__Dennis Romero__ is a native of Pojoaque, New Mexico. After graduating from Pojoaque High School in 1985, he attended UNM under a NROTC scholarship where he earned his B.S. in Civil Engineering. Upon completing his undergraduate studies, he was commissioned as an Ensign in the U.S. Navy. Following a year of military school, Dennis reported aboard the U.S.S. St. Louis, an amphibious ship homeported in Sasebo, Japan, where he served as the ship's communications officer for two years. Following his tour in Sasebo, he transferred to the U.S.S. Independence, an aircraft carrier homeported in Yokosuka, Japan, where he served as an engineering officer for eighteen months. Upon resigning his commission in 1994, Dennis began graduate school at New Mexico Tech. His primary interests are in the fields of environmental geology, aqueous chemistry, and waste management.

A THREE-DIMENSIONAL CONCEPTUAL MODEL OF THE WATER QUALITY DISTRIBUTION IN THE ALBUQUERQUE BASIN

Dennis Romero
Department of Geoscience
New Mexico Tech
Socorro, NM 87801

INTRODUCTION

The City of Albuquerque was once under the impression that it sat atop a "world class" aquifer with a source of water comparable to that of one of the Great Lakes of the midwestern United States. A 1961 New Mexico State Engineer study conducted by Bjorklund and Maxwell (1961) emphatically stated that the Albuquerque metropolitan area, along with outlying areas of Bernalillo and Sandoval counties, had an aquifer with excellent hydrogeological characteristics which offered a virtually unlimited water supply. For over thirty years, the City of Albuquerque and the State of New Mexico used the Bjorklund and Maxwell characterization as the basis for managing the water resources within the Albuquerque Basin.

A recent 1992 joint study by the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) and the City of Albuquerque Public Works Department reevaluated the hydrogeological structure and characteristics of the Albuquerque Basin. The final report issued as a result of this study (Hawley and Haase 1992) concluded that Albuquerque's groundwater supply was not as plentiful as once thought, and that drastic efforts will be required to prevent further depletion of the Albuquerque aquifer.

Both the Hawley and Haase report and a subsequent attempt at numerically modeling the information it contained (Thorn et al. 1993) did an outstanding job describing the hydrogeology of the Albuquerque Basin in terms of the amount of groundwater present and the factors which control the flow of groundwater throughout the basin. Both the NMBMMR (Hawley and Haase 1992) and U.S. Geological Survey (USGS) (Thorn et al. 1993) studies primarily were concerned with present groundwater levels in the basin, the changes which have occurred in these water levels during the past 25 years, and the permeability characteristics of the host aquifer. While knowledge of the permeability distribution within the aquifer is vital to exploiting groundwater resources, it also is extremely important to examine the chemical processes related to the lithological and hydrological flow pattern of a hydrologic system (Alley 1993).

It is possible to construct a conceptual model of the Albuquerque Basin's geochemical characteristics and water quality distribution based on (1) the Hawley and Haase hydrogeological model, (2) water analyses from City of Albuquerque water wells, and (3) sound geological and chemical principles. Previous studies have characterized the water quality and geochemistry of the Albuquerque Basin from a two-dimensional perspective (Logan 1990; Titus 1963; Anderholm 1987); however, to date, there has been no examination of the variation of water quality with depth within the Albuquerque Basin. The primary focus of this paper is to describe a first attempt at developing a conceptual understanding of the three-dimensional water quality distribution of the Albuquerque Basin based on the above three "building blocks."

DESCRIPTION OF THE HAWLEY-HAASE MODEL

The team of scientists led by John Hawley and Stephen Haase used well records, geophysical logs, borehole cuttings, well pumping records, and core samples to characterize the composition and architecture of the basin. The resulting model described in detail the composition, structure, and textural character of the various parts of the Santa Fe Group—the major aquifer in the Albuquerque Basin, and the surficial river and basin-fill deposits throughout the northern basin (Hawley and Haase 1992). Hawley and Haase divided their model into three basic components shown in six cross sections which accompanied the final report. The three basic components of the Hawley and Haase model are structural features, hydrostratigraphic units, and lithofacies units.

The structural features of the model include fault zones within and surrounding the basin, mountain uplifts, bedrock units beneath the basin fill, and igneous intrusive and volcanic rocks that penetrate the basin deposits. The fault zones greatly influence the thickness and composition of sedimentary deposits throughout the basin, as well as sometimes acting as impermeable boundaries to groundwater flow (Haneberg and Hawley 1995). Uplifts of the Sandia-Manzano range form the basin's eastern boundary, while the igneous extrusive formations of the West Mesa form the western boundary.

The hydrostratigraphic units of the Hawley-Haase model are composed of basin fill classified on the basis of origin and stratigraphic position. These hydrostratigraphic units include alluvial fan piedmont deposits, river valley deposits, basin floor playas, and ancestral river valley deposits.

Lithofacies units serve as the cornerstone of the Hawley-Haase model. The lithofacies units were classified according to mineralogy, texture, sedimentary structure, and post-depositional deformation (Hawley and Haase 1992). The model divided the basin deposits into ten lithofacies and four sublithofacies classified according to sand+gravel/silt+clay ratios, bedding thickness, bedding configuration, and bedding continuity. Hawley and Haase described the hydraulic conductivity of these lithofacies by using six ranges of permeability values.

After gathering the necessary data and information, Hawley and Haase (1992) constructed six cross sections. The Llano de Albuquerque (West Llano) section and Louisiana section run from north to south, with the West Llano section crossing the western portion of the basin and the Louisiana section covering the eastern end. The four east-west sections of the model, listed from northernmost to southernmost, are the Paseo del Norte section, the Menaul section, the Gibson section, and the Pajarito section. With the exception of the Pajarito section, locations of the cross sections can be seen in Figure 1.

METHODS AND MATERIALS

Initial preparations for constructing the water quality distribution model involved simplifying the permeability classifications of the lithofacies and sublithofacies in the Hawley and Haase hydrogeological model. Hawley and Haase originally included six permeability zones in their model. It became apparent in the initial planning stages of the water quality model that six permeability zones would be too much to deal with for the first attempt of this conceptual model. The six permeability zones of the Hawley and Haase model were reduced to three categories: highly permeable regions with average hydraulic conductivities (K) greater than 30 ft/day; moderately permeable regions with average hydraulic conductivities ranging from 0.3 to 30 ft/day; and low permeability regions with average hydraulic conductivities less than 0.3 ft/day. After simplifying the Hawley and Haase permeability scheme, the lithofacies of all six cross sections of the Albuquerque Basin were coded according to the permeabilities outlined above. The City of Albuquerque water wells nearest each of the cross sections were then projected to show their relative locations and depths.

Following the initial preparations, water quality data for pertinent municipal wells within the basin was obtained from the City of Albuquerque Public Works Department. Stiff diagrams were constructed to examine the water chemistry and total dissolved solids (TDS) for each of these wells. The Stiff diagrams were then scaled down in size and transferred to locations on each of the cross sections where their corresponding wells were located. The changes in water chemistry and TDS with respect to the location of the wells' screened intervals and aquifer composition were then examined.

RESULTS AND OBSERVED TRENDS

Due to the limited amount of water analyses for both the West Llano and Pajarito cross sections, only four of the six cross sections described by Hawley and Haase were examined for trends with respect to water chemistry and TDS.

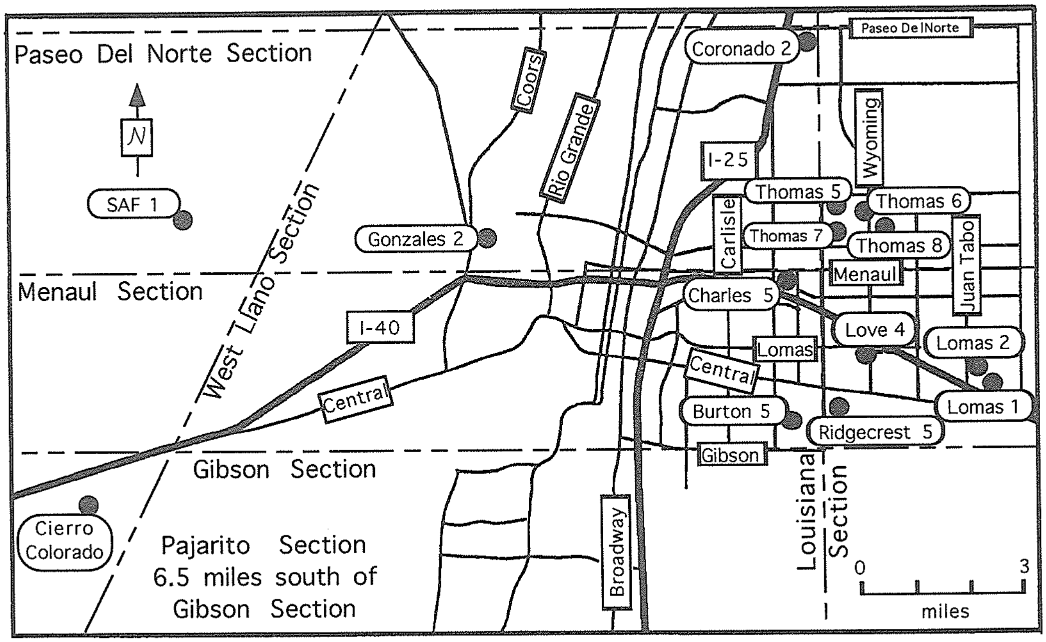

Figure 1. Overview of Albuquerque metropolitan area with locations of the Hawley and Haase model cross sections shown (modified from Hawley and Haase 1992).

Paseo del Norte Section

The Paseo del Norte section is the northernmost cross section in the Hawley-Haase Model (Figure 1). It cuts through the northwest portion of the Albuquerque area which is currently experiencing a major surge in industrial, commercial, and residential growth. This cross section also illustrates the potential to exploit the groundwater reserves of the Zia Formation, an eolian sand which traverses the base of the Lower Santa Fe Unit throughout the western portion of the Albuquerque Basin.

The Paseo del Norte section, shown in Figure 2, has no wells west of the Volcano Cliffs field. Analyses for both SAF and Intel Test Well 3 have been projected onto the western portion of this section to illustrate what the quality of groundwater obtained from the western edge of this section may resemble. SAF 1 is located some three miles south of the Paseo del Norte cross section, while Intel Test Well 3 is located roughly seven to ten miles to the north.

Note the differences in sodium (Na^+) concentration between samples obtained from the two wells. Well SAF 1 contains a relatively high Na^+ concentration in contrast to the moderate Na^+ content of water obtained from the northern Intel well. This large difference in Na^+ concentration is very likely due to the recharge of the northwestern portion of the Albuquerque aquifer by the Rio Salado (Hawley 1994). Rio Salado, as the name implies, is a river with very high TDS, specifically sodium and chloride. The Stiff diagrams for samples obtained from SAF 1 and Intel 3 dramatically illustrate that aquifer recharge from Rio Salado is occurring south of the City of Rio Rancho and north of the Menaul cross section. Also of interest is the fact that the Stiff diagram for Intel 3 shows a much greater amount of alkalinity (CO_3^{2-} and HCO_3^{2-}) and hardness (Mg^{2+} and Ca^{2+}) than that of SAF 1. It is difficult to make generalizations based on only two samples; however, samples from these two wells suggest Na^+ concentrations in groundwater north to south in the western region of the Albuquerque basin, while both hardness and alkalinity decrease from north to south.

Moving eastward, toward the Rio Grande, the Stiff diagrams for samples obtained from the Volcano Cliffs wells and Zamora 1 all show a signifi-

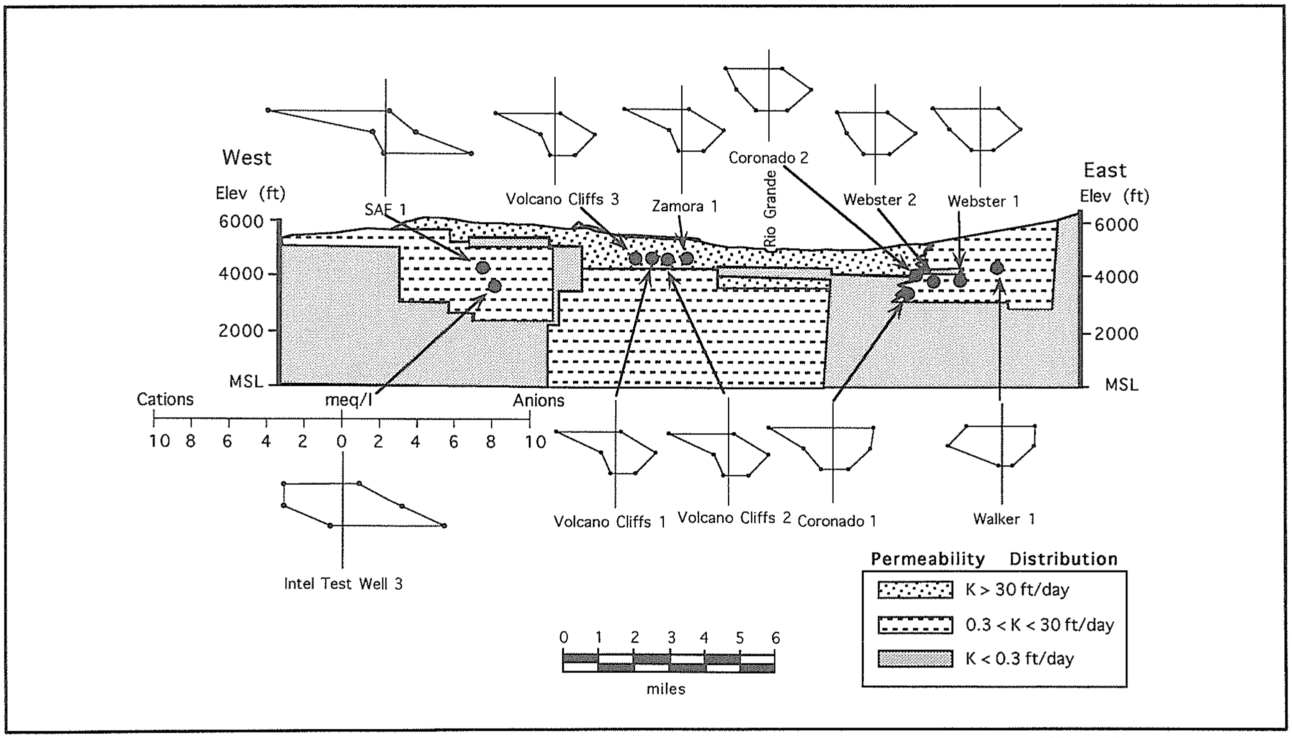

Figure 2. Paseo Del Norte cross section showing relative depths of City of Albuquerque wells and Stiff diagrams corresponding to their respective water analyses (modified from Hawley and Haase 1992).

cant decrease in Na^+ and sulfate (SO_4^{2-}) concentrations from that of SAF 1. Upon crossing the Rio Grande, a significant increase in both hardness and alkalinity can be seen along with a moderate decrease in both sodium and sulfate concentrations.

Also of interest is the fact that the Coronado 1, the deepest well in the eastern portion of the Paseo del Norte cross section, exhibits a significant increase in both sodium and chloride (Cl^-) concentrations, as well as TDS. These increases are attributed to the fact that Coronado 1 is deeper than the other wells in the eastern portion of this section and is located much closer to a region of poor permeability than any of the other eastern wells. Generally, water in deeper zones has been in contact with the aquifer matrix for longer periods of time than shallower groundwater. Therefore, the groundwater contains greater amounts of solute because it has been exposed to a greater amount of mineral dissolution. Groundwater in low permeability regions also has a longer residence time than waters at similar depths in more permeable zones. For these reasons, groundwater in low permeable zones is expected to have a somewhat higher TDS and chloride concentrations (Freeze and Cherry 1989).

The last major point concerning the Paseo del Norte cross section concerns wells Coronado 1 and Webster 1 and 2. Although Coronado 1 and the two Webster wells are shown to lie within different zones of hydraulic conductivity, their water chemistry is almost identical. A satisfactory explanation for this could not be found until John Hawley explained to the author that the highly permeable region in which Coronado 1 is located, shown in Figure 2, was drawn incorrectly. Actually, this zone of moderate permeability extends just past Webster 1 and will be shown in future versions of the Hawley-Haase model (Hawley 1994). Note that this highly permeable zone ends just after Webster 1. A significant increase in TDS, most notably Ca^{2+}, can be seen by comparing the Stiff diagrams for the Webster wells with that of Walker 1, which is located in a moderately permeable zone.

Menaul Cross Section

The Menaul cross section (Figure 3) is located three miles south of the Paseo del Norte section (Figure 1). This section contains a significant number of municipal water wells which supply the City of Albuquerque.

Upon examining the Stiff diagrams for the three wells located west of the Rio Grande, distinct patterns emerge: groundwater high in both sodium and sulfate is located in the western edge of the basin; sulfate and sodium concentrations decrease from west to east; and both hardness and alkalinity increase from west to east. The high sodium and sulfate concentrations in groundwater located in the western portion in the basin are in great part caused by the presence of a large amount of igneous material located on the basin's western boundary which is composed of great amounts of potassium, sodium, and sulfate (e.g., sodium feldspars and potassium feldspars).

The wells located to the east of the Rio Grande also reveal some very distinct patterns: both sodium and sulfate concentrations decrease from west to east; both alkalinity and hardness increase from west to east; and the deepest well in the eastern portion of the Menaul section contains the highest TDS and chloride concentration.

Gibson Cross Section

The Gibson cross section (Figure 4) contains the southernmost City of Albuquerque municipal wells and runs parallel to Kirtland Air Force Base and the Albuquerque International Airport (Figure 1).

As with the Menaul section, the following trends can be seen west of the Rio Grande: groundwater high in both sodium and sulfate is located in the western edge of the basin; sulfate and sodium concentrations decrease from west to east; and both hardness and alkalinity increase from west to east. The Stiff diagram for the Cerro Colorado analysis dramatically illustrates the affects that rock type and poor hydraulic conductivity can have on water chemistry. Cerro Colorado is located in a region of poor permeability which is composed largely of igneous rock. The Cerro Colorado analysis contains relatively high levels of sodium, chloride, and sulfate. It is interesting to note that TDS levels in Cerro Colorado are at approximately 1100 mg/l, while the TDS levels in Don 1 (a well at the same depth as Cerro Colorado, but located within a moderately permeable zone) are at approximately 480 mg/l.

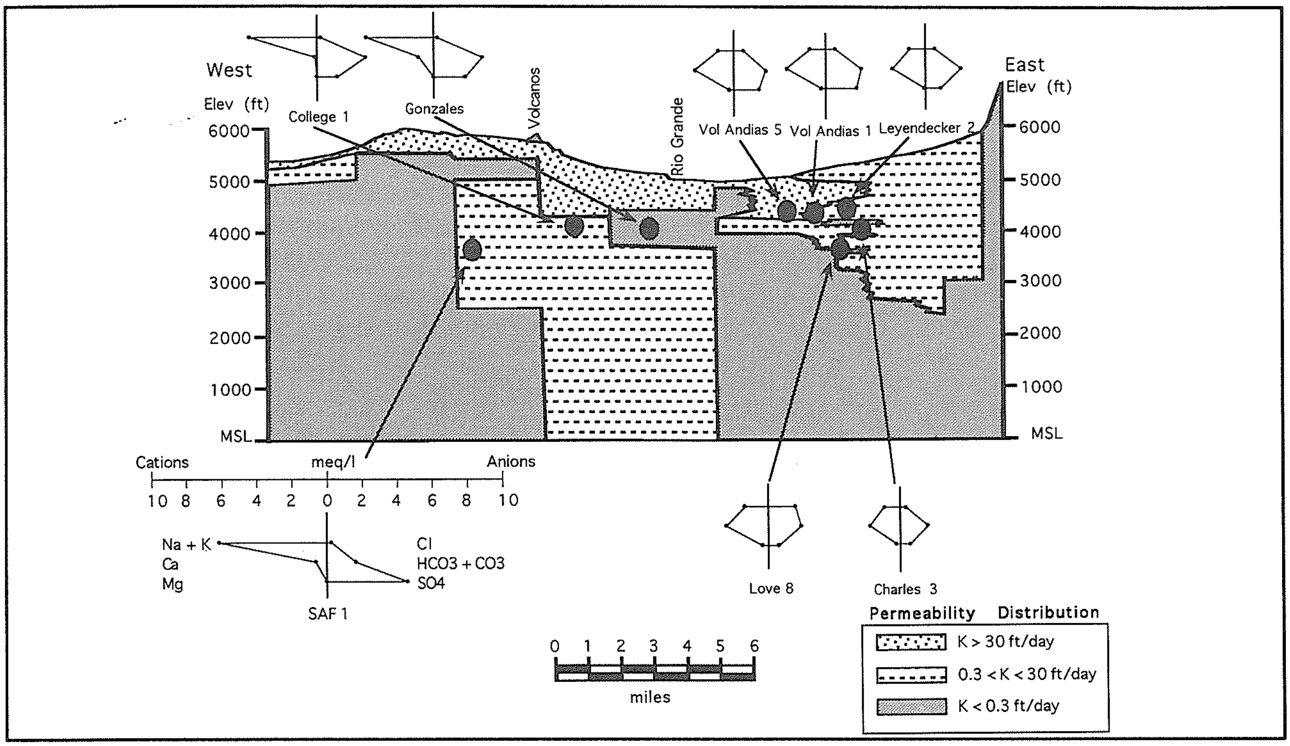

Figure 3. Menaul cross section showing relative depths of City of Albuquerque wells and Stiff diagrams corresponding to their respective water analyses (modified from Hawley and Haase 1992).

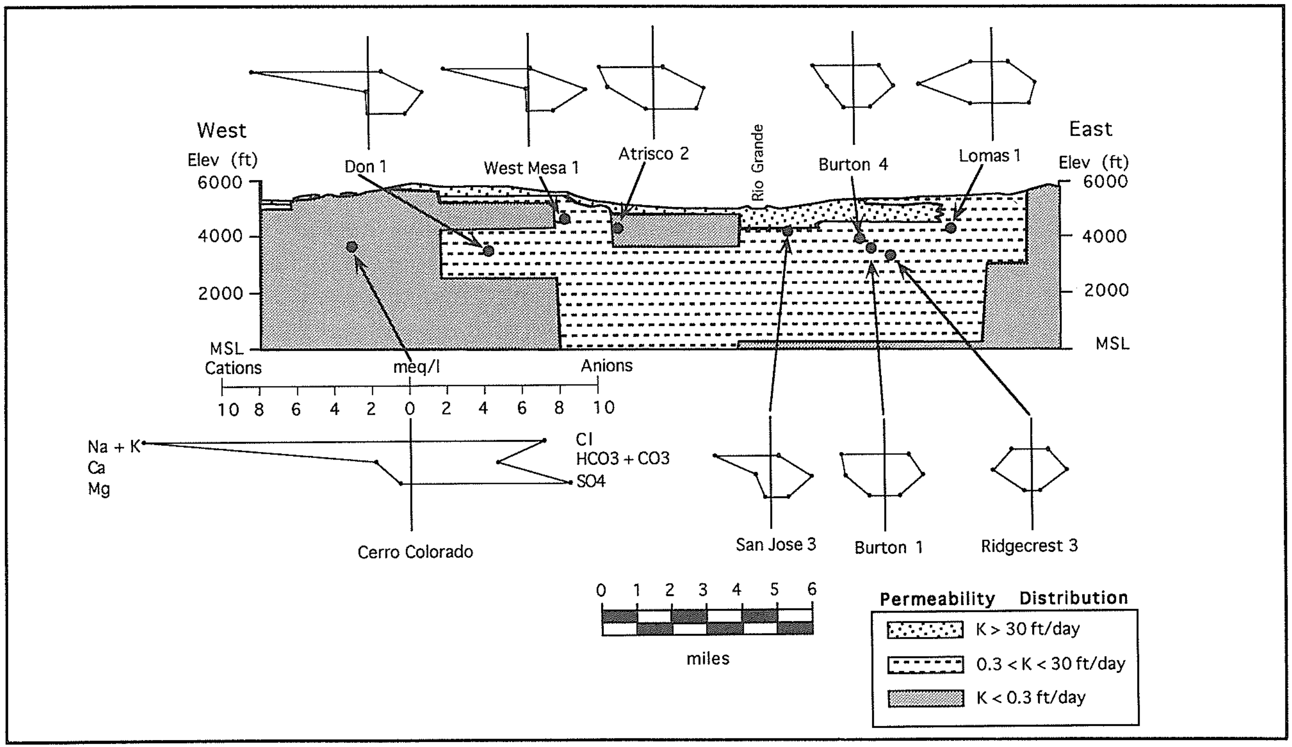

Figure 4. Gibson cross section showing relative depths of City of Albuquerque wells and Stiff diagrams corresponding to their respective water analyses (modified from Hawley and Haase 1992).

The wells located to the east of the Rio Grande also illustrate the following trends: both sodium and sulfate concentrations decrease from west to east; and both alkalinity and hardness increase from west to east.

Of particular interest in the Gibson section are the wells Burton 1, Burton 4, and Ridgecrest 3. All three wells are located relatively close to each other and within the same permeability zone. Note that Burton 4 is the shallowest of the three, followed by Burton 1, with Ridgecrest 3 being the deepest. If TDS were a function of depth only, Ridgecrest 3 would have the highest TDS level and Burton 4 the lowest—this, however, is not the case. Burton 4, the shallowest well, has the highest TDS of the three with 295 mg/l. Burton 1, some 200 feet deeper, has a TDS of 280 mg/l. Finally, Ridgecrest 3, the deepest of the three (roughly 100 feet deeper than Burton 1), has the lowest TDS of the three wells at 255 mg/l.

Louisiana Cross Section

The Louisiana cross section (Figure 5) runs north to south on the eastern side of the basin and bisects all four of the east-west sections (Figure 1). Due to the northern boundary of Kirtland Air Force Base, the City of Albuquerque has no municipal wells south of Gibson Boulevard along this section.

In general, both sodium and sulfate concentrations decrease from north to south. Also, both the hardness and alkalinity of the groundwater increase from north to south. It is interesting to note that groundwater coming from Love 8 contains a much higher TDS than any of the nearby Leyendecker wells. Also, Love 8 contains a higher amount of hardness than the Leyendecker wells despite the fact that it is 1.5 miles southward. In addition, Love 8 contains a greater concentration of chloride than any of the nearby wells. This aberration might be explained by the proximity of regions of poor permeability. Shales can act as membranes (Fritz 1986). Consequently, solute rejected by shale membranes builds up in the aquifer as some of the groundwater moves through the low permeable regions resulting in higher than normal TDS.

TDS Trends

To examine the variation of TDS within the basin, the TDS of wells located along each of the four cross sections discussed above were plotted with respect to relative well locations. Figures 6, 7, and 8 show the TDS variations of three east-west sections of Paseo del Norte, Menaul, and Gibson. Figure 9 shows the TDS distribution versus relative location for the north-south Louisiana section. In addition, TDS levels as a function of depth were plotted for each of the three permeability zones (Figure 10).

Figure 6 shows that TDS along the Paseo del Norte section is greatest near the Rio Grande and tends to decrease toward the edges of the basin. Figure 7 shows TDS along the Menaul section decreases from the river to the east and increases west of the river. Figure 8 shows that TDS along the Gibson section tends to increase both eastward and westward of the river.

The trends illustrated by figures 6 through 8 may be due to the loss of hydraulic connectivity between the river and the aquifer, or may be due to a factor as simple as a variation of rock type throughout the basin.

Figure 9 shows that, in general, TDS along the eastern side of the basin tends to decrease from north to south. Again, it is important to note that the quality of water south of the Gibson section was not examined due to the lack of information regarding the portion of the basin located within Kirtland Air Force Base.

Figure 10 illustrates that TDS within the basin does not always increase with depth. TDS levels for wells located in each of the three zones were plotted against depth. Note that TDS does not always increase with increasing depth. Maximum TDS levels for each of the three zones occur between depths of 1000 and 1500 feet and, for the moderately permeable zone, decrease significantly at greater depths.

SUMMARY

Although this paper has only outlined the first attempt at developing a three-dimensional model of the water quality distribution within the Albuquerque basin, many of the following results and trends observed are quite valid and should be examined in greater detail in future studies.

- TDS increases from north to south on the eastern side of the basin.

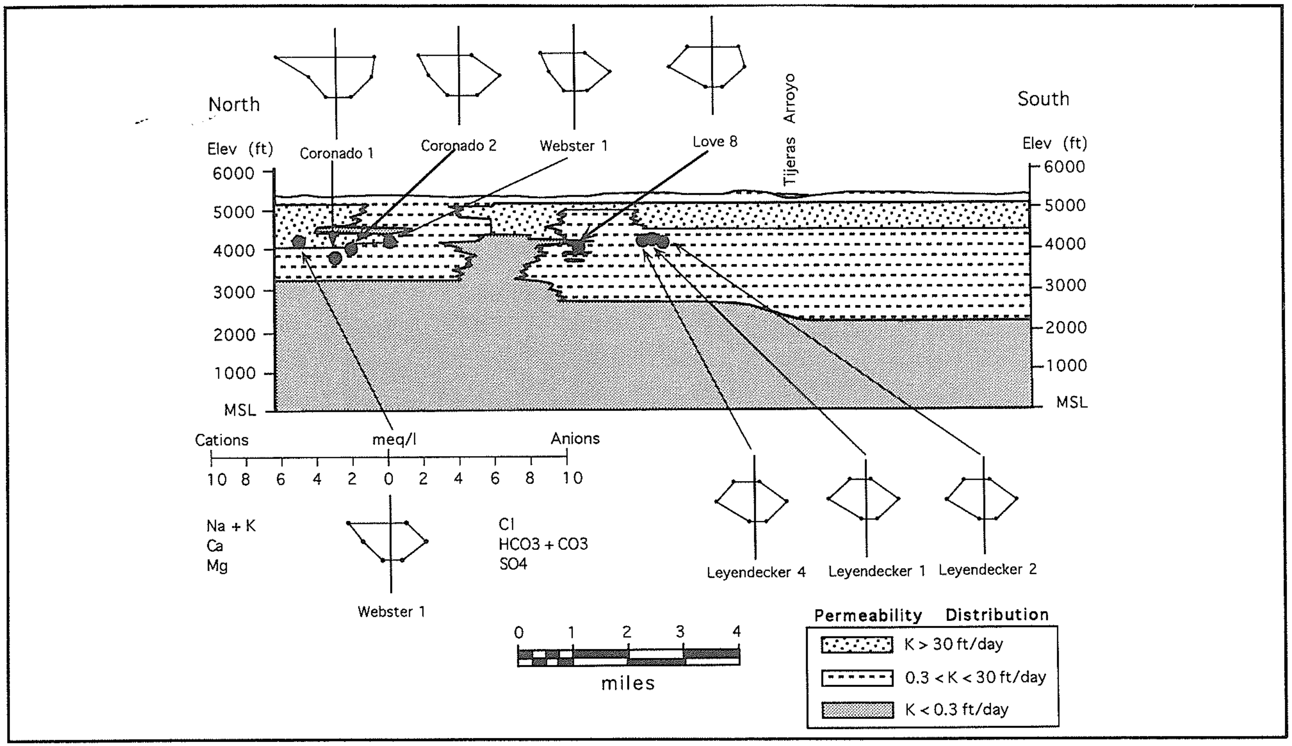

Figure 5. Louisiana cross section showing relative depths of City of Albuquerque wells and Stiff diagrams corresponding to their respective water analyses (modified from Hawley and Haase 1992).

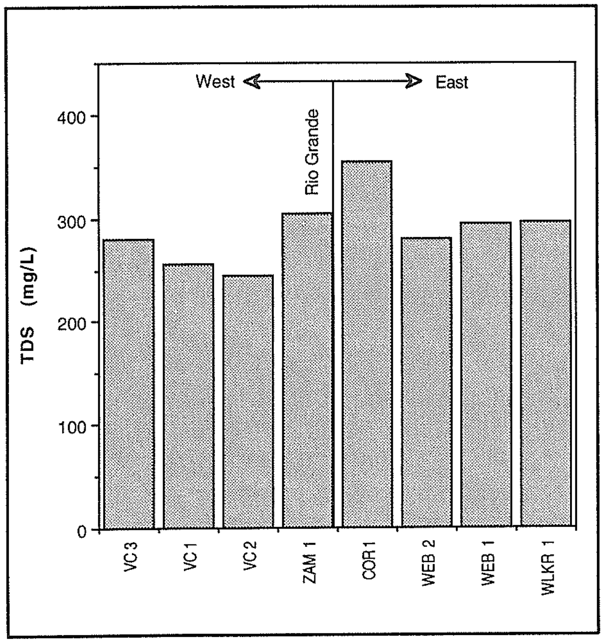

Figure 6. Variation of TDS with respect to relative location for City of Albuquerque wells located along the Paseo Del Norte cross section.

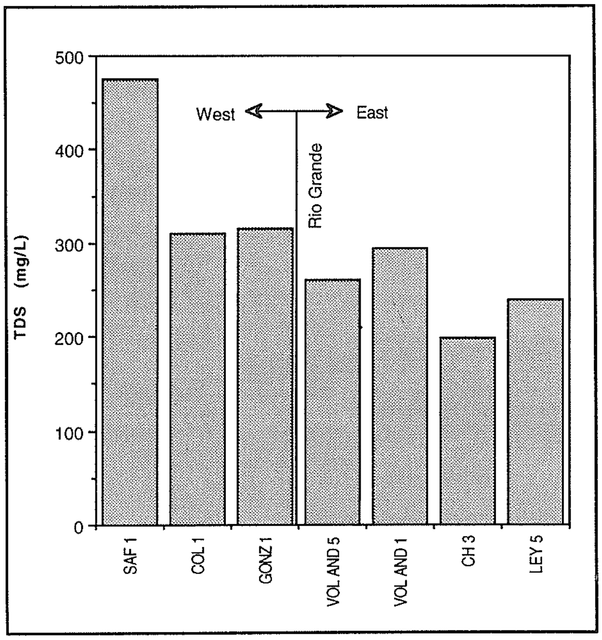

Figure 7. Variation of TDS with respect to relative location for City of Albuquerque wells located along the Menaul cross section.

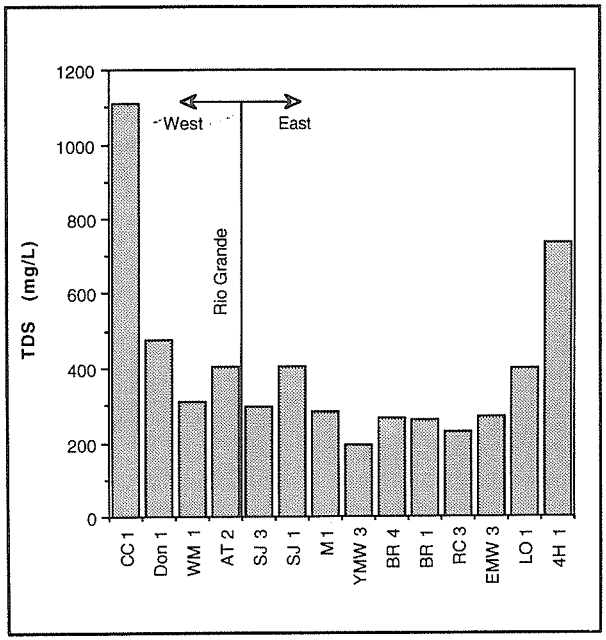

Figure 8. Variation of TDS with respect to relative location for City of Albuquerque wells located along the Gibson cross section.

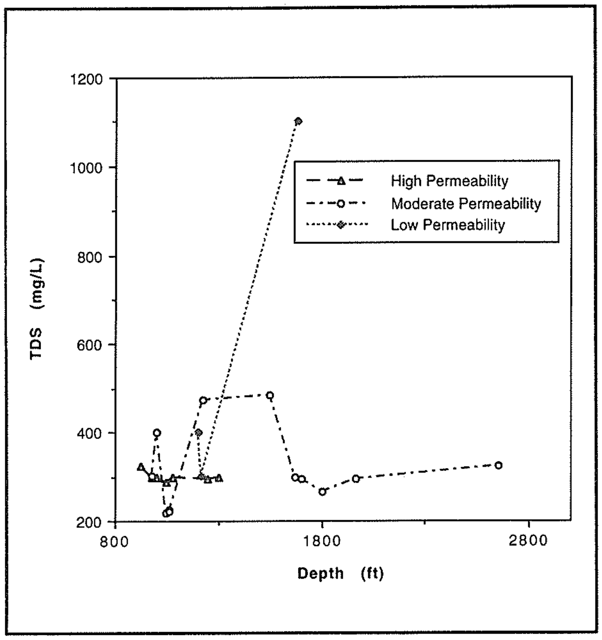

Figure 10. Variation of TDS with respect to depth for City of Albuquerque wells located within the three permeability zones.

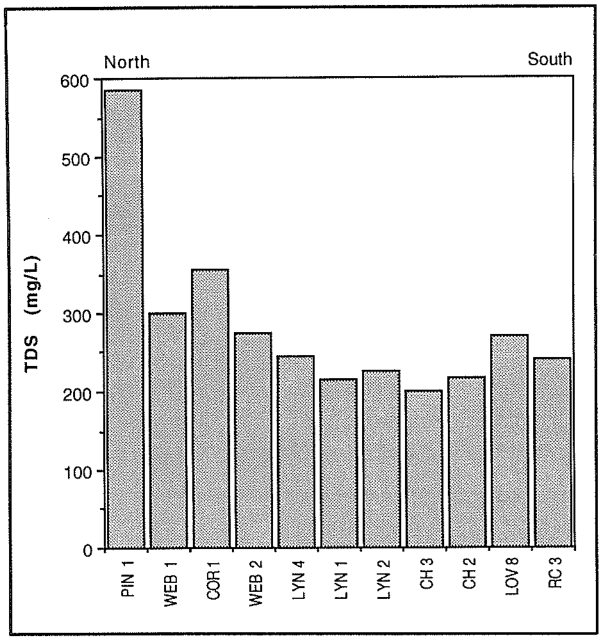

Figure 9. Variation of TDS with respect to relative location for City of Albuquerque wells located along the Louisiana cross section.

- TDS decreases from the basin edges toward the Rio Grande.
- Groundwater in the western basin tends to be high in sodium and sulfate, yet relatively soft and low in alkalinity.
- Groundwater in the eastern basin is relatively hard yet low in sodium and sulfate.
- The northwest portion of the City of Albuquerque may have a higher water quality and greater supply than previously thought.
- Water chemistry patterns suggest much more complex flow patterns than previously thought.
- Groundwater quality does not always decrease with depth in the Albuquerque Basin.
- Aquifer permeability and rock type may be the dominant factors in determining groundwater quality within the Albuquerque Basin.

Further attempts at examining the water chemistry and quality within the basin should definitely be made if the City of Albuquerque is to continue with its present rate of growth.

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