa Fe, New Mexico:*** Mark Hudson and Tien Grauch, USGS

9:15-9:40 am ***A Preliminary Hydrogeologic Framework of the Santa Fe Area:*** Peggy S. Johnson and Daniel J Koning, NM Bureau of Geology and Mineral Resources

9:40-10:05 am ***Applications of Carbon-14 Ground-water Dating in Hydrologic and Geochemical Studies of the Regional Aquifer, Pajarito Plateau, New Mexico:*** Patrick A. Longmire, LANL

10:05-10:20 am **Coffee Break**

10:20-10:45 am ***Modeling Flow and Transport on the Pajarito Plateau:*** Ardyth Simmons and Danny Katzman, LANL

10:45-11:10 am ***Hydrologic Analysis of a Proposal to Expand the Buckman Well Field:*** Tom D. Morrison

11:10-11:35 am ***Applying Hydrology to Water Resource Management: The City of Santa Fe Buckman Wells 10-13 Groundwater Monitoring Program:*** Claudia I. Borchert, City of Santa Fe

11:35-12:00 ***Utilization of EBTAG Data to Support the Santa Fe County Well Drilling Program:*** Karen M. Torres, Santa Fe County

12:00-1:15 pm **Lunch Break** (food available for purchase at the cafeteria next door)

1:15-1:40 pm ***Hydrologic Analyses of the Santa Fe River Watershed in Support of River Restoration Projects:*** Susan Gant, US Army Corps of Engineers

1:40-2:05 pm ***Hydraulic Analyses of 7 miles of the Santa Fe River in Support of River Restoration Projects:*** Lisa A. Shoaff, US Army Corps of Engineers

2:05 – 2:30 pm ***An Exploration Drilling Project in the Rio Puerco Valley and an Unresolved Geologic Puzzle***: Dirk Van Hart

Poster Session and EBTAG Membership Discussion (concurrent)
2:30 -6:00 pm **Poster Viewing** (North Jemez Room)
3:00- 3:30 pm **Discussion on expanding membership to and participation in EBTAG** (South Jemez Room)

SOME SEMINAL REFERENCES ON THE HYDROGEOLOGY OF THE RIO GRANDE RIFT REGION, NEW MEXICO, AUTHORED OR CO-AUTHORED BY ZANE E. SPIEGEL, PH. D. 1926-2008

Compiled by John W. Hawley, Emeritus Sr. Environmental Geologist
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March 5, 2008

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Spiegel, Z.E., 1958, Preliminary report for coordinated development of surface and ground water in the Tularosa area, Otero County, New Mexico: New Mexico State Engineer Open-file Report, 4 p.

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Applying Hydrology to Water Resource Management: The City of Santa Fe Buckman Wells 10-13 Ground-Water Monitoring Program

BORCHERT, Claudia I., City of Santa Fe Water Division, 801 W. San Mateo Rd., Santa Fe, NM 87505, ciborchert@santafenm.gov

Administering and managing the water resources in the Española Basin requires reliable ground-water information. One of the goals of the City of Santa Fe's Buckman Wells 10-13 Ground-Water Monitoring Program is to collect ground-water data to enable better management and administration of the ground-water resources in the Buckman well field area. The data collected through the monitoring program will help determine the pumping effects from the City's Buckman Wells 10-13 (BW10-13) on nearby wells. The New Mexico State Engineer required a monitoring program as a condition of approval to the City's Buckman 10-13 supplemental well permit, which granted the City the right to divert 6,000 ac-ft from the new emergency wells.

The City's Monitoring Plan contains five components. First, the City will identify all the senior wells within a four-mile radius of the Buckman 10-13 and in the Tano Road area. Secondly, the City will monitor ground-water levels in an OSE-approved network of ground-water wells, including the four new supplemental production wells (BW10-13), eight monitoring wells, and seven domestic/livestock wells within several miles of BW10-13. Thirdly, the impacts to all the senior wells within the monitoring area will be projected based on the observed changes to ground-water levels. Finally, if the induced drawdown limit in any senior well is forecast to reach 70% within ten years of a biannual report to the OSE, the City shall within one year submit a plan to come into compliance with the permit to the OSE. Not all of the impacts on wells in the monitoring area are due to pumping of BW10-13; other potential contributions to water level decline include recharge decline, local domestic wells, commercial wells, and Buckman Wells 1-8 with their 1970s priority right. All information collected through the monitoring program, including the monitoring plan, the well identification survey, the collected ground-water level information, post-2006 Buckman wellfield pumping data, and the biannual well impact analysis will be available to the public on the internet.

The data collected through this monitoring program will provide water resource managers, water rights administrators, and the public more information on how pumping effects promulgate through the principal aquifer in the Española Basin. Comparison of the collected data to existing ground-water model simulations may result in enhancements to the existing ground-water models and identification of additional data needs. The monitoring program also provides the OSE, the affected parties and the City an early warning that the 70% induced drawdown threshold may be reached, giving the stakeholders ample time to explore various mitigation measures. One mitigation measure already being considered by the City is managing the Buckman well field conjunctively with the Buckman Direct Diversion (the City's San Juan-Chama surface water diversion project), relying on the ground-water primarily for drought backup and emergency uses.

Characterization of the Three-Dimensional Hydrogeology at Los Alamos National Laboratory, the Pajarito Plateau and the Basin Beyond

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For more than ten years, Los Alamos National Laboratory (LANL) has funded the development of geologic data to support studies relating to the possible flow and transport of contaminants within the subsurface. These data have been used to create three-dimensional physical properties and flow process models. Geological models have provided a first approximation of the three-dimensional distribution of hydraulic and reactive transport properties. Fine-scale distribution of properties within the identifiable geologic units can be assigned through stochastic processes, application of alternative facies models based on a conceptual knowledge of the geology, or collection of sub-unit scale physical properties information which may be used to determine hydrologic properties.

We describe the most recent 3-D model of the Pajarito Plateau (2005) that has been used to define the spatial distribution of physical properties for models of groundwater flow and contaminant transport. We also present a 3-D model of subsurface, electrical conductivity that was developed from data collected through a GEOTEM, airborne electromagnetic survey (AEM) of LANL. A 3-D model of these AEM data may provide information on the distribution of hydrologic properties within units.

We present components of the 3-D geologic model and a model of subsurface electrical conductivity within the Plateau. We also identify a planned extension of the 3-D geologic model which incorporates the region around the Buckman well field, and extends south and west into the Española Basin.

Applications of ^{14}C Ground-water Dating in Hydrologic and Geochemical Studies of the Regional Aquifer, Pajarito Plateau, New Mexico

DALE, Michael, R.[1], GRANZOW, Kim[1], and LONGMIRE, Patrick[2]; [1]NMED DOE Oversight Bureau, 134 State Road 4, Suite A, White Rock, NM 87544, **mdale@lanl.gov**, kgranzow@lanl.gov; [2]Earth and Environmental Sciences Division, Los Alamos National Laboratory, Mail Stop D469, Los Alamos, NM 87545, plongmire@lanl.gov

The New Mexico Environment Department's DOE Oversight Bureau and Los Alamos National Laboratory (LANL) initiated a project in 2005 to determine radiocarbon (^{14}C) ages of regional-aquifer ground water beneath the Pajarito Plateau, New Mexico. Carbon-14 data provide a mean age of ground water consisting entirely of submodern (pre-1943) or mixed (pre- and post-1943) components. Radiocarbon and other chemical and isotope data have application in validating the LANL flow and transport numerical model by delineating ground-water flow paths and quantifying travel times from recharge zones within the Sierra de los Valles to discharge zones at White Rock Canyon springs. Results from this investigation are also applicable in assessing regional aquifer sustainability and vulnerability to contamination. A total of 91 samples were collected from 29 monitoring wells, 7 production wells, and 18 springs. The majority of the radiocarbon results were measured in ground water samples collected from monitoring wells completed in the upper saturated portion of the regional aquifer. The White Rock Canyon springs discharge at or near the regional water table.

Unadjusted ^{14}C ages for the regional aquifer vary from 600 years before present (BP) beneath the western portion of the Pajarito Plateau to a range of 2,100 to 9,700 years BP at White Rock Canyon springs that discharge west of and along the Rio Grande. Ground-water ages greater than 8000 years BP measured for supply wells are associated with longer and deeper flow paths associated with longer residence times. $\delta^{13}C$ values for the regional aquifer range from -14.7 to -8.7 per mil, suggesting that correction of radiocarbon dates due to $CaCO_3$ (calcite) dissolution is not required for a vast majority of regional aquifer samples. All ground-water samples collected from the Puye Formation are undersaturated with respect to calcite, calculated by the computer code MINTEQA2. Calcite is rarely observed within the Puye Formation; however, this mineral commonly occurs within the Santa Fe Group. Several samples collected from supply and monitoring wells completed within the Santa Fe Group and located within the east-central part of the Pajarito Plateau are calculated to be in equilibrium with calcite. Radiocarbon results for these samples may require a small correction.

An initial evaluation of ground-water flow rates independent of model validation is calculated from average age differences between two points along a flow path at 4 locations with the assumption that no recharge is occurring. Ground-water flow rates using this simplistic method varied from 3 to 10 ft/yr near the regional water table. Lines of equal age tend to follow the regional water-level contour lines. Distortions in the age lines are observed beneath perennially wet canyons, most notably Frijoles and Water canyons. This suggests that mixing through active line-source recharge to the regional water table is occurring. Detection of tritium, nitrate, chromate, and/or perchlorate at the regional water table in several locations supports this process. Vertical age gradients derived from three multi-screened wells ranged from 0.01 to 0.17 m/yr (0.04 to 0.57 ft/yr), suggesting that anisotropic conditions occur below the regional water table.

Geohydrologic Conditions of the Ancha-Galisteo Aquifer System along the Southern Margin of the Española Basin

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The Tertiary-Quaternary Ancha Formation is an unconsolidated to locally carbonate cemented/weakly lithified deposit of interbedded arkosic sand, silt, and sandy gravel that is a locally important aquifer. Groundwater flow in the distal southwestern part of the Ancha Formation aquifer is derived from both regional flow and from local recharge derived from the Tertiary intrusives that form the Cerrillos Hills. General flow direction is from east to west, and locally southeast to northwest, toward the Santa Fe River canyon. Discharge from the Ancha Formation aquifer in the area is primarily to Alamo Creek, Cienega Creek, Bonanza Creek, and to springs that discharge to the streams. Springs are typically located at the contact between the Ancha and underlying lower-permeability cemented volcaniclastic rocks of the Espinaso Formation and Galisteo Formation shale and sandstone beds. The Ancha Formation aquifer is underlain by Galisteo Formation/Espinaso Formation sediments and Mancos Formation shale, siltstone, and minor sandstone throughout most of the area. The overlying Cerros del Rio basalts are typically unsaturated. Ground water elevations in the Ancha and Galisteo Formation wells are similar, indicating a single interconnected aquifer system. Ground water flow in the Galisteo Formation is primarily through fractured sandstone and conglomerate beds located between shale and mudstone interbeds.

Pumping test data show a large hydraulic conductivity (K) difference between the Ancha and Galisteo Fm aquifers, with Ancha Fm K of 20-25 ft/day and Galisteo Fm K of 0.01 to 0.02 ft/day. In areas where the Ancha overlies the Cretaceous Mancos shale, the contrast in K is still greater. The distal Ancha Fm aquifer is relatively thin, with a saturated thickness of approximately 50 ft. However, due to its much greater K relative to underlying aquifers, productive wells in the area typically extract water from the Ancha. The aerial extent of the Ancha Fm is therefore important for evaluating water resources in the area. Detailed mapping focused on delineating the Ancha Fm and structures that cut the Ancha are critical for evaluating the geohydrologic system. Mapping in the area shows that the Ancha is present below the Cerros del Rio basalts along the rim of the Santa Fe River canyon and contacts with underlying units can be mapped throughout the canyon, and provide evidence for structures that offset the Ancha Fm but are buried by overlying basalt flows.

Distribution of Radionuclides in Northern Rio Grande Fluvial Deposits near Los Alamos National Laboratory, New Mexico

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The New Mexico Environment Department's Department of Energy Oversight Bureau identified radionuclide contamination originating from the Los Alamos National Laboratory (LANL) in abandoned channels, old flood plains, and other fluvial deposits along the Rio Grande. The highest proportions of LANL contaminants in sediments are nearest to the discharge sources. Sediment sorting by fluvial processes throughout the past 60 years contributed contaminant concentrations in White Rock Canyon.

We collected sediments from multiple-depth intervals in cores and outcrops at five sites along the Rio Grande and from within the active Rio Grande channel at 8 sites. We identified contaminant sources by evaluating atom ratios of plutonium isotopes 239 and 240, by statistical comparisons of downstream radiochemical measurements to background reference conditions, by comparing NMED data to LANL historical background values, and by investigating grain-size distribution and contaminant concentration relationships.

We selected a site at Santa Clara Pueblo ~ 12 km upstream of the Los Alamos Canyon and Rio Grande confluence at Otowi Bridge to demonstrate background conditions. The remaining four sites are downstream of the Otowi Bridge. Cañada Ancha is ~ five km downstream, while the Pajarito and Water canyon sites are about 11 and 14 km below the bridge, respectively. The Frijoles Site, farthest downstream, is approximately 19 km below the bridge.

Most of the LANL legacy contaminants in sediments along the Rio Grande were derived from the Los Alamos watershed. We found that $^{239/240}$plutonium was the most persistent radionuclide found in terraces downstream of LANL. By far, the largest concentrations were found at the Cañada Ancha site followed by the Frijoles site, and then the Water Canyon site. Elevated ^{137}cesium and uranium isotope concentrations were also found at Cañada Ancha, followed by the Frijoles site. Strontium-90 was found to be elevated at the Cañada Ancha site and ^{241}americium was elevated at the Frijoles site. Contaminant measurements at the Pajarito site were all indistinguishable from background, although we identified legacy contaminants at levels diluted below the background references.

Eight active-channel sediments were collected within the Rio Grande including locations 61 km (38 miles) north of the Otowi Bridge at Pilar, New Mexico to 134 km (83 miles) south of the Otowi Bridge to Albuquerque. The three sites upstream of Otowi Bridge represent upper Rio Grande background reference values while the five sites downstream of Otowi Bridge represent the downstream sample population. Upstream and downstream channel sediments were indistinguishable and reflect radionuclide concentrations similar to global fallout levels.

Using Principal Component Analysis (PCA) and Cluster Analysis (CA) to Define Ground Water Chemistry in the Regional Aquifer Beneath the Pajarito Plateau

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PCA and CA statistical tools were used with metal and general geochemistry data to delineate geochemical groupings in the regional aquifer beneath the Pajarito Plateau and Rio Grande. Traditional graphical methods of classification typically use only major ions, while the multivariate statistical methods can include trace metal data and other geochemical parameters such as pH. This provides a more complete chemical evaluation. The cluster analysis is a neutral approach to delineation of facies that groups locations by common chemical signatures, without the bias of preconceived notions such as flow paths, anthropogenic inputs, or geographical features. The PCA reveals which constituents or groups of constituents are responsible for the greatest variability in the data set. From this, a picture of natural, or background, water quality can be extracted.

The conceptual model of regional ground water is based on multiple chemistry, numerical modeling, and physical hydrogeologic studies. Regional ground water infiltrates in the Jemez Mountains in the west and Sangre de Cristo Mountains in the east, converging and discharging at the Rio Grande, with a concurrent increase in total dissolved solids and metals with residence time. Ground water facies exist within this flow regime and the geochemistry is controlled by host rock interactions and altered by dilution and mixing with surface water and alluvial or intermediate depth waters. In addition, 50 years of human residence and industrial activity on the Plateau have added chemical signatures to some areas. PCA and CA methods were used to extract different water groupings or facies and the associated natural background water chemistry from these complicating factors. Water supply wells, monitoring wells, and local springs supplied data on inorganic constituents from 2000 to the present. Four statistically distinct ground water groups were found. Waters sampled from near the Rio Grande showed higher total dissolved solids (TDS) and levels of some metals, likely indicating older, more evolved regional ground water. Waters from the western Pajarito Plateau showed lower TDS and metals, indicating a less evolved facies, while water sampled from the central Plateau showed intermediate TDS and metals and is likely indicative of mixed waters.

Hydrologic Analyses of the Santa Fe River Watershed in Support of River Restoration Projects

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The hydrologic analysis of the Santa Fe River from its headwaters to NM highway 599, (53 sq mi) and the Arroyo de los Chamisos, from its headwaters to a point west of the City of Santa Fe (26 sq mi) was completed in 2007 by USACE, Albuquerque District for the City and County of Santa Fe. The study consisted of simulating the precipitation-runoff processes of the watershed and generating hydrographs of peak stream flow at critical locations within the watershed systems for the 50%, 20%, 10%, 4%, 2%, 1% and 0.2% probability discharges. An HEC-HMS model was created using HEC-GeoHMS in ESRI ArcMap and Santa Fe County surface data. Resulting hydrographs of runoff may be used directly or in conjunction with other analysis software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and system operation.

Isotopic Evidence for Partial Natural Attenuation of Chromate Contamination at Los Alamos National Laboratory, New Mexico

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The Los Alamos National Laboratory environmental project is investigating hexavalent chromium [Cr(VI)] groundwater contamination. The primary anthropogenic source of Cr(VI) is potassium dichromate ($K_2Cr_2O_7$) used as a corrosion inhibitor in cooling towers at LANL's main power plant located in upper Sandia Canyon. Between 1956 and 1972, an estimated 31,000 to 72,000 kg of Cr(VI) were released into the canyon.

One potential remedy for groundwater Cr(VI) contamination is monitored natural attenuation (MNA), wherein naturally occurring electron donors lead to the reduction of Cr(VI) (mobile under oxidizing and basic pH conditions) to the much less toxic Cr(III). Above pH 6, Cr(III) precipitates as insoluble amorphous $Cr(OH)_3$ with equilibrium concentrations of total dissolved Cr less than 50 μg/L, the New Mexico Water Quality Control Commisson groundwater standard. Chromium(III) also coprecipitates with ferrous iron [Fe(II)] as $Cr_xFe_{1-x}(OH)_3$, which has a lower solubility than amorphous $Cr(OH)_3$. Key potential reductants include solid organic matter, Fe(II) in reactive minerals and volcanic glass, which is particularly abundant within the Cerros del Rio basalt, and dissolved organic carbon derived from natural and anthropogenic sources.

Ratios of ^{53}Cr to ^{52}Cr ($\delta^{53}Cr$) have experimentally been demonstrated to reflect the degree of reduction of total dissolved Cr(VI) to Cr(III). During both abiotic and biotic reduction of Cr(VI) to Cr(III), there is a kinetic isotope affect in which the lighter isotope, ^{52}Cr, reacts preferentially, leaving the remaining dissolved Cr(VI) pool enriched in the heavier isotope, ^{53}Cr. The degree of isotopic enrichment of ^{53}Cr can be used to calculate the fraction of Cr(VI) reduced. Uncertainties in this analytical method include the Cr isotopic composition of the source $K_2Cr_2O_7$ and the kinetic fractionation factor associated with reduction of Cr(VI).

$\delta^{53}Cr$ values in surface water and groundwater in and beneath Sandia and Mortandad canyons range from 0.3 ‰ in a surface water sample to 2.93 ‰ in an intermediate depth well (MCOI-5, Mortandad Canyon). The 0.3 ‰ value reflects no reduction of Cr(VI) to Cr(III), as most industrial Cr sources have an isotopic composition similar to 0.3 ‰. The higher isotope value reflects approximately 45-60 % reduction. Cr isotope values do not indicate where along a flow path Cr(VI) reduction has occurred. Intermediate depth well MCOI-5 is completed in the Cerros del Rio basalt, whereas another intermediate depth well (SCI-1, Sandia Canyon) completed in saturation on top of the same basalt unit shows only a few percent reduction. These results suggest that Fe(II) in the basalt is an important contributor to reduction of Cr(VI). Most wells examined, including the well with the highest levels of Cr(VI) (R-28 in Mortandad Canyon, total dissolved Cr ~440 μg/L), show reduction of approximately 15 to 30%, suggesting that chemical reduction could be a contributing component of a potential MNA remedy.

Updated 3D Model of the Geological and Geophysical Framework of the Southern Española Basin near Santa Fe, New Mexico

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For the past several years, we have been using geological and geophysical data to model the three-dimensional (3D) geometry and subsurface structure of the southern Española rift basin. Our 3D geological model utilizes software that allows multiple surfaces to represent the distribution and thickness of geologic units, offset of these surfaces along faults, and display of subsurface control data (well picks, geophysical inversions). A digital elevation model (DEM) of topography forms the top of the model. We have recently updated the model mainly to incorporate revisions to geophysical interpretations that refine previous concepts of the 3D geology and improve the accuracy and visualization of the model.

The rift basin is mostly filled with sediment of the Tesuque Formation (upper Oligocene-Miocene), the primary aquifer for the region. The shape of the basin floor above bedrock (Oligocene through Precambrian) controls the thickness of the Tesuque aquifer and is modeled primarily through analysis of aeromagnetic and gravity data constrained by other geological and geophysical data. Recent modifications and improvements to this analysis include (1) updating interpretations of lithology in wells, electrical geophysical soundings, and seismic data; (2) merging with existing geological and geophysical interpretations in the area of the La Bajada constriction on the southwest; (3) considering the connection to basin structure adjacent to the study area on the north and northwest; and (4) better integrating gravity and aeromagnetic analyses throughout the study area.

Structurally, the basin model has an overall form of a north-plunging syncline that descends abruptly across a faulted curvilinear hinge zone southwest of Santa Fe. An extensive, shallow (<75 m) platform underlies the Santa Fe Embayment south of the hinge zone. The platform is composed of Oligocene-age volcanic rock overlain by young rift sediment of the Ancha Formation (Pliocene-lower Pleistocene) and underlain by as much as to 2 km of pre-rift sedimentary rock. The volcanic platform is locally deeply incised; one paleovalley probably contains >150 m of Tesuque Formation in the Eldorado area and the volcanic rock is entirely missing beneath Ancha Formation in two other areas. The pre-rift section is truncated on the north at a buried paleo-escarpment, which generally coincides with the hinge zone. North of the hinge zone, the syncline broadens and descends north-northwestward to depths of 2–2.5 km. Its eastern limb rises with variable dip to the north-trending mountain front of the Santa Fe Range. The model includes >20 intrabasin faults that have sufficient length and offset to significantly affect the basin. A central zone of discontinuous faults transects the basin length and includes the San Ysidro Crossing fault zone, which has a hydrologic head drop across it. The southwestern flank of the model incorporates east-dipping strata that probably reflect protracted footwall uplift of the La Bajada fault zone before eruption of the mostly 2.8-2.4 Ma Cerros del Rio volcanic field that is imaged along the western flank of the model.

Buried Landscapes: Paleotopography of the Cerro Toledo Interval, Bandelier National Monument, Jemez Mountains Volcanic Field

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Prior landscapes preserved between eruptive cycles of the Jemez volcanic field form subsurface pathways that influence the flow of contaminants and groundwater. Knowledge of how fluids move from the surface through perched zones to the aquifer is still developing. This study looks at the prior landscape “sealed” between two major ash flows (Otowi and Tshirege Members of the Bandelier Tuff at 1.6 and 1.2 Ma), within Bandelier National Monument (BNM) on the Pajarito Plateau, a 50 km long, 15 km wide tableland of tuff that abuts the eastern flank of the Jemez volcanic field. The ~380,000 year interval between the Bandelier eruptions, informally termed the Cerro Toledo interval, contains up to 120 m thick deposits that provide favorable settings for perched zones. Windows into this landscape are exposed in Frijoles and Alamo Canyons, two narrow, deeply incised, subparallel canyons that lie within the northern section of BNM. Structure contour and isopach maps derived from recent field observations of exposed contacts in BNM are combined with previously mapped geologic surface data and drill-hole data for the southern part of Los Alamos National Laboratory to provide a glimpse of the topography that developed on the surface of the Otowi Member prior to eruption of the Tshirege Member. The nonwelded Otowi Member was easily eroded, resulting in a landscape characterized by rolling hills with gentle gradients. Episodic eruptions of plinian ash and erosion of the Sierra de los Valles, accompanied by possible seismic shaking during the collapse of a portion of Rabbit Mountain, resulted in pulses of sediment that periodically overwhelmed developing drainage systems. Regional base level was controlled by the ancestral Rio Grande, whose location shifted in response to silicic volcanism from the Jemez Mountains to the west, mafic flows from the Cerros del Rio volcanic field (~3.0-1.1 Ma) to the east, as well as possible seismic activity within the rift. The basaltic flows from the east created a broad resistant tableland which provided local knickpoints for streams draining the Otowi headlands, allowing broad washes to form adjacent to the master stream. In addition, continuing eruptive activity, occasional landslides, earthquakes, and undercutting of the ancestral Rio canyon formed ephemeral impoundments which may have temporarily raised base level along particular reaches influencing rates of tributary drainage network development and affecting where large, episodic outflows of sediment would have been deposited.

A Preliminary Hydrogeologic Framework of the Santa Fe Area

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The New Mexico Bureau of Geology is finalizing work on geologic, hydrologic, and geochemical studies in the southern Española Basin (SEB) and integrating the multiple data sets into a hydrogeologic framework for the region. This work, conducted in collaboration with the New Mexico Office of the State Engineer Hydrology Bureau, has progressed along several fronts: (1) geologic mapping; (2) hydrologic data collection and compilation; (3) geochemical sampling; (4) examination of lithologic data in exploration holes; and (5) structural and stratigraphic analysis of the Ancha Fm. Current efforts are focused on analyzing the spatial relations of ground water flow and geochemistry with geologic structures, formations and lithostratigraphic units. We use these relations to integrate data into a hydrogeologic framework.

Under NMBGMR's geologic mapping program (STATEMAP/EDMAP), and USGS efforts, most of the 7.5-minute quadrangles in the Española Basin are complete or in progress. Geologic maps are available at http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/home.html. A geologic compilation map of the SEB is available as an open-file report, OFR-481, at http://geoinfo.nmt.edu/publications/openfile/home.cfm. Data on wells, water levels, aquifer hydraulic properties, and aquifer geochemistry are stored in an ACCESS database that facilitates integration of multiple data sets and will be available with final publications.

Mapping lithostratigraphic units has culminated in a basin depositional model of the late Oligocene- to Miocene-age Tesuque Fm (Santa Fe Group). These units include lithosomes S, B, and A. Lithosome S was probably deposited on an alluvial fan by an ancestral Santa Fe River. Strata consist predominately of pebbly sand near the axis of this fan (approximately coinciding with the present Santa Fe River) that allows for high rates of westward ground water flow and infiltration of Santa Fe River surface water west of the San Isidro Crossing fault (SICF) – indicated by TDS, Ca/Na ratios, SO_4/Cl ratios, and a water-table mound centered over the river channel. To the north, alluvial slope deposits of lithosome A interfinger westward with basin-floor deposits of lithosome B.

Relatively coarse sediment of the Pliocene-age Ancha Fm is partially saturated to the west, but only locally saturated along the southeast side of the SEB. Coarse-grained Ancha sediment filling paleovalleys cut into the Tesuque Fm support high-yield wells. High hydraulic conductivity values are derived from aquifer tests in paleovalley-fill and ancestral Santa Fe River deposits of the Ancha Fm, and in coarse-grained strata of lithosome S.

The structure of the SEB consists of a half graben to the north transitioning to a syncline south of the Santa Fe uplands that deforms both the shallow Santa Fe platform and the north-down, arcuate flexure named the Rancho Viejo hinge zone. The Barrancos structure, which includes the SICF and north-striking, basement highs NW of Santa Fe, impounds westward ground water flow. Impounded groundwater spills around the north end of the SICF. Localized bedrock jointing and dilation is inferred at intersecting faults between Santa Fe and upper Arroyo Hondo, and northwest of Agua Fria. In the latter, a northeast-trending monoclinal structure intersects the Barrancos structure and the syncline. These two locations coincide with strong upward ground water gradients and a noteworthy suite of dissolved constituents that includes elevated TDS, chloride, sulfate, sodium, calcium, and, northwest of Agua Fria, elevated arsenic.

Miocene Sedimentation and Tectonism across the Colorado Plateau-Rio Grande Rift Margin, Northern Jemez Mountains, North-Central New Mexico

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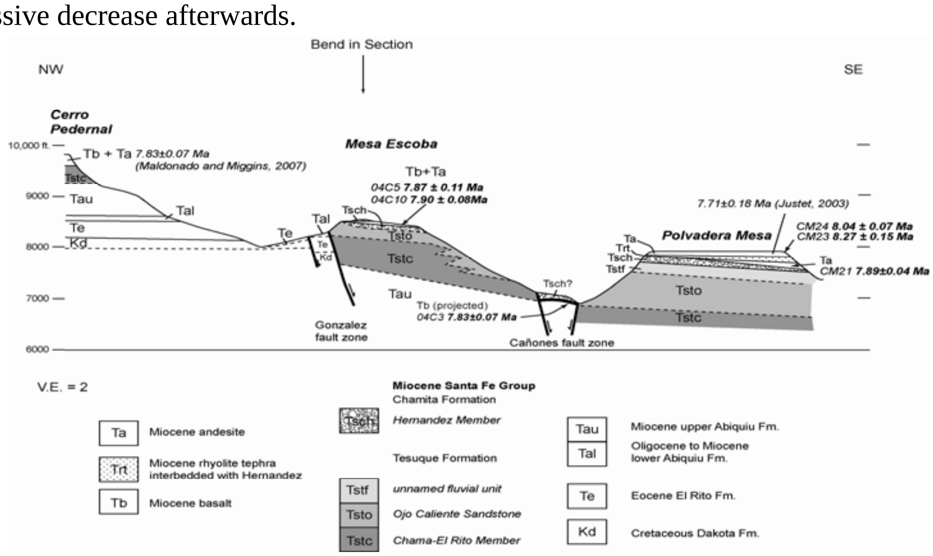
The northeast-striking Cañones fault zone (CFZ) has traditionally been viewed as the main boundary between the Colorado Plateau and the Rio Grande rift in the northern Jemez Mountains; however, normal faults with vertical stratigraphic offsets of ~3 to 110 meters occur in the Chama Basin on the Colorado Plateau as far west as the village of Coyote, ~20 km west of the CFZ. A similar broad zone of distributed deformation ~17 km is present to the east of the CFZ in the Abiquiu embayment. The Cañones fault zone was an east-side-up reverse fault during Laramide deformation. Previous workers determined that the reverse fault was reactivated as an east-side-down normal fault starting in late Oligocene time (25-28 Ma), based on stratal thickness variations in the conglomerate of Arroyo del Cobre and the Abiquiu Formation across the fault zone. Deformation across the fault zone continued during the deposition of the Tesuque and Chamita Formations of the Miocene Santa Fe Group 18 to 8 Ma. Santa Fe Group sediments thicken dramatically toward the southeast from ~90 m on Cerro Pedernal to >300 m on Polvadera Mesa, becoming thicker towards a prominent gravity low that underlies the northern Jemez Mountains. Basalt and andesite lava flows that were erupted from Jemez volcanic field centers on the La Grulla Plateau at 7-8 Ma rest on the Chama-El Rito Member of the Tesuque Formation on Cerro Pedernal, on Ojo Caliente Sandstone (Tesuque Formation) and Hernandez Member (Chamita Formation) on Mesa Escoba , and on Hernandez Member on Polvadera Mesa. The Ojo Caliente Sandstone, which generally overlies the Chama El Rito Member, appears to be absent on Cerro Pedernal, but is on average ~120 m thick on Mesa Escoba. A previously unrecognized, ~100-m-thick, fluvial unit that is part of the Tesuque Formation is interbedded with and overlies the Ojo Caliente Sandstone and is unconformably overlain by the Hernandez Member of the Chamita Formation on the north end of Polvadera Mesa on the hanging wall of the CFZ. Approximately 670 m of down-to-the-east faulting has since disrupted the 7-8 Ma lava flows. 2.8-3.0 Ma basaltic andesite and dacite that flowed across the Cañones fault zone are generally not offset. Faults 3 to 10 km east of the Cañones fault zone have displaced a 3.8 Ma dacite by 100 m and a 5.6 Ma basalt by 11 m. We infer relatively high displacement rates for this zone in early to middle Miocene time, and a progressive decrease afterwards.



Thickness variations in the Miocene Tesuque Formation and Chamita Formation of the Santa Fe Group. $^{40}Ar/^{39}Ar$ ages in bold type are from this study.

Mio-Pliocene Tectonic Activity along the Pajarito and Santa Clara Faults Based on Offset Santa Fe Group Deposits and Basalt Flows, Española Basin, North-Central New Mexico

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The Pajarito fault (PF) and Santa Clara fault (SCF) belong to a significant, north-south fault system traversing the central part of the Española Basin. The generally north-striking, east-down PF passes along the east side of St. Peter's Dome and terminates northwards as a fault-tip monocline at Los Alamos. A 5 km-wide zone consisting of several west-down faults separates the PF and SCF between Rendija and Chupaderos Canyons. To the north, two parallel, east-down faults strike northeast, the Santa Clara Canyon fault to the west and the SCF 2.5-3.0 km to the east (both included as the SCF in discussion below). The northern SCF fault ends at a structural zone that includes the west-striking Chamita syncline. Here, strain steps right to northeast-striking faults of the Embudo fault (EF) system. Like the EF system, the SCF exhibits a significant component of lateral slip (probably left-lateral).

We interpret the timing of vertical displacement (throw) along the PF and SCF by comparing thickness changes and vertical offsets of faulted stratigraphic intervals in the Santa Fe Group. Fine-grained basin-floor deposits on the SCF footwall suggest relatively low rates of throw at 15-16 Ma. Our thickness comparisons across the SCF indicate a pronounced increase in throw rates ca. 12.7 Ma and suggest a prior increase in fault activity between 13 and 15 Ma. Inter-well correlations in the Guaje well field, located in the zone of west-down faults between the PF and SCF, show that a 13.2 Ma basalt flow is offset 75 m by a west-down fault but overlying 11.5-12 Ma flows are offset less than 10 m – indicating fault activity between 11.5-13 Ma. At St. Peter's Dome, lateral juxtaposition of different early-middle Miocene Santa Fe Group units occurs along two previously unrecognized NNW faults, indicating 100-250(?) m of stratigraphic separation. However, overlying strata of the Keres Group (~9-10 Ma) is not noticeably offset by these two faults (< ~30 m) – indicating >70 m of stratigraphic separation between 13 and 10 Ma. Similarly, a north-striking fault that intersects the SCF near Clara Peak produced 430-480 m of stratigraphic separation during 13.5-10 Ma. About 430-500 m of stratigraphic separation of post-10 Ma Chamita Formation strata and lesser vertical offset of the Pliocene-age Puyé Formation indicates that significant vertical motion along the SCF occurred after 10 Ma. In summary, we interpret significantly higher throw rates along the SCF and PF after ca. 13 Ma.

We infer that lateral motion along the SCF commenced by 9-12 Ma and peaked at 6-4 Ma using the Chamita syncline, which we assume is related to transpression created by the right-step between the EF and SCF. Cross-sections suggest thickness changes across the Chamita syncline for post-12 Ma strata. On the north limb of the fold, 6.5-7.0 Ma strata dip 20-27° S but overlying 3-4 Ma basalts only dip ~7° S, consistent with strong folding at 6-4 Ma.

Aqueous Geochemistry and Environmental Fate of Uranium, Pajarito Plateau and Surrounding Areas, New Mexico

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Uranium is an actinide of considerable interest in environmental geochemistry studies conducted at Los Alamos National Laboratory (Laboratory), located west of the Rio Grande on the Pajarito Plateau, and in surrounding areas of the Española Basin, New Mexico. The regional aquifer beneath the Pajarito Plateau contains background concentrations of total dissolved uranium ranging from 1.3 to 10.5 nanomolar (nM), and measurable dissolved oxygen (0.06 to 0.19 millimolar, mM), nitrate(N) (<0.11 mM) and sulfate (<0.07 mM). The regional aquifer varies from a calcium-sodium-bicarbonate to a sodium-calcium-bicarbonate solution with bicarbonate concentrations exceeding 1.1 mM. Uranyl carbonato complexes are predicted to dominate in groundwater. Concentrations of natural reductants including hydrogen sulfide and dissolved organic carbon are not sufficient to enhance stability of uranium(IV) complexes and solid phases. Background distributions of total dissolved uranium are believed to be controlled by chemical alteration of volcanic glass, specific adsorption of uranium(VI) complexes onto hydrous ferric oxide, and cation exchange of uranyl cation with calcium in smectite. The regional aquifer shows variable saturation with soddyite and is oversaturated with haiweeite depending on calcium and/or silica activity. Anthropogenic uranium has been released from Laboratory outfalls to surface water since 1943. Surface water on the Pajarito Plateau provides recharge to alluvial and perched-intermediate depth groundwater and the regional aquifer. Elevated above-background concentrations of uranium (maximum of 50 nM) occur in the regional aquifer downgradient from Laboratory outfalls. Nitrate, perchlorate, and/or tritium coreleased with uranium(VI) have migrated to the regional aquifer at depths of 183 m or greater within 40 years since 1943. These chemicals are used to determine the source of uranium in addition to uranium isotopes. Laboratory uranium contamination in groundwater is limited to west of the Rio Grande. East of the Rio Grande between Santa Fe and Española, background concentrations of total dissolved uranium up to 7.6 micromolar have been detected. This area contains numerous volcanic glass deposits in various stages of alteration and roll-front uranium(VI) ore bodies.

Hydrologic Analysis of a Proposal to Expand the Buckman Well Field

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The Office of the State Engineer (OSE) is charged with the administration of the state's surface and ground water resources. Any person or entity proposing a diversion or change of point of diversion or place or purpose of use must file an application for a permit with the State Engineer. A permit will not be granted if the State Engineer finds impairment to existing water rights due to stream depletion or excessive drawdown. To illustrate the hydrologic analysis for applications filed in the Santa Fe area, a summary is presented here of the OSE evaluation to assess an application filed by the City of Santa Fe to expand the Buckman well field.

In 2003 the City proposed the addition of four new wells to supplement its permitted diversion of 10,000 acre-feet per year (af/yr) from the Buckman well field. Due to the age of the well field and associated water level declines, the City was capable of extracting about 5,600 af/yr. The four supplemental wells were completed outside of the Buckman cluster approximately 4 to10 miles southeast of the well field.

Pumping from the old well field would be limited to 4,000 af/yr while the new wells would produce a total diversion of 6,000 af/yr. Although an increase in the total well field diversion was not proposed, the shift in pumping would create significant new impacts on the Rio Tesuque, La Cienega Springs and nearby domestic and stock wells.

The impacts due to the proposal were computed by applying a revised version of the McAda – Wasiolek MODFLOW groundwater model. Following the computation of well effects additional analyses were required to assess impairment. Well completions of 54 nearby wells were assessed to determine drawdown allowances.

While hydrologic tools are in place to evaluate impairment, continued data collection and modeling are necessary to refine this process. The studies may also lead to strategies to mitigate negative impacts.

Surface Water - Shallow Groundwater Interactions in an Irrigated Valley in the Northern Part of the Española Basin

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Ditch and crop seepage from irrigated valleys can have multiple hydrological benefits including aquifer recharge, temporary storage, and delayed return flow. We are conducting a study aimed to characterize the hydrological interactions between surface water and shallow groundwater in the irrigated corridor between the Alcalde main irrigation ditch and the Rio Grande in the northern part of the Española basin. We did impoundment tests along sections of the ditch and inflow-outflow tests along the entire ditch to calculate ditch seepage rate. We installed twenty-two experimental wells and along with 18 collaborator-domestic wells we equipped them with water level loggers to measure water level fluctuations along the entire valley. We installed stage-measurement stations along the ditch and the river to measure ditch and river water stage and for calculating ditch flow. We calculated deep percolation below the root zone in apple and alfalfa crop fields following flood irrigation, both the most common type of crops and irrigation practice in the valley. We evaluated the continuum of water transport through the vadose zone and shallow groundwater response to flood irrigation and wetting front transport velocity and water flux were calculated for different soil types. Ditch seepage ranged from 12% to 16% over the entire Alcalde ditch. Seasonal patterns in water level fluctuations were observed and water level rise was attributed to ditch and crop seepage. An average of 32 cfs flow was calculated in the Alcalde ditch during the irrigation season. Deep percolation of 15% to 60% was calculated from crop fields depending on soil properties and amount of water applied. The average velocity of propagation of the wetting front ranged from 10 cm/h to 375 cm/h depending on soil type and soil depth observation point. The Hydrus 1-d model was used to obtain the hydraulic parameters of different soil types that are being used in expanding plot results to larger spatial areas. Modflow is being used to estimate groundwater flow and return flow to the river at the larger valley scale. A System Dynamics model will be used to expand the field-measured results to the regional scale.

Geophysical Constraints of Rio Grande Rift Structure and Stratigraphy Based on Magnetotelluric Resistivity Soundings and Regional Borehole Geophysical Rock Properties, Northern New Mexico

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Geophysical interpretations of magnetotelluric (MT) soundings, calibrated by sparse borehole geophysical data from deep wildcat petroleum exploration wells along the flanks of the Rio Grande Rift and in the Albuquerque and Española basins, significantly improve geologic constraints for mapping subsurface stratigraphy and structure in the Rio Grande Rift near Santa Fe and Los Alamos, New Mexico. To distinguish between various stratigraphic units, regional borehole resistivity data were used to characterize the typical resistivities encountered in the Rio Grande Rift. Digitized induction logs were smoothed with a 100-ft moving average to minimize the effects of thin layers unresolvable with MT soundings. These averaged resistivities were then used to test for the minimum thickness detectable with MT soundings at a given stratigraphic horizon using the averaged resistivities likely to be encountered above and below the horizon. Borehole resistivity data for the Santa Fe Group and the Galisteo Formation below the water table were moderately conductive (about 5-50 ohm-m), while Tertiary igneous rocks were resistive (greater than about 100 ohm-m). Resistivity data for the Mancos Shale indicate that it is a strong (2-10 ohm-m) electrical conductor. Where the Mancos occurs in the upper kilometer of crust it may function as local hydrogeologic basement. Permian and Pennsylvanian rocks were moderately conductive (10-100 ohm-m), while Precambrian crystalline rocks were resistive (greater than about 100 ohm-m). In the Española basin, MT soundings, located south of Los Alamos across the Pajarito fault and west of Santa Fe across the Cerros del Rio volcanic field suggest significant new geologic interpretations of buried Cenozoic sedimentary and igneous rocks, Santa Fe Group, Espinaso Formation, Galisteo Formation, and for older Mesozoic and Paleozoic sedimentary rocks. Conductive Mesozoic rocks appear to be down-dropped about 3,000 ft across the Pajarito fault accompanied by about 3,000 ft thickening of Tertiary sediments. Conductive Mesozoic rocks appear to be down-dropped beneath the Cerros del Rio volcanic-field near the 1200-ft well by about 3,000 ft accompanied by about 3,000 ft thickening of Tertiary sediments.

Simulation of Groundwater Flow in Part of the Española Basin from Black Mesa to Cochiti, New Mexico

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This poster describes a three-dimensional numerical model of groundwater flow in part of the Española Basin from Black Mesa to Cochiti, New Mexico. The principal aquifer system of the modeled area consists of the Santa Fe Group. The primary water bearing formations are the Tesuque Formation and the Los Alamos area main aquifer.

We compiled data from various available sources to provide information for the construction of a three-dimensional hydrogeologic unit solids model. The solids model provides a framework for specifying hydrologic parameter zones. Model parameter zones are generalized so that each hydrogeologic unit (Tesuque Formation, Los Alamos Aquifer, etc.) is represented with a constant set of parameters.

The groundwater system is represented by a grid with 63 layers, 216 rows and 175 columns. In plan view, the model grid is constructed out of square cells 1,056 feet (1/5 mile) long on a side. Each grid layer is 200 feet thick. The grid covers an area of 1,100 square miles and ranges in thickness from 2,000 to 12,000 feet thick. The layer structure of the model grid follows the idea conceived by the U.S. Geological Survey (Hearne, 1985). Hearne's grid represented the Tesuque Formation by incorporating a geologic dip in the model grid layers. The grid developed for the model herein builds on that approach by incorporating the dip defined by a structurally interpolated surface generally representative of the base of the Santa Fe Group. The Tesuque Formation consists of inter-bedded deposits of sediments with contrasting permeability. The dip of the beds creates a preferential pathway for groundwater flow. That condition creates steep hydraulic gradients (50 to more than 100 feet per mile) where the movement of water is across, rather than parallel to, the dipping beds. The grid layering approach provides a generalized method to inspect the influence that the structural beds have on the groundwater flow system.

A combination of parameter estimation and trial-and-error techniques resulted in model parameters in the range of other published values. The Tesuque Formation aquifer is generally simulated with K_x = 1.0 ft/d and K_z = 0.003 ft/d (as simulated by Hearne (1985)) and includes a reduction in permeability with depth. Other primary water producing formations have a horizontal to vertical anisotropy factor of 10.0 to 1.0 for hydraulic conductivity with K_x in the range of a few feet per day. Specific storage and specific yield are 2.0 x 10^{-6} per foot and 0.15 everywhere for all primary water bearing formations.

Model results indicate that the structural dip of the Tesuque Formation aquifer is an important factor that affects the groundwater flow system. Incorporation of the modeled Tesuque Formation with the dipping bed structure appears to provide a generalized method to account for the observed condition of steep regional head gradients, in areas such as the Pojoaque River Basin, and for a flattening of head gradients as observed near Aqua Fria. The model is capable of representing observed field conditions and provides a tool to assist with regional water planning.

Hydraulic Analyses of Seven Miles of the Santa Fe River in Support of River Restoration Projects

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The hydraulic analysis of the Santa Fe River from Camino Alire to NM highway 599, (7 mi) was completed using HEC-GeoRAS in ESRI ArcMap, and HEC-RAS in 2007 by USACE, Albuquerque District for the City and County of Santa Fe. The purpose of the hydraulic analysis was to compute the water surface elevations, and generate floodplains for the updated 50%, 20%, 10%, 4%, 2%, 1% and 0.2% probability of discharges in the study reach. These water surface elevations will be used in conjunction with the planning and design of a recreational trail project in the 7-mile river corridor.

Modeling Flow and Transport on the Pajarito Plateau

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The major impacts that Los Alamos National Laboratory (LANL) has had on groundwater has been from past, large-volume liquid releases (as documented in the Hydrogeologic Synthesis Report (LANL, 2005). The main source of groundwater contamination is liquid discharges into canyons. Storm-water events are the dominant mechanism for down-canyon transport of contaminants in the surface environment. Channel and stream-bank sediments with adsorbed contaminants are entrained in flood water. Groundwater is found in three zones: alluvial, perched intermediate (vadose), and the regional aquifer. Alluvial groundwater provides a significant lateral fast pathway that rapidly flushes conservative contaminants into the deeper vadose zone, whereas sorbing contaminants tend to remain close to the source.

Perched water is caused by a variety of local hydrogeologic heterogeneities, and adds complexity to the characterization of subsurface pathways. Vadose zone travel times to the regional aquifer water table are a function of infiltration rate and hydrogeology. In dry canyons and on mesa tops, downward percolation rates through the vadose zone are low (<10 mm/y), whereas in wet canyons, downward percolation rates are high (1000 mm/y). Furthermore, transport in the vadose zone takes place largely through the Bandelier Tuff, where percolation occurs principally through the rock matrix. In the Bandelier Tuff, travel times to the regional aquifer are on the order of decades from the canyon bottoms to >1000 years from dry, undisturbed mesas. Where basalts form the vadose zone medium, however, transport takes place exclusively along fast pathways and the measured transport times from the surface to the regional aquifer are on the order of days to months.

In the regional aquifer, flow is predominantly lateral due to strong anisotropy differences (Kx >> Kz; however, evidence for vertical flow paths also exist. Numerical models indicate that travel times to supply wells range from 50 to 5,000 years and travel times to springs vary within the same orders of magnitude. Geochemical and isotopic data corroborate this finding. Carbon-14 and He-^{3}H age indicators yield different fluid ages in the regional aquifer. However, both isotopic systems provide evidence that fluids are generally a mixture of young (<60 yr) and old waters. In addition, deep groundwater generally increases in age from west to east. Groundwater from the greatest depths typically shows no indication of anthropogenic influence.

The understanding gained from utilizing data in numerical models to test conceptual models has led to assessment of the monitoring network. Well networks are evaluated in context of area-specific contaminant issues. The goal of the network assessments is to meet 95% likelihood of detection of potential contamination in regional groundwater prior to arrival at a water-supply well or the Laboratory boundary. Network assessments consider the location of wells and well screens, the physical condition of wells, and their geochemical performance, to produce an optimized and enhanced monitoring network.

Utilization of EBTAG Data to Support the Santa Fe County Well Drilling Program

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In investigating potential well sites and design of wells, Santa Fe County Water and Waste Water Operations relies on data regarding the Santa Fe Group as analyzed by the New Mexico Office of the State Engineer, the NM Bureau of Geology and Mineral Resources, and the U.S. Geological Survey. A well recently drilled to serve the new public works building was designed to capture a high porosity unit measured by borehole geophysical logs for the County-State Land piezometer. Due to the proximity of this piezometer, less than 1000 feet, permission was obtained by from the OSE and USGS to utilize this piezometer as a monitoring well during pump test of the public works well. The well was drilled to a depth of 920 feet, perforated from 710 to 910 feet and pumped for 20 hours at a rate of 148.5 gpm. Total drawdown at the well was 22.5 feet but no response in water levels was measured in the monitoring well. Transmissivity was estimated at 1052.5 ft^2/day which is a higher rate than reported in wells of similar depth near the Community College and Las Campanas. Sieve analysis of cuttings of the high porosity unit showed course sand as the primary grain size. Summary analysis of the aquifer in this area shows favorable conditions for a municipal well.

An Exploration Drilling Project in the Rio Puerco Valley and an Unresolved Geologic Puzzle

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In the summer of 2007 a drilling program was conducted in the Rio Puerco Valley, west of the city of Rio Rancho. The objective was to discover brackish groundwater in Mesozoic and Paleozoic formations below the State's jurisdictional depth of 2,000 ft in producible volumes that would justify installation of an on-site desalinization plant. The program consisted of two wells, designated EXP-5 and EXP-6. The project's principals were Sandoval County and Recorp Partners of Scottsdale, AZ.

The project area lies within the Rio Puerco fault zone, a complex zone of northeast-trending normal faults with a generally down-to-the-east sense of dip slip. One of these faults – the Moquino fault – occurs between the two wells. The surface bedrock units are of Upper Cretaceous-age to the west and Miocene-age to the east.

A few, widely-spaced wells have been drilled over the years in the quest for oil and natural gas. Published data from these wells, a stratigraphic cross section through the Cretaceous strata of the Albuquerque basin, and surface geologic maps provided the key interpretative framework.

The first project well drilled was EXP-6. Once below a thin skin of alluvium the borehole entered the coal-bearing Menefee Formation in the upper part of the Cretaceous section, followed by a section of sandstones and mudstones of uncertain affinity. At 1,685 ft, the well topped a massive anhydrite. This unique unit was the Todilto Formation of Middle Jurassic age – a true stratigraphic "Rosetta Stone" – which anchored subsequent correlations both back up and down the hole. It was clear that a considerable thickness of section had been faulted out above the Todilto Formation.

The well continued drilling through Triassic redbeds and entered the Permian section at 3,719 ft. The Permian-age couplet of the San Andres Limestone and the underlying Glorieta Sandstone – so important as a regional aquifer to the west – was a principal target of the well. At 3,772 ft, in the Glorieta Sandstone, the well experienced a "kick" and brackish water flowed to the surface at an estimated rate of about 900 GPM through a 2" valve, carrying large volumes of red Triassic mudstone with it. After gaining control a liner was set to the top of the Permian and the big rig moved off. A completion rig drilled EXP-6 to a total depth of 3,840 ft, about 30 ft into the Permian-age Yeso Formation.

The second well, EXP-5, was positioned about a mile to the west, at the foot of a cliff of Cretaceous-age Gallup Sandstone in the middle part of the Cretaceous section. The well encountered the definitive Todilto anhydrite at 1,448 ft, and drilled a "normal" (i.e., unfaulted) section from the Cretaceous down to the top of Precambrian granitic basement at 6,350 ft. Total depth was 6,450 ft. No flows of water comparable to that in EXP-6 were encountered in EXP-5.

A critical, unresolved structural issue is the amount of section faulted out in the EXP-6 well, or, put another way, the amount of throw on the Moquino fault. Such a determination is needed to predict formation depths, and therefore drilling times and casing programs for future wells drilled east of the fault. Estimation of the amount of throw hinges on a reliable correlation of the partial Cretaceous sections drilled by the two wells to a Cretaceous standard, but such a standard is currently lacking. The throw on the fault thus remains a puzzle. I tentatively conclude that it may be as high as 1,850 ft. Validation of this number must remain contingent on comparison of EXP-5 and EXP-6 to a "normal" Cretaceous section drilled by a future well.

Analysis of Historic Seepage Investigations on the Santa Fe River, New Mexico

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Fourteen separate seepage investigations have been conducted on the Santa Fe River from May of 1973 to April of 2007. The first six of these studies measured from below Nichols Reservoir to the current gage at the mouth of the canyon Santa Fe River above Cochiti Lake which is located 7.9 miles above the confluence with the Rio Grande. The next eight seepage investigations were conducted on specific reaches. Two of these 1997 measurement studies were conducted 1-1/2 miles downstream of the gage at the Santa Fe River above Cochiti. The five most recent investigations were conducted from near the St. Francis Bridge or the gage above St. Francis, downstream on the reach of the river that flows over the Santa Fe Municipal well field.

The Santa Fe River upstream of St. Francis has several diversions and urban runoff inflows so no consistent gain or loss is apparent. The next seven miles downstream of St. Francis has shown a rather consistent loss until the Siler Road or Airport Road wastewater treatment plant inflows. Downstream from the wastewater inflows, the streamflow tends to increase in magnitude partly due to inflow from La Cienega and Alamo Creeks. Downstream from the gage above Cochiti the streamflow appears to diminish.

For each specific reach of the Santa Fe River, a flow difference per mile can be calculated and partly explained by the magnitude of the upstream streamflow and the water temperature. The flow difference per mile increases as the flow approaches full channel flow. Water temperature affects viscosity which also has an effect on channel infiltration.

Chemical Fingerprints of the Bandelier Tuff: Implications toAccurate Characterizations and Correlations of the Cooling Units

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The Quaternary Bandelier Tuff erupted from the Toledo and Valles Calderas of the Jemez volcanic field in north central New Mexico and covers the Pajarito Plateau of the Española Basin and the adjacent rift shoulder to the west. The upper and lower Bandelier Tuffs yielded ages of 1.22 and 1.62 Ma and consist of a series of units defined by basal thinner pumice fallout deposits that heralded the eruptions of rapid successions of thick ash-flow tuff deposits. Several primary pumice fallout layers and tuffaceous sediments of the Cerro Toledo interval separate the lower and upper deposits of the Bandelier Tuff.

Chemical and chronological results from distal and proximal pyroclastic or tephra deposits provide temporal and spatial constraints to local and regional stratigraphic sequences, geological processes, and to paleontological, archaeological, and paleoclimatic records in continental and marine settings. The Bandelier Tuff is chemically and chronologically well characterized. The tuff deposits were erupted in rapid succession, resulting in discrete cooling units that are characterized by lateral and vertical physical, mineralogical, and chemical variations. However, chemical and mineralogical compositions of bulk tephra samples are compromised by contamination from lithic fragments and by differences in mineral content between proximal and distal deposits of the same unit related to phenocryst sorting during eruption. To minimize the influence of contamination and physical processes, major, trace, and rare earth element compositions of tephra are best determined on discrete or bulk glass shards that are carefully separated from bulk samples. Major, trace, and rare earth element results from electron microprobe and inductively coupled plasma mass spectrometer laser ablation (ICPMS-LA) analyses of discrete glass shards or pumices of the Bandelier Tuff and the intervening Cerro Toledo interval pumice beds provide detailed chemical compositions of the various cooling units. Unlike chemical results from bulk analysis, the glass shard chemistry represents the magmatic composition of the unit and it does not vary with distance from the eruption center.

With few exceptions, the Bandelier Tuff and the Cerro Toledo interval glass shards exhibit minor variations in their major element compositions. However, variation diagrams of trace and rare earth element ratios indicate compositional variations that represent distinct chemical fingerprints for each of the units. The chemical fingerprints provide reliable chemical data for establishing accurate correlations between outcrops and subsurface stratigraphic and hydrostratigraphic units of the Bandelier Tuff across the Pajarito Plateau and beyond.