U.S. Geological Survey Middle Rio Grande Basin Study--Proceedings of the First Annual Workshop, Denver, Colorado, November 12-14, 1996

By James R. Bartolino, editor

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CONVERSION FACTORS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
foot per day (ft/day)	0.3048	meter per day (m/day)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch (in.)	25.4	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
inch per year (in./yr)	2.54	centimeter per year (cm/yr)
mile (mi)	1.609	kilometer (km)
microgal	0.000001	centimeter per square second (cm/s^2)
milligal	0.001	centimeter per square second (cm/s^2)
millimos per meter (mmhos/m)	1.000	millisiemen per meter (mS/m)
square mile (mi^2)	2.590	square kilometer (km^2)

Rock and soil sample colors are reported using the Inter Society Color Council-National Bureau of Standards (ISCS-NBS) color names and Munsell alpha-numeric notation.

Rock ages are reported in thousands of years before the present (ka) and millions of years before the present (Ma).

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8\,(°C) + 32.$$

Specific conductance is reported in microsiemens per centimeter (µS/cm) at 25 degrees Celsius.

Chemical concentrations in water (in weight-per-volume units) are reported in milligrams per liter (mg/L), micrograms per liter (µg/L), or picograms per liter (pg/L), which are roughly equivalent to parts per million (ppm), parts per billion (ppb), and parts per quadrillion, respectively, when concentrations are less than about 7,000 milligrams per liter.

Chemical concentrations (in weight-per-weight units) are reported in percent by weight (wt%), micrograms per kilogram (µg/kg), and picograms per kilogram (pg/kg), which are equivalent to parts per hundred, parts per billion (ppb), and parts per quadrillion, respectively.

Chemical concentrations (in volume-per-volume units) are reported in cubic centimeters per liter (cc/L), which are equivalent to milliliters per liter (ml/L) or parts per thousand (ppt).

INTRODUCTION

Approximately 40 percent (about 600,000 people) of the total population of New Mexico lives within the Middle Rio Grande Basin, which includes the City of Albuquerque (fig. 1). Ongoing analyses of the central portion of the Middle Rio Grande Basin by the U.S. Geological Survey (USGS) in coöperation with the City of Albuquerque and other cooperators have shown that ground water in the basin is not as readily accessible as earlier studies indicated. A more complete characterization of the ground-water resources of the entire Middle Rio Grande Basin is hampered by a scarcity of data in the northern and southern areas of the basin.

The USGS Middle Rio Grande Basin Study is a 5-year effort by the USGS and other agencies to improve the understanding of the hydrology, geology, and land-surface characteristics of the Middle Rio Grande Basin. The primary objective of this study is to improve the understanding of the water resources of the basin. Of particular interest is to determine the extent of hydrologic connection between the Rio Grande and the Santa Fe Group aquifer. Additionally, ground-water quality affects the availability of water supplies in the basin. Improving the existing USGS-constructed ground-water flow model of the Middle Rio Grande Basin will integrate all the various tasks that improve our knowledge of the various components of the Middle Rio Grande water budget. Part of this improvement will be accompanied by extended knowledge of the aquifer system beyond the Albuquerque area into the northern and southern reaches of the basin. Other improvements will be based on understanding gained through process-oriented research and improved geologic characterization of the deposits. The USGS will study the hydrology, geology, and land-surface characteristics of the basin to provide the scientific information needed for water-resources management and for managers to plan for water supplies needed for a growing population.

To facilitate exchange of information among the many USGS scientists working in the Middle Rio Grande Basin, yearly technical meetings are planned for the anticipated 5-year study. These meetings provide an opportunity to present research results and plan new field efforts. This report documents the results of research presented at the first technical workshop held in Denver, Colorado, in November 1996.

The report is organized into this introduction, five chapters that focus on USGS investigations in progress in the Middle Rio Grande Basin, and three appendixes with supplemental information. The first chapter provides an overview of the USGS program in the basin. The second chapter describes geographic data and analysis efforts in the basin. The third chapter details work being done on the hydrogeologic framework of the basin. The fourth chapter describes studies on ground-water availability in the basin and is divided into three areas of research: ground-water/surface-water interaction, ground-water flow and aquifer properties, and recharge. The fifth chapter is devoted to an overview of New Mexico District Cooperative Program studies in the basin. Finally, the appendixes list publications and presentations made during the first year of the study and 1996 workshop attendees. The report concludes with a list of selected references relevant to the study.

The information in this report presents preliminary results of an evolving study. As the study progresses and individual projects publish their results in more detail, the USGS hopes to expand the scientific basis needed for management decisions regarding the Middle Rio Grande Basin.

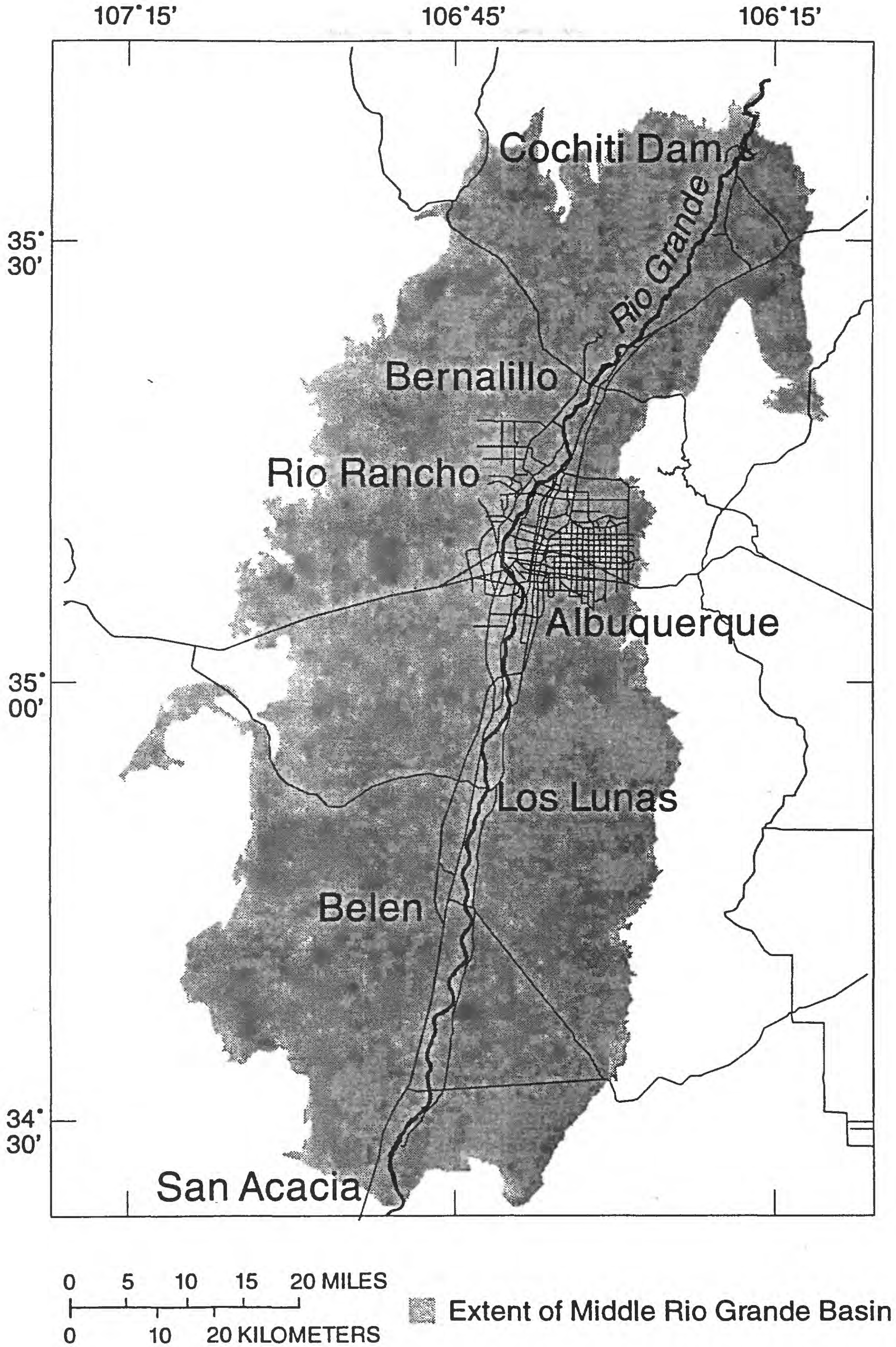

Figure 1.--Extent of the Middle Rio Grande Basin, central New Mexico.

GENERAL REMARKS

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES INVOLVEMENT IN THE USGS STATEMAP PROGRAM

By Paul W. Bauer[1]

Vast areas of New Mexico have yet to be mapped in detail. For purposes of the people of New Mexico and the national 1:100,000-scale geologic map data base, the most critical unmapped areas are the populated areas of the Rio Grande corridor. Most of this corridor is of vital economic, social, and scientific welfare for the State. The most immediate challenge to cities along the corridor relate to water. A combination of rapid population growth, permeable alluvial aquifers, large topographic relief, and the alternating scarcity and abundance of meteoric water gives rise to a host of hydrogeologic and engineering geologic problems. The Albuquerque, Española, and San Luis Basins and adjacent uplifts have become the focus of geologic and hydrogeologic interest by local, tribal, State, and Federal officials due to concern over the quality of ground water for an expanding population. Understanding watersheds and basin-fill stratigraphy is critical for ensuring potable water for the future and for mitigating contamination of aquifers. An understanding of surficial deposits provides critical data on flood-prone zones, areas subject to mass wasting, and soil and sediment properties that influence construction plans and land management. Geologic structures also control ground-water flow; in particular, the hydrogeologic significance of both rift-related normal faults and transverse fault zones is uncertain.

During the first 5 years of the STATEMAP program, the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) will have received $442,751 in matching-funds grants to produce detailed geologic maps of 26 7.5-minute quadrangles along the Rio Grande watershed between Albuquerque and Taos. The quadrangles are: 1993--Tijeras; 1994--Albuquerque East, Sandia Crest, and Placitas; 1995--Sandia Park, Hubbell Spring, and McClure Reservoir; 1996--Mount Washington, Sky Village SE, Alameda, Isleta, Taos SW, Glorieta, Santo Domingo Pueblo, and Jemez Pueblo; 1997--Albuquerque West, Bernalillo, Santo Domingo Pueblo SW, San Ysidro, Loma Creston, San Felipe Pueblo NE, Seton Village, Sedillo, Bosque Peak, Carson, and Dalies.

These quadrangles were selected on the basis of their potential to provide high-quality earth-science data to potential users, with the highest rankings in areas that combine compelling socioeconomic needs with basic scientific problems. The important societal needs that we have identified along the Rio Grande watershed are environmental (ground-water and surface-water supply, availability, and quality; geologic hazards such as flooding, hydrocompaction, and slope stability), earth resources (metallic minerals, industrial minerals, aggregate, and rock resources), land-use planning (landform dynamics, soil properties, water rights, and so on), and transportation. Several of the quadrangles also map rocks (Proterozoic to Cenozoic in age) that are the focus of topical, ongoing investigations in rock and mineral resources, structural geology, stratigraphy and sedimentology, basin evolution, and tectonics. An additional component of evaluating societal needs is the potential for beneficial use of a map by government bodies (State, county, tribal, and local) and private organizations (environmental, planners, developers, and citizens groups). The NMBMMR has actively cultivated working relationships with numerous such groups, all of which have expressed a need for detailed geologic maps. The NMBMMR and the State Geologic Mapping Advisory Board, which consists of 25 members from Federal, State, county, municipal, tribal, and private agencies, is responsible for ranking mapping proposals in New Mexico.

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[1]New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico

Due to the geologic complexity of most areas, we typically take a multidisciplinary approach to mapping, which utilizes a number of specialists from the NMBMMR, New Mexico Institute of Technology, University of New Mexico, and independent mappers for various aspects of the project. We work closely with USGS Geologic Division personnel involved in the Middle Rio Grande Basin Project and expect nearly all our maps to be used in the USGS 1:100,000 compilation of the Albuquerque Basin.

Our objective is to produce digital, detailed geologic maps (1:24,000), with accompanying explanation of units, cross sections, stratigraphic sections, and explanatory texts. In each quadrangle, the work will emphasize both bedrock lithologies and structures, and surficial basin- and arroyo-valley-fill deposits and their importance to ground-water resources. All quads are released as Open-File Reports at the end of the contract year, and many of the maps will be digitized and released as color geologic maps. To date, our STATEMAP geologic maps are of excellent quality, were all completed on schedule and within budget, and are available as Open-File Reports.

THE MIDDLE RIO GRANDE BASIN PROJECT OF THE U.S. GEOLOGICAL SURVEY AND THE NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

By David A. Sawyer[1], Ren A. Thompson[1], and Charles E. Chapin[2]

The Middle Rio Grande Project is a 5-year effort to develop state-of-the art digital geologic map datasets to address critical societal problems in the middle Rio Grande region of New Mexico. Centered on the Albuquerque Basin of the Rio Grande Rift, the map area also includes the Sandia and Manzano Uplifts bordering the basin; the southern Española Basin, Jemez Mountains, Valles Caldera, and Nacimiento Mountains to the north; and the east flank of the San Juan Basin to the west. Rapid urban growth in the Albuquerque and Santa Fe metropolitan areas has created a need for earth-science information to better manage land and water resources to meet the requirements of a burgeoning population. The presence of numerous Pueblo Indian reservations adjoining the areas of rapid growth necessitates that the effects of growth be minimized on traditional users of land and water. For these reasons, the USGS Geologic Division (GD) and the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) have embarked upon this project funded largely by the USGS National Cooperative Geologic Mapping Program, including its STATEMAP component.

The principal resource in limited supply is ground water, the source for virtually all drinking water for urban areas in the region. A USGS interdivisional effort (GD, Water Resources Division, and National Mapping Division), in cooperation with the NMBMMR, is addressing changing land use, the hydrogeologic framework of the Albuquerque Basin, and constraints on ground-water availability. Evaluation of current land use/land cover from aerial photography, Digital Line Graph revision, interpretation of satellite imagery, and comparison with historical data in a GIS system will provide the basis for trend analysis of land-use change. Delineation by geology and geophysics of subsurface extents of axial-channel gravel and sand in the upper and middle Santa Fe Group will be the basis for an improved hydrogeologic framework. Investigations of surface-water/ground-water interactions in the Holocene to Recent Rio Grande fluvial system, recharge into the basin from marginal mountain areas and by basin underflow, and ground-water quality, especially factors relating to arsenic distribution, will lead to a better understanding of ground-water availability.

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[2]New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico

THE MIDDLE RIO GRANDE BASIN STUDIES--AN OPPORTUNITY FOR ORGANIZATIONAL AND PROFESSIONAL GROWTH

By R.K. Livingston[1]

Recent hydrogeologic investigations of the Middle Rio Grande Basin, central New Mexico, have yielded new information about this important, highly complex stream-aquifer system that is strikingly different from what was once thought to be an extensive, high-yielding aquifer. Yet as that optimistic concept has faded to the reality of a much more limited resource, the dependence on this 3,000-mi^2 aquifer system, the water supply for almost 40 percent of the State's inhabitants, has if anything increased. The U.S. Census Bureau recently predicted that the State's population would increase by 55 percent by the year 2025, much of it due to migration from the rest of the country to the four counties in the basin. Thus, the ground-water resources of the Middle Rio Grande Basin are indeed critical from both regional and national perspectives. The USGS continues to play a key role in providing earth-science information of great value to those responsible for managing and administering this important resource.

The USGS study of the Middle Rio Grande Basin officially began in fiscal year 1996 and has become a USGS model of multidivisional efforts to address earth-science problems. Presently, the study includes activities carried out by four organizational units within the USGS: Geologic Division, National Mapping Division, and the National Research Program and the New Mexico District of the Water Resources Division. The following table summarizes for fiscal year 1996 the magnitude of the overall USGS effort among these organizational units:

Organizational unit	Approximate funding
Geologic Division	$1,200,000[1]
National Mapping Division	900,000
Water Resources Division	
National Research Program	380,000
New Mexico District	2,300,000[1]
Total	$4,780,000

[1]·Includes cooperator funds

Clearly the response of the USGS to the water-resources issues of the Middle Rio Grande Basin has been substantial, perhaps even unprecedented. Currently more than 70 personnel are directly involved in some phase of the effort, in addition to extensive well drilling, laboratory, and other support activities. Working as a multidivisional team and in cooperation with numerous State and local cooperators, the USGS is providing assistance that is (1) technically sound, (2) directed at solving problems for water users, and (3) coordinated with data collection and research of other agencies and earth scientists. Though this team approach has brought us new challenges, it has also

[1]U.S. Geological Survey, Albuquerque, New Mexico

brought us new appreciation for our individual and collective capabilities and respect for the quality work force of which we are a part. I hope you share with me a sense of pride in our progress this past year and of excitement and expectation as we continue to demonstrate our agency's ability to provide answers to one of many critical resource issues facing the Nation.

During this workshop, we will focus primarily on what we have accomplished during this past year, and learn from each other's experiences and insight as we plan for the future. However, we must not fail to realize that the success of the Middle Rio Grande Basin Study will be measured not only in terms of a feeling of accomplishment and scientific achievement within our organization, but also in the knowledge gained by others who must administer, manage, or depend on the water resources in the basin. Therefore, our discussion must be expanded to include better ways of conveying this knowledge so that its relevance and importance are clear to all. Effective outreach, like the professional growth we have experienced as participants in this multidivisional effort, will require putting aside our traditional approaches to achieving our mission and trying new and innovative communication techniques. This element of our work, like the technical issues we frequently encounter, will require thoughtful planning and careful execution. This, then, is our challenge for fiscal year 1997--to continue the outstanding work that began this past year, while integrating an ever-increasing element of information transfer to the many customers we serve.

GEOGRAPHIC DATA AND ANALYSIS

GEOGRAPHIC DATA AND ANALYSIS

By David Hester[1]

Project Objective:

Base cartographic data will be generated in support of the Middle Rio Grande Basin (MRGB) study. The base data produced will provide higher resolution and more recent datasets than are currently available from the USGS. Higher resolution base cartographic data will be used as the foundation for mapping the geology of the MRGB, analyzing the land surface, and enhancing the existing ground-water flow model.

Land-surface analysis will characterize the landscape processes and conditions of the MRGB and will help develop techniques for determining landscape change. Historical representations of developed land will be used to see where, how much, and what kind of development has occurred. Based on historical landscape patterns, land-use prediction methods will be investigated for forecasting which areas are likely to experience development and the subsequent effect on the MRGB hydrologic system.

In cooperation with the New Mexico Earth Data Analysis Center (EDAC), MRGB data will be disseminated through the Resource Geographic Information System (RGIS) clearinghouse node.

Project Methodology:

Project milestones are as follows:

Milestone 1: Collect 1996 1:40,000-scale black and white National Aerial Photography Program (NAPP) aerial photography.

Milestone 2: Complete 30-m digital elevation model (DEM) data.

Milestone 3: Digitize selected 1:24,000-scale digital line graph (DLG-3) themes.

Milestone 4: Create 37 1:24,000-scale digital raster graphic (DRG) products.

Milestone 5: Develop template identifying themes, features, and attributes necessary for land-surface characterization.

Milestone 6: In cooperation with the New Mexico EDAC, the USGS disseminates MRGB data through the RGIS clearinghouse.

Milestone 7: USGS State, Federal, and local agencies to determine requirements for 1-m black and white digital orthophoto quads, 10-m DEM's, and revised 1:24,000-scale DLG-3 data.

Milestone 8: Collect DLG-3 land-use and land-cover data for the Middle Rio Grande Council of Governments (MRGCOG) pilot area(s).

Milestone 9: Produce generalized 1:100,000-scale data.

Milestone 10: Characterize the historical and current MRGB landscape types and conditions within the MRGCOG pilot area(s).

Milestone 11: Construct an ARC/INFO data base for the MRGCOG pilot area(s).

Milestone 12: In cooperation with the MRGCOG, the USGS develops techniques for monitoring landscape processes and determining rates and patterns of landscape change.

Milestone 13: Develop a decision-support system that will model the land and water-resource decisions of local officials in the MRGB.

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[1]U.S. Geological Survey, Denver, Colorado

Fiscal Year 1996 Results:

Milestone 1: NAPP contract awarded to Geomatics.

Milestone 2: The 30-m DEM data collection is under way.

Milestone 3: Analog source material was provided for 1:24,000-scale DLG-3 contract digitizing.

Milestone 4: Thirty-seven 1:24,000-scale DRG's were completed.

HYDROGEOLOGIC FRAMEWORK

AIRBORNE GEOPHYSICS FOR HYDROGEOLOGIC AND GEOLOGIC MAPPING OF THE SUBSURFACE--ANTICIPATED RESULTS

By V.J.S. Grauch[1] and Victor F. Labson[1]

Airborne geophysical surveys will be acquired in the fall and winter of 1996 over three areas within the Middle Rio Grande Basin (fig. 2). The overall objective of the surveys is to help improve the understanding of the hydrogeologic framework of the Middle Rio Grande Basin and thereby improve the hydrologic model, especially to the north and south of Albuquerque where subsurface information is sparse. The survey areas are as follows:

(A) Rio Rancho-Sandia Pueblo surveys: A high-resolution aeromagnetic survey (100-m spacing and 100 m above ground level (AGL)) and a time-domain electromagnetic (TEM) and magnetic survey (400-m spacing with about 100-m AGL) to locate unknown or better define known faults and facies changes within the basin fill that may control ground-water flow, and to define the three-dimensional extent of the axial-river-channel aquifer in the subsurface. The TEM and more detailed magnetic surveys will be flown separately for economic reasons.

(B) Llano de Albuquerque survey: A detailed aeromagnetic survey (150-m spacing with 150-m AGL) for the purpose of mapping faults and the extent of basalt under a thin veneer of alluvium.

(C) Cochiti Pueblo survey: A TEM and magnetic survey (400-m spacing with about 100-m AGL) to define the three-dimensional extent of the axial-river-channel aquifer in the subsurface and to map subsurface lithologies.

Feasibility studies of the high-resolution magnetic data included analysis of 3-mi-spaced magnetic profiles flown at 300-400 ft above ground during the National Uranium Resource Evaluation (NURE) program during the 1970's. In one test area, the NURE magnetic data show small-amplitude changes corresponding to faults and lithologic contacts mapped from boreholes and surface exposures. It is anticipated that magnetic surveys of comparable height, but with better areal coverage, will provide more complete maps of these kinds of geologic contacts and will be especially useful where subsurface geologic information is lacking.

The main objective of the TEM surveys is to define the three-dimensional extent of the axial-river-channel aquifer in the subsurface, with anticipated results similar to those from an earlier study farther to the south, using an technologically less advanced system. The earlier studies discovered high resistivities that corresponded to a lithologic facies very similar to the target aquifer in the Albuquerque area.

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[1]U.S. Geological Survey, Denver, Colorado

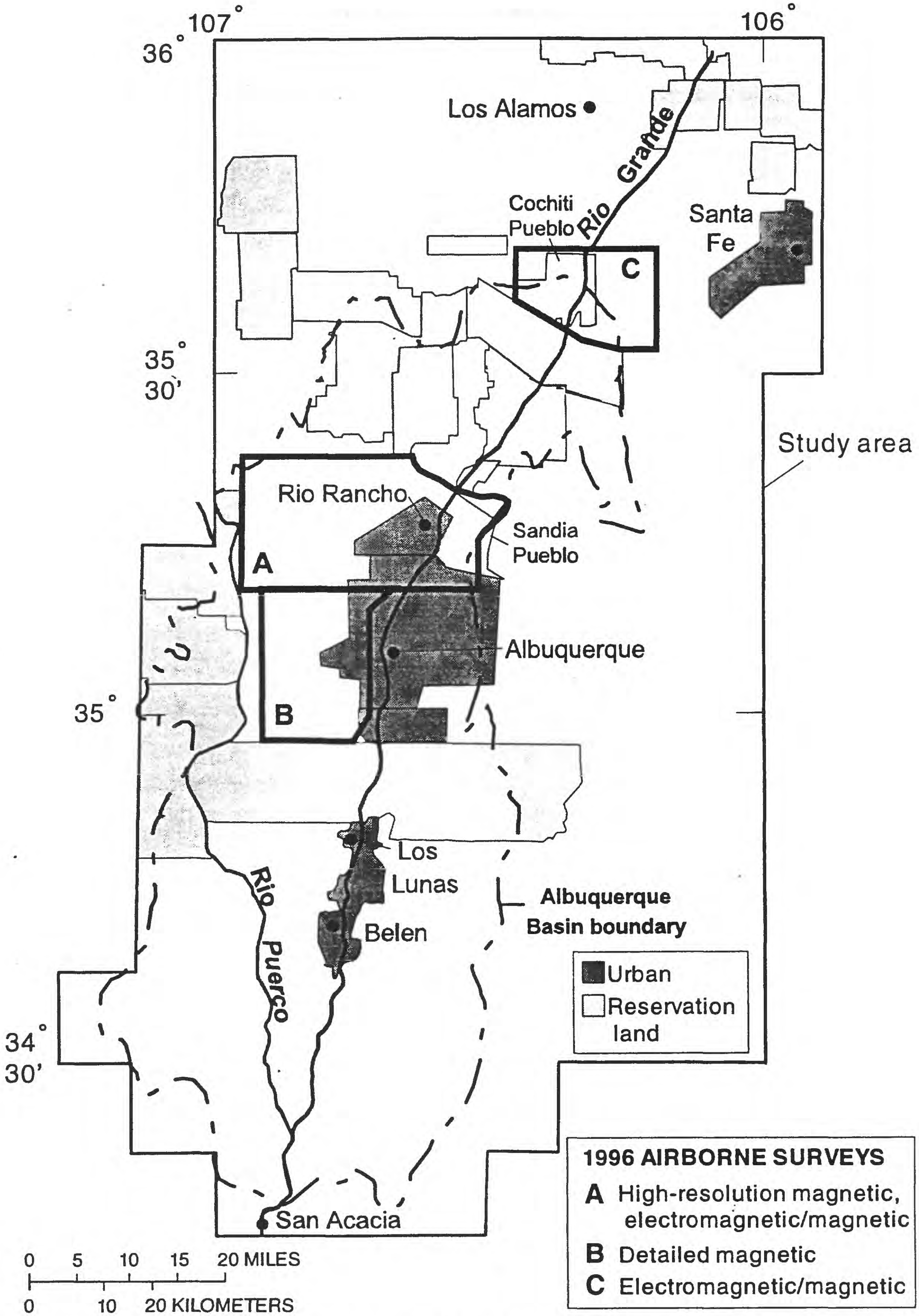

Figure 2.--Airborne geophysical surveys over the Middle Rio Grande Basin, 1996-97.

SEDIMENTOLOGICAL AND HYDROLOGICAL CHARACTERIZATION OF MIOCENE ALLUVIAL-SLOPE DEPOSITS IN THE ESPAÑOLA BASIN

By Andrika J. Kuhle[1] and Gary A. Smith[1]

Sediment derived from hanging-wall uplifts constitutes the largest aerial extent of fill in asymmetric basins, and non-fan, alluvial-slope deposits may be a significant part of this sediment. Thus, alluvial-slope deposits are voluminous and critical to understand in order to characterize the local ground-water flow regime or to determine contaminant migration scenarios. Miocene deposits in the hanging wall of the Pajarito Fault in the Española Basin, northern Rio Grande Rift, are unusually well exposed and provide the opportunity to describe deposition on a non-fan alluvial slope. The study site, located about 40 km north of Santa Fe, New Mexico, consists of a 150-m-thick section of vertically exposed, laterally continuous strata that are dominantly finer grained than axial deposits associated with the Rio Grande. These piedmont deposits, although voluminous, have rarely been addressed, and thus little is known about their hydraulic characteristics or a framework for their depositional environment, which can aid in making large-scale hydrologic models of the basin.

Eight lithofacies were defined and numerous stratigraphic sections were constructed in the study area. The lithofacies are varied and range from massively bioturbated, very fine sand and silt, to coarse and pebbly bedded sand, to well-sorted eolian fine sand. Massive silt with very fine sand is the most abundant lithofacies, followed by fine-sand channel deposits, then coarse pebbly channel deposits, and finally well-sorted, fine-sand eolian deposits. These lithofacies represent numerous small channels and adjacent flood plains on an alluvial slope.

Alluvial aquifer models have been developed for large river systems, and generally these models distinguish between two types of deposits: channel and overbank deposits, which have distinctly different hydraulic characteristics. Granulometric analyses were conducted for samples representing all the lithofacies and used to calculate empirical hydraulic conductivities. Calculated conductivity values range over two orders of magnitude and represent a fairly continuous range of values. For alluvial-slope deposits, a distinction cannot be made between channel and nonchannel deposits in terms of discrete hydraulic properties because channel facies vary over the entire range of values, and nonchannel eolian deposits are at least as conductive as some channel deposits.

More work will be done to quantify the hydraulic conductivities of the deposits by obtaining in situ permeability measurements using an air minipermeameter. Ultimately, the effects of diagenesis will be integrated into patterns of deposition for the different lithofacies to characterize heterogeneity beyond the first-order sedimentological control. Stochastic and process-based simulations will be developed to test against the actual outcrops, and ground-water flow simulations will be applied to the stratigraphic simulations.

[1]University of New Mexico, Albuquerque, New Mexico

GEOLOGIC FEATURES OF THE WIND MESA QUADRANGLE AND SURROUNDING AREAS, ISLETA PUEBLO, NEW MEXICO

By Florian Maldonado[1] and Arthur Atencio[1]

The Wind Mesa quadrangle (1:24,000) is located approximately 15 km southwest of Albuquerque, New Mexico, on the westernmost part of Isleta Pueblo Reservation. This quadrangle has been mapped as part of the geologic compilation of the Belen 1:100,000-scale geologic map. At least 11 quadrangles in the Belen sheet have been mapped or are in progress. The Wind Mesa quadrangle and parts of nine other quadrangles will also be used to compile the newly proposed 1:50,000-scale geologic map for the Isleta Pueblo. Wind Mesa and surrounding areas contain geologic features that include volcanic lava flows and cinder cones, fluvial deposits of the Sierra Ladrones Formation of the Santa Fe Group, local and extensive calcic soils, sand dunes, and high-angle normal faults.

The volcanic rocks include three basaltic fields: (1) the Cat Hills lava flows and associated cinder cones; (2) the Wind Mesa lava flows and cinder deposits; and (3) the Cat Mesa lava flows. Seven lava flows and at least 23 cinder cones are found in the Cat Hills field (Kudo and others, 1977), but only five lava flows and 15 cinder cones are found in the Wind Mesa Quadrangle. The Cat Hills flows are dated at about 140,000 years (Kudo and others, 1977). They probably erupted from south-trending fissures, and typically contain olivine and plagioclase phenocrysts. No major lava flows erupted from the cinder cones, thus the cinder cones probably represent the youngest volcanic event, although locally, thin flows are present on the flanks of some cones. This relation suggests that the flows are either associated with the cones or are older flows that may have been domed by the eruptions that formed the cones. Additional field work is needed to confirm this. The Wind Mesa field is composed of three lava flows and some cinder deposits. The flows contain olivine, plagioclase, and minor pyroxene phenocrysts. The flows have not been dated but have been interpreted to be of Pliocene age. Samples have been submitted for age determination. The Cat Mesa field contains lava flows that are intercalated in the upper part of the Sierra Ladrones Formation of the Santa Fe Group and are characterized by abundant plagioclase phenocrysts. The flows have not been dated but the field is probably of late Miocene because they are found in the upper part of the Sierra Ladrones Formation. Samples from the Cat Mesa field also have been submitted for age determination.

Much of the map area is underlain by a broad geomorphic surface known as the Llano de Albuquerque. This surface is formed on the top of the Sierra Ladrones Formation and is characterized by a well-developed calcic soil that outcrops along the margins of the mesa. In the Wind Mesa area, the lowest Cat Hills flow overlies the Llano de Albuquerque; thus, the Cat Hills and Cat Mesa flows bracket the age of the Llano. Other less developed calcic soils are found locally at or near the top of the Cat Hills cinder cones.

Eolian sands are deposited as dunes and as sheets. The larger dunes are found predominantly on the western edge of the mesa, and the sheets are found interior to the edge of the mesa. In some areas, the geometry of smaller dunes indicates a predominant southwest wind direction. Toward the interior of the mesa, sands appear to have been deposited against fault scarps, partially burying them; thus, the presence of thick sands in the interior of the essentially flat mesa can be used to infer buried fault scarps.

[1]U.S. Geological Survey, Denver, Colorado

Expressions of fault scarps on the mesa are very subtle except near the Wind Mesa volcanic field. The fault traces are part of a north-south-striking, high-angle normal fault system that probably forms a horst and graben system. The fissure location for eruption of the volcanic rocks on the mesa probably followed this fault system.

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QUATERNARY FAULT STUDIES IN THE MIDDLE RIO GRANDE REGION

By Stephen F. Personius[1]

The primary objective of Quaternary fault studies is to produce a digital map and data base of faults and folds that deform Quaternary deposits in the Middle Rio Grande region. This map will be a contribution to the multipurpose 100,000-scale geologic maps being produced as part of the geologic framework of the region, and the data base will be used to quantify potential earthquake hazards in the Albuquerque-Santa Fe urban corridor. As such, funding for these studies comes from both the Geologic Mapping Program and internal and external parts of the Earthquake Hazards Reduction Program of the USGS. Current projects include 1:24,000- or larger scale mapping in critical areas (Embudo, La Bajada, and "West Mesa" fault zones), 1:100,000-scale mapping of broader regions (statewide compilation of Quaternary structures, with focus on the Albuquerque-Belen Basin), and studies of trench and fault exposures (County Dump Fault and eastern strand of the Paradise fault zone).

A variety of data, in addition to mapped fault locations, are being acquired as part of these studies. Of primary importance is the recency of fault activity, which can be determined through detailed mapping and stratigraphic studies of offset deposits and through trench investigations. Soils studies and future applications of paleomagnetic, uranium series, and thermoluminescence (TL) dating techniques will aid in determining ages of faulted and unfaulted deposits. Such techniques will also be useful in trench investigations, which are designed to obtain data on the times and estimated sizes of paleoearthquakes recorded in deformed deposits. Accurate recurrence- and slip-rate data are necessary for probabilistic seismic-hazard evaluations.

Part of this project involves specific fault studies, one of which is being conducted in the cities of Albuquerque and Rio Rancho on the eastern strand of the Paradise fault zone (inadvertently misnamed by Personius, 1996 (Geological Society of America Abstracts with Programs, v. 87, no. 7, p. A378)). An exposure of this fault zone in the city of Albuquerque revealed evidence for at least two surface-faulting events in deposits of probable middle Pleistocene age. Pending TL ages may yield recurrence intervals and the elapsed time since the youngest faulting event. Although more than a dozen faults with demonstrated Quaternary movement are within 50 km of Albuquerque, trench studies of this kind have been conducted on only one other fault (County Dump Fault). Additional detailed studies on several more Quaternary structures are required before fault behaviors can be characterized and earthquake hazards in the region can be quantified.

[1]U.S. Geological Survey, Denver, Colorado

GEOCHEMICAL STUDIES OF ARSENIC IN DRILL-CORE AND GROUND-WATER SAMPLES, ALBUQUERQUE BASIN, NEW MEXICO

By Mark Stanton[1], David Grimes[1], Rick Sanzolone[1], and Steve Sutley[1]

Geochemical analyses of drill-core samples from the 98th Street test hole on the western margin of the Albuquerque Basin in central New Mexico are in progress to determine the residences, abundances, and relative mobility of As in Santa Fe Group basin-fill sediments. Ground-water samples from this newly completed well and additional sites are being analyzed for total inorganic As, inorganic As species (III and V), and major and trace-element concentrations.

Quaternary Santa Fe Group lithologies and grain sizes in the core include red, green, and tan clays; fine-, medium-, and coarse-grained quartz sands (some of which are Fe oxide stained); and gravels (uppermost 400 ft). Heavy minerals were noted in some intervals, but sulfides and organic matter generally were lacking throughout the 1,500-ft core. Depending on lithology, discrete or composite samples are used for grain-size and X-ray diffraction (XRD) analyses, partial sequential-extraction techniques, and clay separations. Solids are analyzed by inductively coupled plasma-atomic emission spectrometry (ICP-AES) for major and trace elements including As, extraction solutions are analyzed using inductively coupled plasma-mass spectrometry (ICP-MS) and ICP-AES techniques, and hydride generation-atomic absorption spectrometry (AAS) is performed on selected As-bearing samples. Bulk XRD has detected major quartz with minor abundances of kaolinite, montmorillonite, calcite, albite, and traces of orthoclase, anorthite, dolomite, and muscovite.

The solid-phase, partial sequential-extraction studies yield valuable information concerning the residence of As in the following operationally defined fractions: (1) water-soluble plus CO_3-exchangeable, (2) Mn-oxide and amorphous Fe oxide, (3) crystalline Fe oxide, (4) sulfide and organic, and (5) residual or "silicate." These five fractions combined represent total As in the solid phase; generally As mobility decreases from fraction 1 to fraction 5. The role of clay minerals in the residence and mobility of As is being investigated in specific intervals using similar extraction and analytical methods. Preliminary analyses indicate that high abundances of As in solid phases are associated with Fe oxides.

Measured field parameters for ground waters include temperature (°C), pH, specific conductance, Eh, dissolved oxygen, alkalinity, and dissolved Fe^{2+}. Aqueous As(III) and As(V) are separated in the field using ion-exchange methods, then analyzed using ICP-MS and atomic absorption spectrometry-graphite furnace; major anions are analyzed using ion chromatography. Analyses of thermal (40-°C) As-bearing ground waters in the northern part of the study area show high conductivities (5,000 μS/cm) and elevated levels of dissolved Fe (2.4 mg/L Fe^{2+}). The results of the study are being used to develop protocols for As preservation, speciation, and analysis based on the particular geochemical conditions in the basin and to provide indicators of subsurface As sources and processes by which As is mobilized from the solid phase to the aqueous phase.

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PRELIMINARY RESULTS FROM THE 98TH STREET STRATIGRAPHIC CORE HOLE, ALBUQUERQUE, NEW MEXICO

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In cooperation with the City of Albuquerque and the New Mexico Bureau of Mines and Mineral Resources, the USGS drilled a discontinuously sampled stratigraphic core hole to a total depth of 1,500 ft (457.2 m) into Santa Fe Group deposits on the west side of Albuquerque during September through November 1996. The core hole is located 3.5 mi (5.6 km) west of the Rio Grande and 0.49 mi (0.77 km) north of Interstate 40, on the east side of 98th Street (35°05'32"N., 106°44'52"W.). The core hole was located here to provide (1) core samples of typical nonlithified and lithified sediments of the upper part of the Santa Fe Group, (2) hydrogeologic characterization of sediments in the area, as previously inferred in the ground-water model of Kernodle and others (1995), and (3) a core hole stratigraphy to be calibrated with geophysical logging tools commonly used in studies of the middle Rio Grande aquifer. In addition, the core hole site is within 1.2 to 1.9 mi (2 to 3 km) of the Don 1, West Mesa 1 and 2, and College 1 and 2 municipal wells, all of which produce water with elevated values of arsenic, as high as 50 ppb in the Don 1 well. A second drill hole at the 98th Street site will contain three nested piezometers; thus, the site will also provide (4) sediment and water samples for analysis of arsenic species and determination of the origin of subsurface arsenic, and (5) an areally representative ground-water monitoring well more than 1 mi (1.6 km) distant from producing municipal wells.

The core hole site lies 400 to 450 ft (122 to 137 m) below the Llano de Albuquerque geomorphic surface to the west, in a small valley cut into Santa Fe deposits 2.6 mi (4.3 km) south of the Albuquerque volcanoes. The site is east of an inferred graben, which is bounded on the west by a fault related to the volcanoes and on the east by a fault expressed by linearly aligned erosional remnants of the Santa Fe Group. The core hole site may be on top of a horst, bounded to the east by an east-dipping fault that is inferred from stratigraphic correlations between College 1 and 2 wells. To the south, the core hole fault block is bounded by the Atrisco-Rincon fault zone, an oblique transverse zone that appears to offset south-trending extensional features (Hawley, 1996). The site is located on the west side of a gravity-low anomaly (Heywood, 1992), which is inferred to reflect mostly a thickening of the Santa Fe deposits in the metropolitan area depression of the central Albuquerque Basin of Hawley (1996).

Sampling recovered 751.5 ft (229.0 m) of core in segments that varied in diameter from 2.1 to 2.375 in. (5.3 to 6.0 cm) and in length from 0.2 to 10 ft (0.06 to 3.05 m). Sampled intervals were distributed evenly over the drilled depth. Cores penetrated all sediment types, although loose sand was selectively lost due to hydraulic erosion by drilling fluids in front of the drill bit. Other core-retrieval problems included thin, lithified zones that became lodged in the core barrel during continuous coring and plastic clay zones that did not break loose during retrieval. The samples are generally compacted but noncemented to very poorly cemented with calcium carbonate, characterized by a loose to very friable consistence for sand and a firm consistence for clay and silty clay.

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Six groups of sediments, distinguished by their lithic characteristics, characterize the core samples. The most abundant lithic group, comprising beds of silty fine-to-medium sand, is the most prevalent sediment type in units 2 and 3 (fig. 3). It consists of a fine sand mode, with a range of sand particles from very fine to medium, and scattered coarse sand grains in some beds. Coarse silt is dispersed as a matrix that partially fills pores. Sorting is poor, and the beds commonly appear massive to indistinctly laminated. However, some beds contain opaque dark minerals that form distinct laminae. The second most abundant lithology is clayey and sandy silt, brown to gray in color, very poorly sorted, generally massive but locally indistinctly laminated. This lithic group includes poorly sorted brown (7.5YR5/4) silty clay, clayey and sandy silt with scattered fine to medium sand grains, clayey silty sand, and beds composed of sets of microlaminated clay and silt. Red (2.5YR4/6) to reddish-brown (2.5-5YR5/4) clay is the third most prevalent lithic group and is composed of massive plastic clay in thin interbeds throughout the core. Clay beds and associated laminated silt and clay sequences constitute a major fine-grained interval in the lower part of unit 3 (fig. 3). The fourth most common lithic group, chiefly in the lower part of the core, comprises medium sand, scattered beds of medium to coarse sand, and beds of granular to pebbly sand. These beds consist of moderately well sorted light-brown to gray sand, without a silt matrix. The sand mineralogy appears to be, in decreasing abundance, quartz, pink orthoclase, plagioclase, hornblende, magnetite, and other heavy minerals, which is similar to feldspathic litharenite to lithic arkose compositions reported for other sands in the basin (Mozley and others, 1992). Interbedded sand and gravel is the fifth most abundant lithic group but is restricted to the upper 80 ft (24.4 m) of core and as scattered, thin bodies in lower intervals. Pebbles and granules in these beds, as well as in beds of medium to coarse sand, consist of quartzite, quartz, basalt, volcanic rocks of intermediate composition, pink granite and gneiss, sandstone, chert, and agate. Carbonate-cemented, indurated sandstone and minor siltstone are the least abundant lithic group, composing less than 2 percent of the total core. These lithified thin beds are scattered throughout the core below the 100-ft (30-m) depth. Carbonate in nodular concretions, discontinuous patches, and thin lenses is scattered throughout the core; carbonate morphology is controlled in part by grain size of the host beds (Mozley and others, 1992).

Based on preliminary field examination, the core is divided into four lithologic units that are defined primarily by their grain size, color, and composition (fig. 3). Unit 1, from the surface to an 18-ft (5.5-m) depth, consists of post-Santa Fe Group surficial sand and gravel, which contains moderately sorted fine sand in the upper part and fine to medium sand with scattered coarse sand beds, pebbles and cobbles, and gravel beds in the lower part. These late Quaternary deposits include eolian sand, mixed eolian and alluvial sand, and alluvial deposits that unconformably overlie the Santa Fe Group in the minor tributary valley. Interbedded sand and gravel of this unit are exposed in shallow arroyo channels south of the drill site. Unit 2, 18 to 80 ft (5.5 to 24.4 m) in depth, consists of interbedded yellowish-brown (10YR5/4) sand beds that are fine to coarse and moderately well sorted, and beds of framework gravel. The proportion of gravel beds increases and the size of gravel clasts coarsens downward through the unit to cobble gravel in the 61- to 80-ft (18.6- to 24.4-m) interval. This unit is the coarsest in the entire stratigraphic section and is a channel sand and gravel deposit that disconformably overlies unit 3. The upper part of unit 3, in the 80- to 240-ft (24.4- to 73.1-m) interval, consists of interbedded pale-brown (10YR6/3) to brown (7.5YR5/4) to light-brown (7.5YR6/4), silty, fine to medium sand that is poorly sorted, with scattered beds of medium to coarse sand, coarse sand with granules, silty clay, and clay. Massive reddish-brown (5YR4/3) clay beds, 0.5 to 1.0 ft (15 to 30.5 cm) thick, were sampled at 122 ft (37.2 m), 178 ft (54.2 m), and 208 ft (63.4 m). The lower part of unit 3, at 240 to 789 ft (73.1 to 240.5

m) in depth, is finer than the upper part and consists of interbedded thin beds of clayey and sandy silt, silty fine sand, brown (7.5YR5/4) silty clay, red (2.5YR4/6) to reddish-brown (2.5-5YR5/4) clay, and scattered beds of medium sand. Clay and silty clay beds make up a large proportion of the core below the depth of 435 ft (132.6 m). The 492- to 630-ft (150- to 192-m) interval includes numerous and relatively thick sequences of red and reddish-brown clay, and silt in sets of laminated beds commonly less than 2 ft (61 cm) thick but as much as 4.45 ft (1.36 m) thick. These laminated sets locally preserve delicate microlaminations of clay and silt, but most beds contain massive clay or silty clay. By contrast, the 709- to 755-ft (216.1- to 230.1-m) interval appears green, consisting of light-olive-brown (2.5Y5/2-4) to dark-grayish-brown (2.5Y4/2) silty clay and silty fine to medium sand. Unit 3 appears to be composed of a generally upward coarsening series of fluvial overbank deposits that may be contained in 3.3- to 33-ft- (1- to 10-m-) thick upward-fining units. Unit 4, at 789 to 1,500 ft (240.5 to 457.2 m) in depth, includes an upper part composed chiefly of sand, and a lower part composed of interbedded sand and silty clay beds. The upper part, which extends to a 1,250-ft (381-m) depth, consists chiefly of brown to dark-brown interbedded fine to medium sand, moderately sorted and without silt matrix, with scattered medium and coarse sand beds, granules and pebbles, and thin beds of pebble gravel. Scattered beds of silty fine sand and silty clay were sampled in the 1,035- to 1,096-ft (315.4- to 334-m) interval. At the depth of 1,096 ft (334 m), the color changed to notably lower chroma, typically grayish brown (10YR5/2), and grain size increased slightly with the inclusion of more medium sand beds. Sorted medium sands are also common below the depth of 1,100 ft (335.3 m), where these coarse beds are interbedded with scattered clay beds. Unit 4 is inferred to be channel-fill sand and fine gravel in the upper part, perhaps with a change in provenance at 1,096 ft (334 m). The lower part of unit 4, which contains sorted medium sand and fine gravel, also contains numerous thin silt and clay deposits, probably reflecting sedimentation in overbank areas.

The cored interval beneath the surficial sand and gravel deposit is in the upper and middle part of the Santa Fe Group (Lozinsky and others, 1991). The coarse-grained deposits in the 18- to 80-ft (5.5- to 24.4-m) interval of the core are correlated with the upper Santa Fe Group, Western Basin fluvial facies (USF-4 hydrostratigraphic unit of Hawley, 1996; previously the Ceja Member of the Santa Fe Formation of Kelley, 1977), which underlies the geomorphic surface of the Llano de Albuquerque. The lower part of the core, which contains typically red and reddish-brown clay beds, is similar to the Middle Red Member of the Santa Fe Formation of Kelley (1977), but may be correlated with either the upper (chiefly eastern or Rio Grande fluvial source areas) or the middle (chiefly western or northwestern fluvial-lacustrine source areas) Santa Fe transition-zone facies of Hawley (Hawley and Haase, 1992, fig. 4; Hawley, 1996, figs. 1-7). The precise age of the deposits remains conjectural. The age of the Llano de Albuquerque surface is constrained by minimal age estimates of its stage IV carbonate soil of more than 500 ka to about 1 Ma (Machette and others, 1997). No tephra or macro fossils were found in the core so the maximum age of any part of the core remains undefined. Paleomagnetic analysis shows that two samples from a 250-ft (76.2-m) depth have reversed polarity, indicating that sediments in the upper part of the core are more than 788 ka, the youngest age of the Matuyama reversed chronozone. No paleosols or major unconformities were sampled in the core. The cored interval likely spans a few million years and probably is older than the Matuyama reversed chronozone at the top.

The 98th Street site is located in model grid 122 South, 35 East of the ground-water model of Kernodle and others (1995). The previous estimates of average hydraulic conductivity for model layers 1-8 was 15 ft/day and for model layers 9 and 10 was 4 ft/day. On the basis of relations of permeability and grain size of uncemented samples of the Santa Fe Group (Detmer, 1995), the previous estimates appear inconsistent with core lithologic units. For example, silty fine to medium sand beds (mode 3.6 phi, d_{10} estimated 4 phi) in the saturated zone of core lithologic unit 3 yield empirical permeabilities of 3 to 10 ft/day. The medium sorted sands of the lower part of the core (mode 1.5 phi, d_{10} estimated 2 phi) yield empirical permeabilities of 14 to 40 ft/day (fig. 3) (Detmer, 1995, fig. 3).

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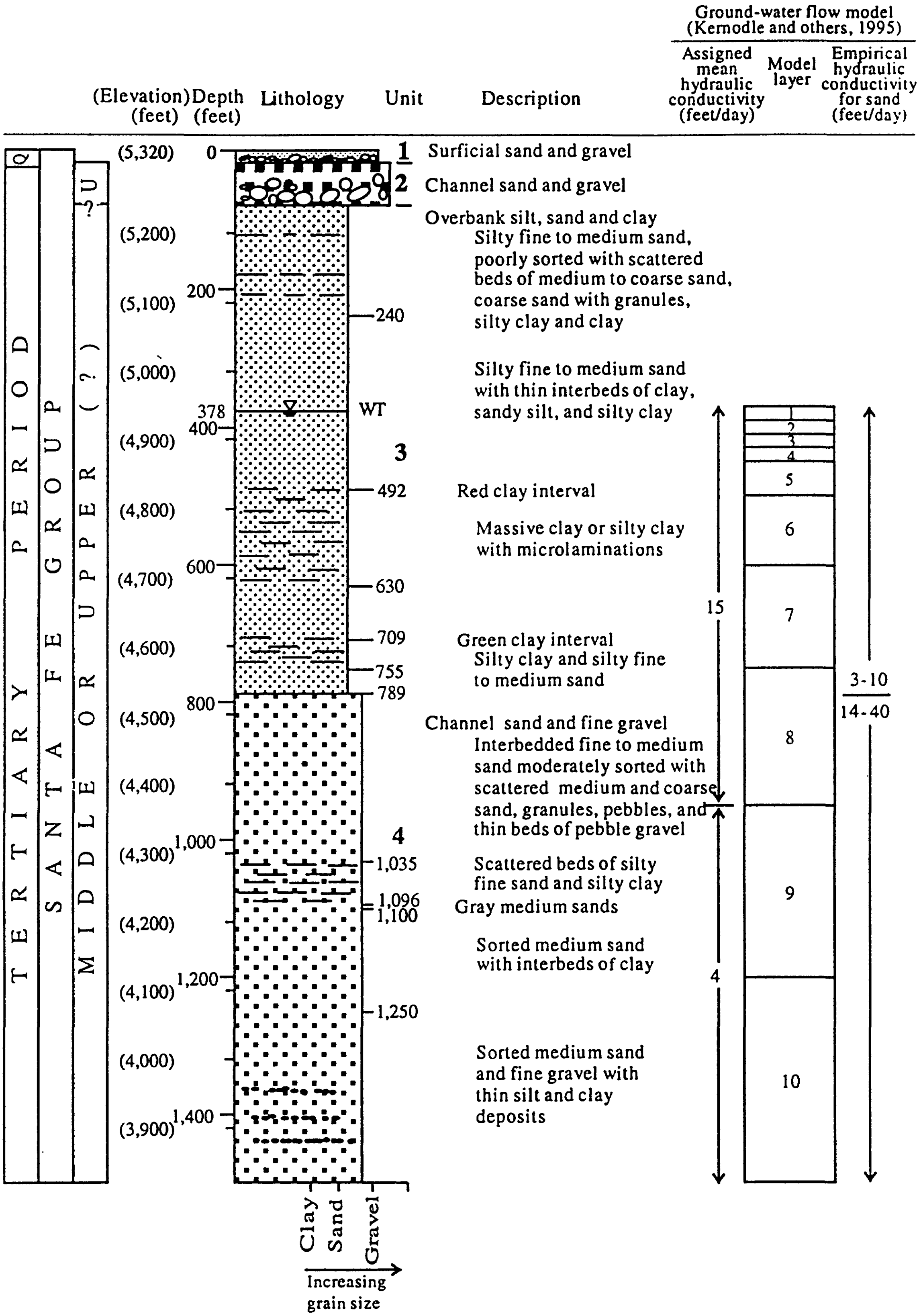

Figure 3.--Preliminary lithostratigraphy of the 98th Street stratigraphic core hole. Age symbol Q represents Quaternary Period; stage symbol U represents upper Santa Fe Group; WT represents water table.

THE CERROS DEL RIO VOLCANIC FIELD AND THE LA BAJADA FAULT SYSTEM--GEOLOGIC OVERVIEW AND STATUS REPORT

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The Cerros del Rio volcanic field is one of several middle Pliocene to Pleistocene basaltic volcanic fields of the Rio Grande Rift in northern and central New Mexico. From north to south, and with decreasing eruptive volume, these include major fields at Taos Plateau, Cerros del Rio, Santa Ana Mesa, and the small volume, short-lived centers at Albuquerque Volcanoes, Wind Mesa, and Cat Hills. Lavas and related pyroclastic and hydromagmatic deposits of the Cerros del Rio field occupy about 700 km^2 and may represent as much 120 km^3 of mafic magma erupted concurrently with large-volume silicic eruptions of the Jemez volcanic field. The field is bounded by the La Bajada and Pajarito Faults on the southwest and northwest, respectively, and is underlain by basin-fill sediments of the Pliocene Santa Fe Group to the north and east. To the west are Puye Formation and Cochiti Formation volcaniclastic deposits shed from the Jemez volcanic highland, and paleo Rio Grande axial-channel deposits. In this context, the Cerros del Rio volcanic field forms the northeastern extent of the bedrock recharge area and overlies Santa Fe Group underflow into the Santo Domingo subbasin.

Eruptive centers of the Cerros del Rio volcanic field are typically central vent volcanoes, ranging from low-relief shield centers to steep-sided, breached cinder cone remnants. Associated lavas range from 49 to 64 wt% SiO_2 and exhibit strong geomorphic correlation with whole-rock chemistry. Low-silica, subalkaline basaltic lavas (less than 52 wt% SiO_2) are thin (less than 3-4 m), far-traveled, and erupted from broad shield volcanoes. Transitional to mildly alkaline basalts and basaltic andesites (50 to 57 wt% SiO_2 and more than 5 wt% Na_2O+K_2O) occur as thick (to 30 m), discontinuous lavas erupted from high-relief, steep-sided, dissected vents. Dacite lavas (more than 63 wt% SiO_2) occur high in the section and are related to late-stage dome growth and eruption of thick (to 50 m) blocky lava flows from poorly defined vent areas.

The northern part of the field largely predates eruption of the Bandelier Tuff and was emplaced during an approximately half-million-year interval based on recent $^{40}Ar/^{39}Ar$ age determinations (2.8 to 2.3 Ma; Woldegabriel and others, 1996). Lava flows in the southern Cerros del Rio field both predate and postdate the Otowi Member (1.61 Ma) of the Bandelier Tuff, and recent mapping (Dethier, Personius, Thompson, Sawyer, and Scott; unpublished data) suggests ages postdating emplacement of the Tshirege Member (1.22 Ma) of the Bandelier Tuff.

Stratigraphic thickness of the volcanic section varies from a few meters for single flows on the margins of the field to more than 250 m in steep escarpments of White Rock Canyon and tributaries to the Rio Grande. Here, detailed stratigraphic reconstructions facilitated by additional $^{40}Ar/^{39}Ar$ age determinations, whole-rock major- and trace-element geochemistry, and detailed petrographic and mineral chemistry analysis will accompany geologic map compilation at 1:50,000 scale and are scheduled for completion by late 1997. Correlation of lava flows or genetically related flow packages across major segments of the La Bajada Fault, both on the surface and from subsurface data, will be used to constrain magnitude and offset along this major basin-bounding structure.

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As a first step toward characterizing geologic attributes of major faults within the greater Albuquerque Basin, various physical characteristics of the basin-bounding La Bajada fault zone have been documented at several localities. Numerous individual, interconnected fault surfaces with normal offsets ranging from centimeters to hundreds of meters compose the fault zone. Along much of its northern part the fault zone is concealed by landslide debris of Cerros del Rio basalt that was shed off the La Bajada escarpment probably in the Pleistocene. Where exposed along the base of the escarpment the fault zone obtains widths as great as about 300 m; older, northeast-striking, sinistral-oblique La Bajada relay faults extend a much greater distance eastward away from the basin underneath Cerros del Rio basalt flows. At exposures of individual La Bajada Fault surfaces, the following characteristics have been documented: (1) fault plane orientation, (2) fault core material and thickness, (3) extent and geometry of wall-rock fracturing (damage zone). (4) fault cementation minerals and distribution, (5) fault kinematics (slip vectors), (6) adjacent regional, systematic joint orientations, and (7) wall-rock bedding attitude. This information is being embedded as geo-referenced point attributes into digital fault layers for incorporation with the geologic data bases of the Los Alamos and Albuquerque 30' x 60' quadrangles, and into more detailed digital geologic data bases at 1:24,000 and 1:50,000 scales. Such embedded fault data should enhance the modeling of faults in geohydrologic flow models of the Middle Rio Grande Basin.

To date, significant fault-zone cementation features that reveal paleoflow patterns of ground water have been observed only in hanging-wall clastic sediments of the Santa Fe Group exposed on the west side of the La Bajada Fault. This observation suggests that the La Bajada Fault, where it juxtaposes bedrock against Santa Fe sediments, acted as a major conduit and source of ground water flowing into Santa Fe basin fill.

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URANIUM-LEAD GEOCHRONOLOGY OF PROTEROZOIC ROCKS IN CENTRAL NEW MEXICO

By Daniel M. Unruh[1], Paul W. Bauer[2], and Steven Ralser[3]

Uranium-lead isotopic analyses of zircon crystals have long been used as the most reliable method of determining the crystallization ages of felsic igneous rocks. Because of the chemical resistance of zircon to alteration by subsequent thermal metamorphism, determining the original age of emplacement of even highly deformed igneous bodies is often possible. In fact, zircon may be insoluble and its U-Pb system may remain at least partially undisturbed even through subsequent melting events. Igneous rocks derived from crustal protoliths commonly have zircons with xenocrystic cores. Uranium-lead analyses of such zircon produces apparent ages that are intermediate between the age of the protolith and the age of emplacement. Consequently, care must be taken in both the selection of individual zircons from the sample of interest and the interpretation of the data. A rare example of xenocrystic zircon coexisting as a discreet population with igneous zircon has been found in a granite dike in Estadio Canyon in the southern Manzano Mountains, central New Mexico.

The Estadio Canyon Dike was analyzed in an attempt to bracket the age of regional deformation in the southern Manzano Mountains. The dike, approximately 30 cm wide, intrudes quartzite and schist of the White Ridge Quartzite and is slightly discordant to the bedding. The dike is exposed approximately 200 m west of the Priest Pluton, dated by the U-Pb method at 1,423 ± 10 Ma (S.A. Bowring, oral commun., 1990). The White Ridge Quartzite is highly and multiply deformed, and field observations suggest that the dike was also deformed during regional deformation. If so, the age of regional deformation would be bounded by the age of the dike and the 1,423-Ma age of the relatively undeformed Priest Pluton.

Zircons in the Estadio Canyon Dike exhibit two morphologically distinct populations of different age (fig. 4). The dominant population (70-80%) consists of colorless to pale-pink, moderately to highly rounded crystals, some with pitted surfaces, a feature typically found among detrital zircons. These zircons yield an apparent average age of 1,643 ± 10 Ma. The subordinate population consists of colorless to pale-pink, euhedral, prismatic crystals with an apparent age of 1,438 ± 6 Ma. These latter features are typical of igneous zircon in granitic plutons, and we interpret 1,438 Ma to be the age of emplacement of the dike. This similarity in the ages of the dike and the Priest Pluton suggests that the dike may be an early phase of the Priest Pluton and that at least the last major deformation event in this area may be contemporaneous with and related to emplacement of the Priest Pluton.

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There is no evidence for intermediate ages among the analyses of single crystals; that is, no evidence for 1,643-Ma xenocrystic cores overgrown at 1,438 Ma, or for that matter, evidence of partial resetting of the U-Pb systems of the older zircons at 1,438 Ma. The intermediate ages obtained for many of the multigrain fractions are interpreted as reflecting mixed populations. These results suggest that the xenocrystic zircons were incorporated into the dike very late in its magmatic history, probably at the time of emplacement, and that the most likely source of these zircons is the surrounding White Ridge Quartzite. If this is true, then the 1,643-Ma age of these zircons must predate the onset of regional metamorphism.

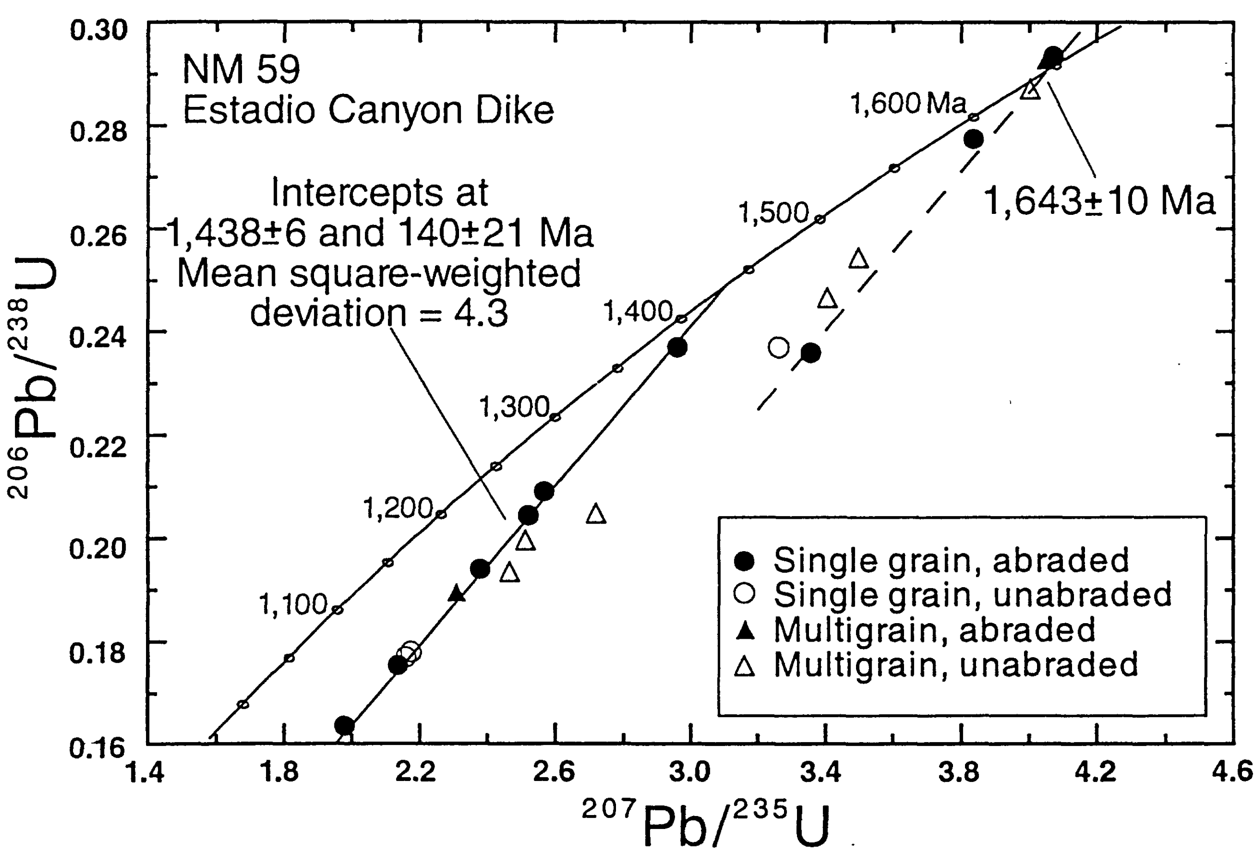

Figure 4.--U-Pb evolution for zircon from sample NM59, a granite dike in Estadio Canyon. The 1,438 ±6-Ma age is interpreted as the emplacement age of the dike, and the 1,643 ±10-Ma age represents the average age of xenocrystic zircon in the rock.

ELECTROMAGNETIC SURVEYS IN THE RIO GRANDE FLOOD PLAIN, MIDDLE RIO GRANDE BASIN, NEW MEXICO

By Dennis G. Woodward[1]

Quantifying the hydraulic linkage of the Rio Grande to the Santa Fe Group aquifer system is of prime importance in managing the water resources in the Middle Rio Grande Basin. The river and aquifer are linked through the approximately 80-ft-thick sequence of inner valley alluvium underlying the Rio Grande flood plain. These alluvial deposits, which contain sediments ranging from cobbles to clay, are a major factor controlling the volume of water that can move between the Rio Grande and the aquifer system. Horizontal hydraulic-conductivity values for the coarse deposits in the inner valley alluvium range from 65 to 350 ft/day and for silty clay can average 0.2 ft/day (McAda, 1996). Silty clay layers exist within much of the inner valley alluvium; although many of these layers are discontinuous, they have been found to be as thick as 15 to 20 ft locally. Knowledge of the distribution and geometry of silts and clays in the inner valley alluvium is essential for quantifying the ability of the alluvium to transmit water vertically between the Rio Grande and the Santa Fe Group aquifer system. This article describes the first and second phases of a study evaluating the use of electromagnetic surveys in providing this information.

In an effort to determine the presence or absence of significant silty clay layers buried in the inner valley alluvium, a series of electromagnetic surveys have been conducted at selected locations in the Albuquerque metropolitan area. During this initial phase of the study, the survey locations were selected in areas where existing subsurface information (generally drillers' logs) indicated either the presence or absence of significant silty clay deposits. Surveys were conducted using two ground transient electromagnetic systems: Geonics EM-47 (time domain) and EM-34 (frequency domain). The EM-47 surveys, which used 5-m loops, were not successful due to the presence of cultural "noise"--buried metallic objects in the flood plain, overhead power lines, or nearby fences. A total of 20 spreads, each 100 m long, were surveyed with the EM-34 system; each spread consisted of four stations, 20 m apart in line, where both horizontal and vertical dipole measurements were collected at three intercoil separation distances (5, 10, and 20 m). The 20 spreads were located along ditch roads and in parks in nine different areas.

All interpreted EM-34 results agreed with the subsurface "ground truth": where the drillers' logs showed no significant clay layers in the shallowest 100 ft of sediments, the EM results showed no clay layers, and where the drillers' logs showed significant clay layers, the EM results indicated the presence of clay layers. Generally, the EM-34 results showed that the sand, gravel, and cobble deposits had conductivity values ranging from 10 to 15 mmhos/m, and the buried silty clay deposits had conductivity values ranging from 40 to 60 mmhos/m.

The second phase of this study is scheduled to begin in the spring of 1997 when extensive EM-34 surveys will be conducted in areas in the flood plain where significant silty clay layers in the inner valley alluvium are suspected. This geophysical approach to delineate buried silty clay layers is anticipated to complement work scheduled to begin by the New Mexico Bureau of Mines and Mineral Resources to map buried silty clay layers by interpreting drillers' logs.

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GROUND-WATER AVAILABILITY

Ground-Water/Surface-Water Interaction

VERTICAL HYDRAULIC CONDUCTIVITY OF THE AQUIFER UNDERLYING THE RIO GRANDE USING TEMPERATURE PROFILES, MIDDLE RIO GRANDE BASIN, CENTRAL NEW MEXICO

By James R. Bartolino[1]

One of the most important questions concerning the hydrology of the Middle Rio Grande Basin, New Mexico, is how much water is recharged from the Rio Grande into the Santa Fe Group aquifer system. Currently (1996), the New Mexico State Engineer Office uses the methods of Glover and Balmer (1954) to estimate this volume of water. Results from a numerical model of the Albuquerque Basin (Kernodle and others, 1995), however, suggest that the Glover-Balmer equations overestimate the volume of water recharged from the river during the period of historical simulation (1901-94). This article describes the plan and progress of a study whose purpose is to determine the vertical hydraulic conductivity of the aquifer underlying the Rio Grande at several sites, and to use this information in conjunction with the Albuquerque Basin model of Kernodle and others (1995) to provide more accurate estimates of the volume of water recharged by the Rio Grande. By using the methods of Lapham (1989), vertical hydraulic conductivity will be modeled using piezometer core data and vertical temperature profiles.

Seven piezometer nests were installed in July and August 1996 at four sites along the Rio Grande in the Albuquerque area: upstream from the State Highway 44 bridge in Bernalillo; upstream from the Rio Rancho sewage treatment plant in Corrales; upstream from the Paseo del Norte bridge in Albuquerque; and upstream from the Rio Bravo bridge in Albuquerque. At each of the first three sites, one piezometer nest is located on the bank and the other nest is on a sandbar in the river channel. At Rio Bravo, only one nest was installed on the bank because of the lack of accessible sandbars. Three piezometers were installed at different depths in each nest (except the sandbar nest at Bernalillo where only two piezometers were installed due to the shallow depth). All piezometers were completed in river valley alluvium of the Santa Fe Group aquifer system. During installation, a core was collected at each nest for determinations of wet- and dry-bulk densities.

Once a month, the vertical temperature profile will be measured in the deepest piezometer in each nest and water levels will be measured in all piezometers. In addition, one deep piezometer in existing piezometer nests at the Paseo del Norte and Rio Bravo sites will be temperature logged at the same time to confirm results for the shallow piezometers installed for this study.

Hydraulic conductivity will be modeled using the measured temperature profiles and the sediment properties at each nest with either the SUTRA model of Voss (1984) or the VS2DH model of Healy and Ronan (1996). Monthly temperature logging began in September 1996, and sediment samples were sent to a laboratory in October 1996. Temperatures will be logged for a minimum of 1 year to obtain representative results.

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TRACING YOUNG WATER IN THE MIDDLE RIO GRANDE BASIN, ALBUQUERQUE, NEW MEXICO--A PROGRESS REPORT

By L. Niel Plummer[1], Eurybiades Busenberg[1], and Laura M. Bexfield[2]

Concentrations of environmental tracers and other natural chemical and isotopic substances are being determined in ground water from the Santa Fe Group in the vicinity of Albuquerque, New Mexico, and regionally throughout the Middle Rio Grande Basin. The analyses include major- and minor-element chemistry, tritium (^3H), tritiogenic helium-3 (^3He), chlorofluorocarbons (CFC-11, CFC-12, CFC-113), sulfur hexafluoride (SF_6), oxygen-18 ($\delta^{18}O$), and deuterium (δD) in water, carbon-13 (^{13}C) and carbon-14 (^{14}C) of dissolved inorganic carbon (DIC), and other dissolved gases (including dissolved oxygen, nitrogen, argon, and carbon dioxide). These data are being used to (1) identify recharge areas, (2) date the young (0 to 50 years) and old (greater than 2,000 years) water in the aquifer, (3) trace movement of young (post-1940's) ground water, and (4) estimate recharge rates. ^{14}C, δD, $\delta^{18}O$, and dissolved-gas data are being used to determine whether paleowater (water recharged during the last glacial period) is present in the basin. Data on $^3H/^3He$ and CFC's are being used to date recent recharge along the mountain front and to date the young fraction in ground-water mixtures, such as water pumped from wells open to large intervals in the Santa Fe Group aquifer that may contain components of river water and/or mountain-front recharge. Such information will (1) help refine the ground-water flow model (Kernodle and others, 1995) developed for the Albuquerque Basin by providing improved estimates of recharge to the aquifer system and estimates of ground-water age that can be compared to model-predicted age, and (2) address issues related to streamflow loss from the Rio Grande near Albuquerque by tracking movement of water from the Rio Grande and from the drain and canal system into the Santa Fe Group aquifer in response to ground-water withdrawals in the Albuquerque area.

Seventy-six municipal, domestic, and monitoring wells were sampled in the vicinity of Albuquerque in June 1996, and another 66 wells were sampled regionally throughout the Middle Rio Grande Basin in August 1996. In addition, seven samples of Rio Grande water were collected and five springs were sampled during the summer of 1996. Two City of Albuquerque production wells were sampled periodically over an 8-hour period following startup. The sampling also included air and shallow (less than 1 m) soil gas. Most of the samples are currently being analyzed.

Preliminary data on dissolved nitrogen and argon indicate that recharge temperature is mostly in the range of 10 to 20 °C, and water from many wells recharged at temperatures within ± 2 °C of the mean annual temperature 13.6 °C at Albuquerque. Most water contains 0 to 15 cc/L of excess air. The internal pressure of dissolved gases exceeds the local barometric pressure in most samples, and water from some wells has internal gas pressures nearly twice that of the local barometric pressure. Water from several wells located near the Rio Grande in Albuquerque has recharge temperatures of 21 to 25 °C and contains 150 to nearly 400 pg/kg of CFC-12. Rio Grande water is near equilibrium with atmospheric concentrations of CFC-11 and CFC-12, but is approximately 400 percent supersaturated with CFC-113. Partial degradation of CFC-11 occurred in three of the seven river-water samples prior to analysis (within 3 months of collection). Rio Grande water is near equilibrium with atmospheric concentrations of sulfur hexafluoride (approximately 1

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femtomole per liter in water), whereas most ground water has SF_6 concentrations in considerable excess of air-water equilibrium (maximum concentrations of several hundred femtomoles per liter). The preliminary CFC concentrations are typically at or below the detection limit of 0.3 pg/kg in most ground water sampled regionally in undeveloped areas throughout the basin, but CFC's are observed in most ground water near Albuquerque, indicating water that contains at least a fraction of post-1940's water.

Additional sampling is planned for the monitoring network currently being installed by the City of Albuquerque in cooperation with the USGS and for approximately 60 other wells in areas throughout the Middle Rio Grande Basin where data indicate that further sampling may resolve uncertainties.

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TEMPORAL GRAVITY STUDY OF THE ALBUQUERQUE BASIN

By Michael C. Carpenter[1]

A temporal gravity study is being done in the Albuquerque Basin within the Middle Rio Grande Basin from 1996 through 2000. The objectives of the study are to (1) determine the mass change of subsurface water during the study period, (2) use corresponding water-table declines to estimate specific yield of the aquifer, (3) determine rates of subsidence using repeated precise differential Global Positioning System (GPS) measurements of gravity-station locations, and (4) establish procedures, monuments, and documentation adequate for additional measurements at intervals of 5 to 50 years.

The network of 42 gravity and GPS stations, established in 1993 (Charles Heywood, Hydrologist, U.S. Geological Survey, written commun., 1996), spans the areas of the Albuquerque Basin where significant water-level declines are predicted. The network includes an accurately determined gravity base station (119R00), an accurately determined GPS reference station (EAGLEAIR), and seven stations on the bedrock periphery of the basin. Many of the existing stations that are near production wells and large water-storage tanks, which can introduce noise in the measurements, will be replaced in the network by about 11 stations near piezometers with continually recorded water levels (Thorn, 1996).

The measurement procedure consists of double-run loops. Each loop starts with an observation at a base station, continues with a sequence of observations at four to five stations, and concludes with an observation at the base station. Free-air effects due to changes in altitude of stations between surveys, instrument drift, and earth-tide effects are removed. Differences between surveys separated by 6 months or more are calculated for each station and are interpreted as changes in storage of subsurface water. Changes in moisture content in a thick unsaturated zone, such as exists in the Albuquerque Basin, may affect observations. This problem will be addressed by establishing the surveys at approximately the same time each year at the end of a dry season and comparing rainfall and temperature records for anomalies in recharge and potential evapotranspiration.

The method is based on the mass of water of a Bouguer slab (Dobrin, 1976, p. 418). The change in gravitational acceleration (g) is:

$$\Delta g = 12.77 \cdot \Delta\rho \cdot b \qquad (1)$$

where Δg is in microgals; the constant 12.77 includes the gravitational constant G and conversion from meters to feet; $\Delta\rho$ is density contrast, in grams per cubic centimeter; and b is thickness, in feet. In addition,

$$\Delta\rho = S_y \cdot \rho_w \qquad (2)$$

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where S_y is dimensionless specific yield and ρ_w is the density of water, or 1 g/cm^3 (Pool and Eychaner, 1995). For a predicted water-table decline of 20 ft in 4 years and a specific yield of 0.15, the predicted change in gravitational acceleration is about 40 microgals.

In the fall of 1996, the two gravity meters that are available for this study were not operating correctly. The drift rate for meter D79 can exceed the manufacturer's specification by a factor of 10. Loop-closure drift for the 1993 observations using gravity meter D79 varies from +80 microgals to -102 microgals. In September 1996, the difference in gravity between two stations using gravity meter D79 was 19.647 milligals, and the difference using meter D127 was 19.728 milligals. The discrepancy between the two meters is 81 microgals. Thus, potential errors exceed the anticipated signal by a factor of 2. Because of the large range in drift, meter D79 is being tested for leakage and will be serviced, and meter D127 has been repaired. Loop-closure drifts less than 10 microgals are obtainable with properly functioning meters. Surveys of sufficient accuracy and precision to resolve the anticipated signal of about 40 microgals can and will be done if sufficient resources are available.

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IMPROVING THE MIDDLE RIO GRANDE MODFLOW MODEL USING MODPATH AND ENVIRONMENTAL TRACERS

By Ward E. Sanford[1] and L. Niel Plummer[1]

Concern over the availability of ground water in the Albuquerque area has led to the recent development of a computer-simulation model of the ground-water system in the Middle Rio Grande Basin (MRGB) (Kernodle and others, 1995). The model was constructed using the USGS computer code MODFLOW (McDonald and Harbaugh, 1988). The model-input parameters were obtained from field estimates of aquifer transmissivities, vertical conductivities, and recharge rates. Initial comparisons between observed and computed water levels suggest that the parameters in the model are a reasonable representation of the system. Ground-water flow models, however, can inherently produce results that are nonunique. Environmental tracers currently being collected from ground water in the MRGB (fig. 5A) will provide independent constraints on the model parameters.

Environmental tracers being collected include oxygen-18, deuterium, tritium, carbon-13, carbon-14, chlorofluorocarbons, dissolved nitrogen and argon, and major cation and anion concentrations. It is anticipated that the most important tracer for the regional study will be carbon-14. Carbon-14-based ages of ground water can be used to calculate independent flow velocities and recharge rates. In addition, estimating how recharge rates have varied over the past several thousand years may be possible. The carbon-14 data will first be adjusted for extraneous sources of carbon using corrections based on carbon-13 values and the computer model NETPATH (Plummer and others, 1994). Other environmental tracers will aid in determining the extent to which Rio Grande water has entered the aquifer system. This information will be compared to model predictions of river infiltration. River-aquifer leakance parameters will then be adjusted in the model to improve the match between observed and computed infiltration rates.

Computed ground-water ages and source areas are being calculated with the USGS computer code MODPATH (Pollock, 1994). MODPATH can be used in conjunction with MODFLOW to create maps of the ages and source areas of ground water in the MRGB predicted by MODFLOW. Preliminary results from MODPATH suggest that much of the shallow ground water in the MRGB is less than 10,000 years old (fig. 5B) and that Rio Grande water has entered the aquifer system extensively only within a few kilometers of the river itself. The accuracy of these model predictions will be tested once the environmental tracer data have been analyzed.

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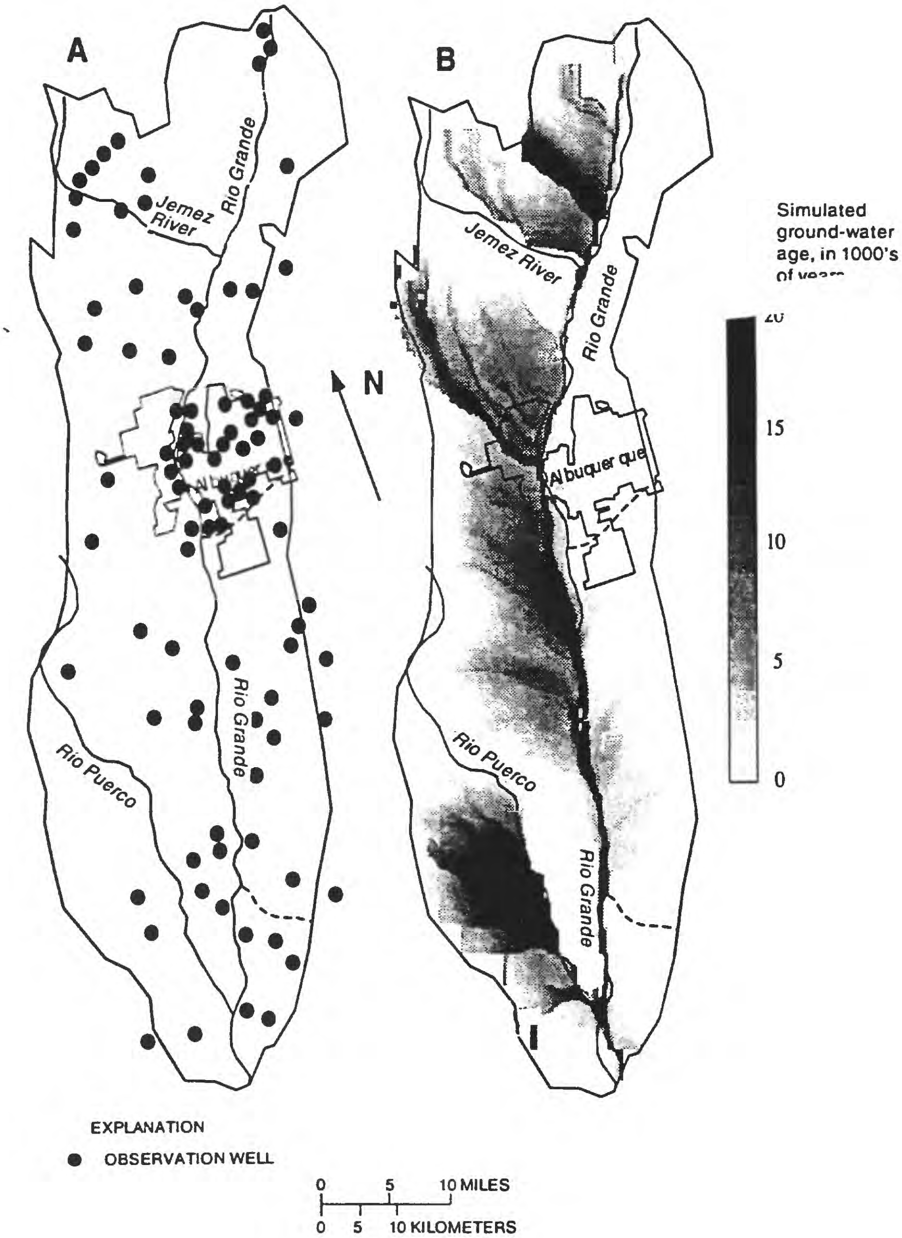

Figure 5.--Distribution of (A) observation wells at which environmental tracers have been sampled and (B) simulated age of ground water using MODPATH for layer 1 of the steady-state MODFLOW model.

APPLICATION OF PARAMETER ESTIMATION METHODS TO THE GROUND-WATER FLOW MODEL OF THE MIDDLE RIO GRANDE BASIN

By Claire R. Tiedeman[1]

Nonlinear regression is being used to estimate parameters of the Middle Rio Grande Basin (MRGB) ground-water flow model through application of MODFLOWP (Hill, 1992), which combines parameter estimation techniques with the USGS MODFLOW model. Calibration by nonlinear regression uses an objective criterion to determine the best fit of model-simulated quantities to measurements of hydraulic head and other flow-system characteristics, and yields statistics describing the uncertainty in the estimated parameters. The uncertainty in model-predicted quantities, such as hydraulic heads and water budgets, can be computed from the parameter uncertainties.

To apply parameter estimation methods to the MRGB flow system, the spatial and temporal discretization used in the finite-difference model of Kernodle and others (1995) has been coarsened, resulting in a flow model with a significantly shorter computation time. Preliminary MODFLOWP simulations have been performed with the coarsened model to examine the sensitivities of hydraulic heads to the model parameters. Parameters with large sensitivities are most likely to be estimated by the regression procedure. These parameters include the hydraulic conductivity of several hydrogeologic zones, mountain-front and tributary recharge, underflow from adjacent basins, and specific yield. Parameters that have small sensitivities, and thus are least likely to be estimated, include recharge from agricultural and septic field drainage and the hydraulic conductivities of the Rio Grande riverbed, the canal beds, and the drains.

Work planned for fiscal year 1997 includes continued application of MODFLOWP to the MRGB ground-water flow model. On the basis of the initial MODFLOWP sensitivity simulations, it is anticipated that a subset of the flow model parameters can be estimated. If parameter estimates obtained from the regression procedure are reasonable (on the basis of prior hydrologic and geologic information about the MRGB), an assessment can be made of the uncertainty in the model parameters and in the simulated water budget of the basin under current and projected ground-water conditions. Results of the MODFLOWP simulations can also be used to guide additional data collection and may lead to changes in the conceptual model of the basin, such as revised hydraulic-conductivity zonal boundaries.

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TRIBUTARY, MOUNTAIN-FRONT, AND INTERARROYO RECHARGE IN THE MIDDLE RIO GRANDE BASIN, NEW MEXICO--COLLABORATIVE NRP/NEW MEXICO DISTRICT RESEARCH PROGRAM

By Jim Constantz[1], David A. Stonestrom[1], and Carole L. Thomas[2]

There are few direct measurements of tributary, mountain-front, and interarroyo recharge in the Middle Rio Grande Basin (MRGB), but there are some indications that these sources represent about half the total recharge to the basin. Improved constraints on recharge from these three sources are needed to reduce uncertainties in current ground-water models used to estimate recharge for the MRGB. Several environmental tracer methods, the core-sample/centrifuge method (Nimmo and others, 1994), and three thermal-pulse methods are being tested at three sites on the eastern side of the basin. The first two methods are discussed in detail in other articles; details of thermal-pulse methods are discussed here and in two other articles. Thermal-pulse methods rely on temperature as a natural tracer to estimate various hydraulic parameters in the subsurface. In the present study, we are using different approaches for three sites with distinctly different hydrological properties and levels of instrumentation. The Santa Fe River site represents an example of tributary recharge in the relatively wet, northern MRGB and is the most extensively instrumented site. Two thermal-pulse procedures will be tested pending fiscal year 1997 funding: simulations using VS2DH (Healy and Ronan, 1996) and a simple arrival-time procedure (Constantz and Thomas, 1996). The Abo Arroyo site represents an example of tributary recharge in the dry, southern MRGB and is presently instrumented to a lesser degree. Continuous streamflow and precipitation are being collected at the upper limit of the study reach, and a streambed-temperature profile is being monitored at the bedrock/alluvium transition 500 m downstream from the upper site. A new thermal-pulse procedure designed to relate upstream flows to downstream flows will be tested pending fiscal year 1997 funding. The Bear Canyon site represents an example of mountain-front recharge in the eastern MRGB and is the least instrumented site. The planned analysis is similar to that described in Constantz and Thomas (1997, in press). Presently, continuous precipitation is being collected and streambed temperature-profiles are being collected at two locations. The procedure of A.D. Ronan, D.E. Prudic, C.E. Thodal, and J. Constantz (unpublished data, 1996) will be used pending fiscal year 1997 funding. No thermal-pulse methods are currently being tested to estimate interarroyo recharge because the core-sample/centrifuge method and environmental tracer methods are more promising for these lower recharge locations.

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RECHARGING FLUXES THROUGH LAYERED ALLUVIUM--CENTRIFUGE HYDRAULIC PROPERTY MEASUREMENTS INTERPRETED BY DARCIAN FLOW SIMULATION

By John R. Nimmo[1]

Accurate measurement of unsaturated hydraulic conductivity (K) and soil moisture can indicate long-term average recharge rates at selected points (Nimmo and others, 1994). This method requires core samples from deep enough in the unsaturated zone that moisture fluctuations are negligible. This condition implies a uniform matric pressure, so that water flow is steady and driven only by gravity. Then the value of K at the water content existing in the field profile numerically equals the downward flux density (q), interpretable as the local recharge rate. The steady state centrifuge method (SSCM) is well suited for the required measurements because it gives accurate K values in the low-water-content range important at arid and semiarid sites.

The layered character of alluvial deposits in the Middle Rio Grande Basin presents several difficulties. Probably the most serious is that matric-pressure gradients may be significant near layer boundaries. It is necessary, therefore, either to show these gradients to be negligible or to quantify them to get the total driving force that relates K to flux.

At a comparable site in the Mojave Basin of California the SSCM technique has recently produced significant results and possible solutions to the problem of nonuniform matric pressure (Nimmo and others, 1996). SSCM-measured unsaturated-K data for five gravel-free core samples were scaled to represent the properties of a known sequence of 42 layers, based on the mean grain size in each layer. Using these scaled properties, a numerical solution of Darcy's law yields the matric pressure as a function of depth. The magnitude of this gradient can be compared to gravity to determine whether the fluxes estimated from K are valid. Flux density estimates established this way beneath a Mojave Basin streambed range from 2 to 130 cm/yr. They decrease with depth, suggesting that the effective recharge area under the streambed spreads laterally as water moves through the different layers.

In the Middle Rio Grande Basin, core samples will be obtained near the Santa Fe River and other recharge features of interest. SSCM measurements to be made in 1997 and 1998 will be interpreted by the Darcian flow simulation to put confidence limits on the point recharge estimates and to provide information toward quantifying the lateral flow and effective area needed to estimate the total aquifer recharge from a given source.

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MODELING HEAT AND WATER MOVEMENT BENEATH STREAMS IN ARID ENVIRONMENTS

By Anne Dudek Ronan[1], Amy E. Stewart[2], and Jim Constantz[2]

Percolation of water beneath streams in the Middle Rio Grande Basin (MRGB) is being studied by using temperature as a natural tracer. The computer program VS2DH (Healy and Ronan, 1996) is being used to simulate the flow of water and heat in the variably saturated sediments beneath Bear Canyon, Abo Arroyo, and the Santa Fe River. These simulations will be used along with stream and sediment temperature measurements to estimate infiltration and to help interpret subsurface flow patterns.

VS2DH was successfully used to simulate unsaturated water and heat flow beneath an ephemeral mountain stream located in Vicee Canyon, Nevada, a site that has several features similar to those at study sites in the MRGB. Field data from experiments conducted at Vicee Canyon reveal that streamflow is lowest in late afternoon when stream temperature is highest and highest in the early morning when stream temperature is lowest. Evapotranspiration from the water surface and the sparse vegetation is insufficient to account for the decreased afternoon streamflow. Instead, the decreased afternoon streamflow is due to increased infiltration rates. During the afternoon, stream temperatures increase, causing an increase in the streambed hydraulic conductivity due to temperature effects on pore-water viscosity. Because the surface crust of the streambed constitutes a flow-controlling layer, the temperature dependence of the hydraulic conductivity leads to temperature-dependent infiltration rates. VS2DH was used to simulate infiltration into the streambed and unsaturated flow beneath the stream. A lower permeability surface crust was needed in the model simulations to duplicate the measured subsurface temperature profiles. Model results also indicate that diurnal changes in infiltration can be explained by the temperature dependence of hydraulic conductivity. Hydraulic and thermal parameters were calibrated to data collected in May 1994. The same parameters were used to simulate the June 1995 experiment, with only approximately 25-percent error in predicted infiltration rates. Results suggest that once the parameters have been determined, infiltration rates at other times can be estimated solely on the basis of stream temperatures (A.D. Ronan, D.E. Prudic, C.E. Thodal, and J. Constantz, unpublished data, 1996).

Experience with simulations at Vicee Canyon is being used to guide development of the computer model for the MRGB. Four different two-dimensional transverse stream cross sections will be modeled that correspond to the four thermocouple nests that have been installed beneath the Santa Fe River. A longitudinal cross section will also be modeled beneath the uppermost thermocouple nest to evaluate subsurface flow above the vertical-flow-restricting bedrock layer. Presently, Bear Canyon has two thermocouple nests and Abo Arroyo has a single thermocouple nest. Future plans include additional thermocouple nests and modeling at Bear Canyon and Abo Arroyo.

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ENVIRONMENTAL TRACERS OF RECHARGE WHERE THE MOUNTAINS MEET THE PLAIN--PRELIMINARY RESULTS OF LATERAL AND LONGITUDINAL TRANSECTS ALONG ABO ARROYO, BEAR CANYON, AND THE SANTA FE RIVER AT THE EASTERN MARGIN OF THE MIDDLE RIO GRANDE BASIN, NEW MEXICO

By David A. Stonestrom[1], Katherine C. Akstin[1], and Robert L. Michel[2]

Environmental tracers from core samples are being analyzed to delineate spatial patterns of ground-water recharge and to estimate recharge magnitudes at selected sites along the eastern margin of the Middle Rio Grande Basin in New Mexico. Soil and sediment samples were collected from holes drilled along longitudinal and lateral transects at the mouths of three arroyos: the Santa Fe River near La Bajada (northeastern margin of the basin), Abo Arroyo near Blue Springs (southeastern margin), and Bear Canyon upstream from Tramway Boulevard in Albuquerque (central eastern margin). Core samples were collected in brass liners at selected depths in the unsaturated zone for determination of bulk density. Continuous bulk samples were collected using techniques to minimize evaporation and shipped to the laboratory in water-tight jars. Bulk samples are being analyzed for water content and soluble constituents including chloride, bromide, and boric acid. Chloride and bromide concentrations are being determined by ion chromatography. Boric-acid concentrations are being determined (as elemental boron) by argon-plasma spectrophotometry. These constituents are chemically conservative and can indicate local recharge if assumptions about sources are satisfied. Isotopes of unsaturated-zone water are also being evaluated as indicators of recharge. Pore waters, extracted from samples by cryodistillation, are being analyzed for tritium, deuterium, and oxygen-18. Tritiated water, produced in significant quantities only in the atmosphere, decays with a 12.4-year half life. Tritium concentration thus gives a rough indication of how long a given water sample has been isolated from the atmosphere. The relative abundance of isotopic forms of water deviates from that of source water due to evaporative enrichment. For example, a small fraction of precipitation becoming recharge (that is, a large fraction returning to the atmosphere) leads to a large deviation in isotopic composition between the recharging and meteoric water. When stable isotope results become available, deviations of oxygen-18-to-deuterium ratios from source waters could corroborate (or falsify) recharge estimates based on the conservative solutes.

Preliminary tritium results indicate that all waters analyzed thus far are from recent precipitation (less than 40 years). Chloride, bromide, and boron concentrations show moderate correlation despite significant variability. Results of all tracers examined to date indicate localization of recharge beneath arroyos with recharge decreasing away from arroyo channels. Particular estimates of recharge will be tracer dependent and rest on assumptions that are not completely testable. The use of multiple environmental tracers overly constrains recharge estimates and provides an indication of their accuracy.

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A TEST OF THE STREAMBED TEMPERATURE-PROFILE METHOD FOR MEASURING PERCOLATION RATES AT THE SANTA FE RIVER NEAR LA BAJADA, NEW MEXICO

By Carole L. Thomas[1] and Jim Constantz[2]

Application of the streambed temperature-profile method may provide accurate, economical measurements of percolation rates under stream channels in the Middle Rio Grande Basin of central New Mexico. The method monitors temperature with depth in shallow, saturated or unsaturated sediments below stream channels. The propagation of temperature changes at the sediment-water interface through the sediment profile provides the physical basis for the calculation of ground-water flow rates. This article describes a planned test of the streambed temperature-profile method for measuring percolation rates.

A losing reach of the Santa Fe River near La Bajada, New Mexico, is the site for testing the streambed temperature-profile method. The reach is about 2,300 m long. Four temperature profiles and three streamflow-measurement gages are installed for the purposes of the test.

Each temperature profile consists of six thermocouple-temperature sensors. One sensor is inserted near the sediment-water interface, and five sensors are inserted at 0.5 m, 0.75 m, 1.25 m, 2.25 m, and 3.25 m below the streambed. The thermocouples are set at the desired depths within a 1-in.-diameter steel pipe that is hydraulically driven into the streambed sediments. The pipe is then withdrawn, allowing sediments to collapse around the thermocouples. A data logger records temperatures every 10 minutes. Percolation rates can then be calculated by temperature arrival-time techniques (Constantz and Thomas, 1996) or by modeling techniques (Healy and Ronan, 1996).

The study reach is delimited by streamflow-gaging stations at the upstream and downstream ends of the reach. A third streamflow-gaging station is located in the middle of the reach. The difference in streamflow between any two of the three gages determines streamflow loss. The streamflow loss is adjusted for evaporative loss, then divided by the wetted area to give an average infiltration rate for the reach. Infiltration measurements determined from the streamflow gages can then be used to verify that temperature profiles are providing accurate estimates of percolation rates beneath the stream.

It is planned that percolation rates determined from the four temperature profiles will be compared to identify temporal and spatial variations. Instantaneous, daily, seasonal, and annual percolation rates will then be calculated to define temporal variations. Percolation rates at the four locations and at different depths can then be compared to identify spatial variations.

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NEW MEXICO DISTRICT PROGRAM

PIEZOMETRIC-EXTENSOMETRIC ESTIMATIONS OF SPECIFIC STORAGE IN THE ALBUQUERQUE BASIN, NEW MEXICO

By Charles E. Heywood[1]

A 315-m vertical extensometer was installed near the Rio Grande during the autumn of 1994 to monitor aquifer-system compaction. A precision transducer enabled extensometric measurement of vertical displacements of several microns, corresponding to a vertical strain sensitivity of 10^{-8}. Aquifer potentiometric head adjacent to the extensometer was measured at four depths by transducers with a resolution of 2 mm, and was also recorded in three shallower piezometers approximately 80 m from the extensometer.

To improve understanding of aquifer-system mechanics near the Rio Grande in Albuquerque, a pumping test was conducted during the winter of 1995. The pumping test was preceded by 3 months of no pumping in the vicinity of the extensometer. Beginning on January 4, 1995, a production well 378 m from the extensometer pumped 147 L/s for 54 days. This pumping was followed by a 1-month recovery period. The distribution of increased effective stress in the aquifer system was inferred from pore-pressure measurements in the seven piezometers. Aquifer-system strain resulting from the increased effective stress was measured with the vertical extensometer. Stress-strain plots indicated a linear elastic compressibility of 5×10^{-10} Pa^{-1} for the aquifer system, corresponding to an average elastic specific storage of 6×10^{-6} m^{-1}. Compaction of low-permeability clay interbeds dominated the aquifer-system strain during the latter 50 days of pumping.

Four piezometers adjacent to the extensometer responded to earth tides. The magnitude of horizontal strain due to earth tides was computed from tidal theory, and a corresponding cubical dilatation was calculated by assuming a Poisson ration of 0.25. Spectral analyses of these strains and their corresponding piezometric responses enabled an independent estimation of the specific storage of aquifer sands using poroelastic theory. These estimates suggested a somewhat stiffer elastic response for aquifer sands as compared to the aggregate aquifer system (which includes interbedded clay aquitards) and a decrease of sand matrix compressibility with depth.

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RIO GRANDE VALLEY NATIONAL WATER-QUALITY ASSESSMENT STUDY UNIT

By Gary W. Levings[1]

The National Water-Quality Assessment program of the USGS, which began in 1991, is designed to assess the status of and trends in the quality of the Nation's surface- and ground-water resources and to link the status and trends with an understanding of the natural and human factors that affect the quality of water. The program balances the assessment requirements of 60 individual hydrologic systems (study units) with a nationally consistent structure that incorporates a multiscale, interdisciplinary approach. The Rio Grande Valley study unit contains approximately 45,900 mi^2 in Colorado, New Mexico, and Texas upstream from the surface-water site Rio Grande at El Paso, Texas (fig. 6).

The overall study design of the program included a high-intensity sampling phase that was conducted in the Rio Grande Valley study unit from September 1992 through September 1995. During this phase three types of studies were conducted for the surface-water component of the investigation. Water-column studies assessed physical and chemical characteristics and their relation to hydrologic conditions, sources, and transport. Bed-sediment and tissue studies assessed the occurrence and distribution of selected trace elements and organic compounds. Ecological studies evaluated the relations among physical habitat, water chemistry, and biological community characteristics of streams. Ground-water studies focused on water-quality conditions in major shallow aquifers associated with recent and ongoing human activities. Elements of the ground-water studies included a study-unit survey to assess the water quality of a major shallow aquifer and three land-use studies to assess the quality of recently recharged shallow ground water associated with regionally extensive combinations of land use and hydrogeologic conditions.

Preliminary data analysis indicates that (1) pesticide and nutrient concentrations in surface water and drains in the study area did not exceed Federal and State criteria or standards; (2) trace-element concentrations in surface water are elevated in selected areas in the northern part of the basin; (3) introduced fish species were dominant at most sites sampled, which is indicative of biological stress on these communities; (4) pesticide concentrations in ground water in two areas of intensive agricultural land use were below Federal and State criteria or standards; and (5) concentrations of volatile organic compounds in ground water in an urban land-use study in the Albuquerque area were below Federal and State criteria or standards, although iron and manganese concentrations in some wells exceeded U.S. Environmental Protection Agency secondary maximum contaminant levels.

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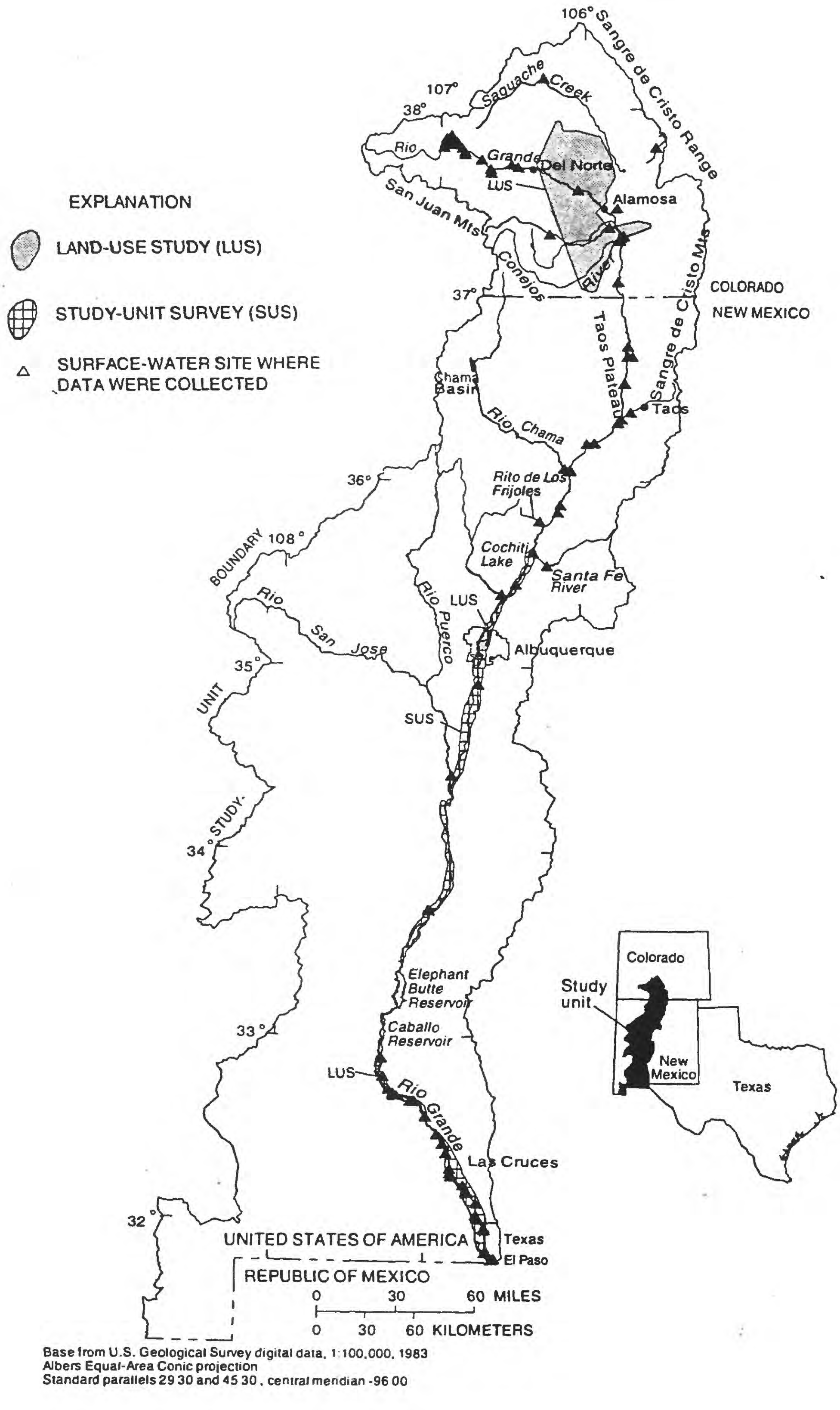

Figure 6.-- Rio Grande Valley National Water-Quality Assessment study unit.

A RIVER- AND RESERVOIR-OPERATIONS MODEL FOR THE UPPER RIO GRANDE BASIN

By D. Michael Roark[1]

Several agencies of the Federal government are developing a river- and reservoir-operations model for the Upper Rio Grande Basin. The agencies involved in the project are the Bureau of Reclamation, U.S. Army Corps of Engineers, USGS, Bureau of Indian Affairs, U.S. Fish and Wildlife Service, and the International Boundary and Water Commission (U.S. Section). This article discusses a plan to develop an operations model as the first phase of a plan to model many of the physical characteristics and operational criteria of the Upper Rio Grande Basin.

The Upper Rio Grande Basin, for the purposes of the model, is the area drained by the Rio Grande and its tributaries from the headwaters in Colorado through New Mexico to the streamflow gage at Fort Quitman, Texas, including a closed basin in Colorado. Flow in the Upper Rio Grande Basin consists of native Rio Grande Basin water and transmountain water from the Colorado River Basin. Streamflow of native water between Colorado, New Mexico, and Texas is governed by the Rio Grande Compact. Streamflow between the United States and the Republic of Mexico is dictated by international treaties.

Because of water ownership, the various types of water (native and transmountain), numerous reservoirs, and complex stream-aquifer relations, operating and planning water operations are difficult. Both Federal and local agencies need a tool to simulate the complex water operations in daily time steps for real-time operations and in monthly time steps for planning. A rule-based object-orientated model, the Power and Reservoir System Model (PRSYM) (CADSWES, 1996), was selected by an interagency committee after technical consideration of many models.

The development of the operations model for the Upper Rio Grande Basin is planned to proceed in two phases. In phase one, a test-case model will be developed for a subsystem of the upper Rio Grande. The test-case model will determine whether PRSYM can simulate water operations successfully. The Rio Chama, a tributary to the Rio Grande, was selected as the test reach. The reach of the Rio Chama to be modeled extends from the transmountain diversions to Abiquiu Reservoir. The Rio Chama test-case reach was selected because its complexity and properties are relevant to the whole Upper Rio Grande Basin. In phase two, the whole Upper Rio Grande Basin will be modeled.

At the present time (November 1996) the conceptual model of the Rio Chama reach is under development. Its completion and the start of development of the full-basin model are scheduled for the summer of 1997. The full basin water operations model is scheduled to be operating in January 1998, and refinements to the model are scheduled to continue until September 1998.

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INSTALLATION OF GROUND-WATER MONITORING WELLS IN THE ALBUQUERQUE, NEW MEXICO, AREA

By Condé R. Thorn[1]

The City of Albuquerque currently (1996) obtains all its municipal water supplies from ground-water reserves. Recent investigations by the USGS, in cooperation with the City of Albuquerque, have indicated that the more permeable units within the aquifer system--the upper part of the Santa Fe Group--are less extensive and thinner than previously thought and that water levels have declined as much as 160 ft in some areas (Thorn and others, 1993; Kernodle and others, 1995). To gain a better understanding of the aquifer system in terms of extent and response to City pumping, more ground-water monitoring wells are necessary. This article describes the expansion of the existing ground-water monitoring network in the Albuquerque area.

The City of Albuquerque, in cooperation with the USGS, recently began a drilling program to install new monitoring wells in the Albuquerque area to expand the existing ground-water monitoring network (Thorn, 1996). Currently (October 1996) five sites are completed and one site is ongoing at 98th Street. The objective of the drilling program is to install new monitoring wells at locations where daily effects of city pumpage are minimal and where hydraulic-head and water-quality data can be obtained for specific depths. The planned monitoring wells will be as deep as 1,700 ft and, except for the West Bluff site, will be located in areas between city production wells (fig. 7) to ensure that the data collected are representative of general conditions in the aquifer system.

At each monitoring site, one triple-completed piezometer nest is scheduled to be installed. The shallow piezometer will be screened from the water table to a depth between 40 and 100 ft below the water table; the intermediate and deep piezometers will be completed with 5-ft screens in the more permeable zones of the middle and bottom parts of the production zone (screened interval) of the nearest city production wells. Each piezometer will be instrumented with a pressure transducer that is connected to a data recorder for continuous measurement of hydraulic head. Water-quality samples will be collected from each piezometer--quarterly the first year, biannually the second year, and annually thereafter.

Data collected from these planned monitoring wells will provide information for long-term ground-water-resource management. Data collected during the installation of the monitoring wells (lithologic and geophysical logs and hydrologic properties derived from cores), along with hydraulic-head and water-quality data collected after installation, will further refine the conceptual and ground-water flow models of the Albuquerque area (Thorn and others, 1993; Kernodle and others, 1995).

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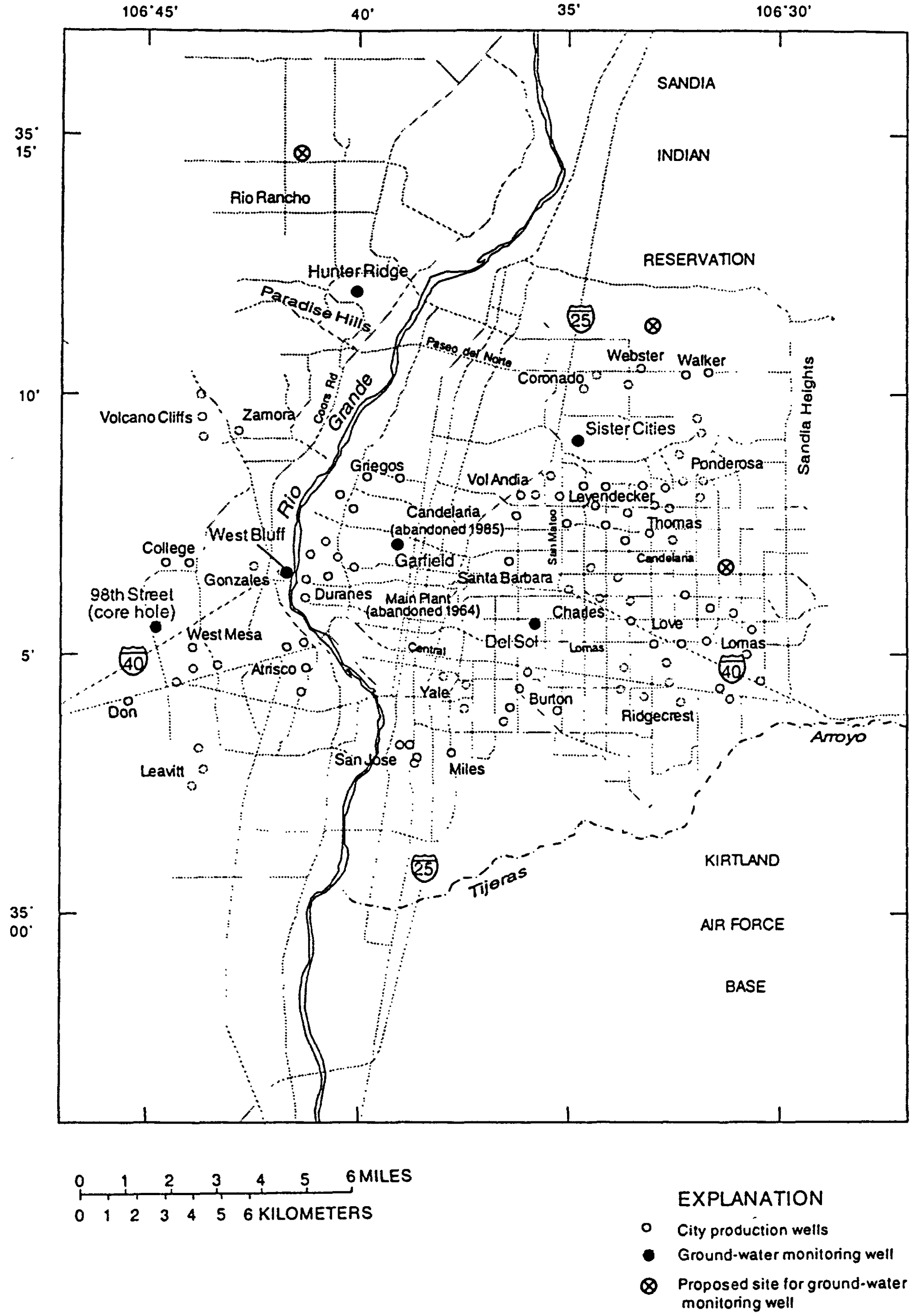

Figure 7.--Location of city production wells, installed ground-water monitoring wells, and proposed ground-water monitoring sites.

ANALYSIS OF AN AQUIFER TEST AT THE GRIEGOS WELL FIELD, ALBUQUERQUE, NEW MEXICO

By Condé R. Thorn[1] and Douglas P. McAda[1]

This article describes the analysis of an aquifer test conducted in 1995 using the City of Albuquerque Griegos 1 production well. The Griegos 1 well was chosen because of its proximity to the Rio Grande (about 4,500 ft from the river) and the ability to cease production from all other city wells within 15,000 ft of Griegos 1 for 3 months prior to and 1 month after the test. The well pumped an average of 2,330 gal/min for about 54 days (January 4 to February 27); the recovery period was about 31 days (February 28 to March 29). The purpose of the aquifer test and analysis was to estimate aquifer properties of the Santa Fe Group aquifer system in the vicinity of the Griegos well field and to estimate seepage from the Rio Grande and riverside drains that resulted from pumping during the test.

Griegos 1 is screened from 232 to 802 ft below land surface in the Santa Fe Group aquifer system. Drawdown was measured in 22 observation wells, which included 3 nonpumping city production wells and 19 piezometers with screened depths ranging from 10 to 978 ft below land surface. The distance from observation wells to the Griegos 1 well range from about 980 to 6,410 ft. Preliminary analysis, using the Hantush-Jacob method, indicates the Rio Grande and drain system to be a recharge boundary.

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INVESTIGATION OF SELECTED TRACE-ELEMENT CONCENTRATIONS AND LOADS IN THE RIO GRANDE IN THE VICINITY OF ALBUQUERQUE, NEW MEXICO, 1994 TO 1996

By Ralph Wilcox[1]

In 1992, the Pueblo of Isleta secured approval from the U.S. Environmental Protection Agency for pueblo surface-water-quality standards. The standards, in part, determine National Pollutant Discharge Elimination System (NPDES) permit limitations for dischargers upstream from the pueblo. There is concern that NPDES permit limitations cannot be meaningfully assigned for upstream dischargers without knowing ambient water-quality conditions in the Rio Grande.

This article describes the purpose and preliminary results of an investigation being conducted by the USGS in cooperation with the U.S. Environmental Protection Agency, the New Mexico Environment Department, the City of Albuquerque, and the Pueblo of Isleta. The objectives of this investigation are to determine (1) ambient concentrations of selected trace elements, principally arsenic, along a 57-mi reach of the Rio Grande from San Felipe Pueblo to Los Lunas, New Mexico (fig. 8); (2) instantaneous loadings of these constituents into the Rio Grande from major tributaries, riverside drains, and wastewater treatment plants (WWTP's) along the study reach; and (3) mean concentrations of inorganic and organic forms of arsenic in the edible portions of fish tissue along the study reach. Water-quality and instantaneous loading results can then be used by regulatory agencies to recommend further studies and/or control of these constituents. Results of fish-tissue analysis could be used by the regulatory agencies to estimate a site-specific bioaccumulation factor for arsenic.

The collection of data for this investigation was completed in August 1996. Eighteen sites (eight on the Rio Grande, one on the Jemez River, five on riverside drains, and four WWTP outfalls) were sampled quarterly for 2 years. The timing of sampling was based on seasonal flow conditions in the Rio Grande. The samples were collected in accordance with USGS trace-element sampling protocol (Horowitz and others, 1994). Additional field quality-control samples were collected, and the USGS National Water Quality Laboratory reported quality-control results for each sampling round. Fish-tissue samples were collected on two occasions from four of the Rio Grande sites and from the Albuquerque Riverside Drain.

Water-quality results to date show dissolved-arsenic concentrations of 2 µg/L in the upstream site Rio Grande at San Felipe, increasing to 4 µg/L in the downstream site Rio Grande at Los Lunas. Values range from 2 to 6 µg/L in the riverside drains; 14 to 20 µg/L in the Jemez River; 7 to 10 µg/L in the Albuquerque WWTP outfall; and 11 to 20 µg/L in the Rio Rancho 2, Rio Rancho 3, and Bernalillo WWTP outfalls. There is little difference between dissolved and total-recoverable arsenic concentrations.

Fish-tissue results show total-arsenic concentrations (wet-weight basis) of 3.01 to 25 µg/kg. Concentrations of organic forms of arsenic in the fish-tissue samples range from less than 0.3 to 21.14 µg/kg.

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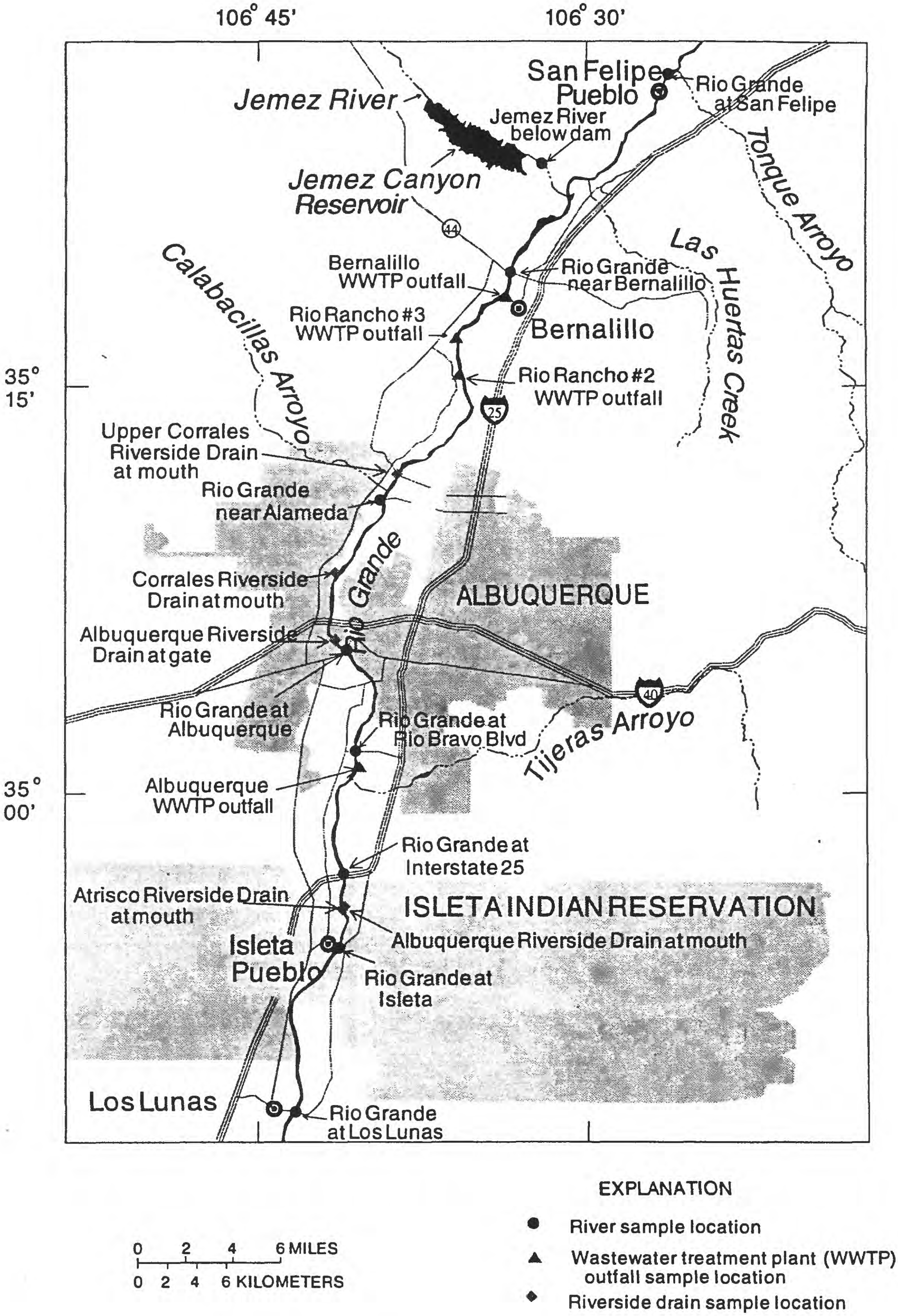

Figure 8.--Surface-water sampling sites.

NEW MEXICO DISTRICT COOPERATIVE PROGRAM IN THE MIDDLE RIO GRANDE BASIN

By Dennis G. Woodward[1]

The New Mexico District of the USGS has established and fostered for many decades a dynamic Federal-State Cooperative Program in the Middle Rio Grande Basin, central New Mexico. In the Cooperative Program, investigative projects and data-collection activities are jointly identified, planned, and funded by the USGS (as much as 50 percent) and by State and local agencies. Generally, the State and local agencies provide at least one-half the funds, and the USGS does most of the work. The collective results of the Cooperative Program have provided the scientific basis and the institutional framework for developing the USGS Middle Rio Grande Basin Study that began in fiscal year 1996. This article briefly describes the historical highlights of the Cooperative Program in the Middle Rio Grande Basin and the components of the present program. Of the approximate $4.8 million allocated in fiscal year 1996 for USGS work in the basin, about $1.8 million was from the Cooperative Program. The major agencies in the Cooperative Program in the basin study are the City of Albuquerque (City) and the New Mexico State Engineer Office (SEO).

One of the earliest highlights of the Cooperative Program in the Middle Rio Grande Basin was the report on the availability of ground water in the Albuquerque area by Bjorklund and Maxwell (1961). They presented regional maps of the geology and water-table configuration in the area. Reeder and others (1967) provided a quantitative analysis of the water resources in the Albuquerque area, and computed effects on the Rio Grande from ground-water pumpage. They presented projected water-table declines and depletions of Rio Grande flow due to projected ground-water withdrawals. Following a period devoted primarily to data-collection activities, the development, construction, and documentation of the Albuquerque Basin ground-water flow model rank as recent significant milestones in the Cooperative Program with the City. Thorn and others (1993) described the geohydrologic framework and hydrologic conditions used in the flow model, and Kernodle and others (1995) presented the results of the flow model. McAda (1996) detailed a plan of study to quantify the hydrologic relations between the Rio Grande and the Santa Fe Group aquifer system in the Albuquerque area; 13 essential activities and informational needs were identified and prioritized. The most recent highlight of the Cooperative Program with the City is the drilling and completion of a series of nested piezometers located throughout the Albuquerque area. By the end of calendar year 1996, seven piezometer nests--each with three piezometers--were completed at five different sites. Generally, the nests have piezometers that measure water levels near the water table, near the middle of the "production zone" in the City wells, and near the base of the production zone in the City wells.

The current (1997) Cooperative Program with the City contains the following components: (1) continuation of the ground-water-level monitoring network; (2) expansion of the monitoring network by completion of more nested piezometers; (3) spinner logging of City production wells to determine the most productive zones of the aquifer; (4) model simulations of an extensive aquifer test using the USGS computer code MODFLOW (McDonald and Harbaugh, 1988) trial-and-error calibrations and MODFLOWP (Hill, 1992) analyses; (5) estimation of seepage rates

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from the Rio Grande and canals and drains in the Albuquerque area; (6) estimation of physical and hydraulic characteristics of canals and drains; (7) monitoring of low-flow conditions in urban storm drains; (8) dissemination of hydrologic information to the public; (9) Rio Grande flood-pulse investigation; and (10) investigation of aquifer compaction and land subsidence. Many of these activities focus on quantifying hydrologic relations between the Rio Grande and the aquifer system, as identified in the McAda (1996) plan. The current (1997) Cooperative Program with the SEO contains the following components: (1) revision of the Albuquerque Basin ground-water flow model; (2) establishment of a petrophysical reference borehole; (3) participation in the nested piezometers network and core analysis; and (4) participation in a large-scale aquifer test in Albuquerque.

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APPENDIXES

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