SUMMARY

Data collection in the southern Sacramento Mountains began in the fall of 2005 and will be complete in July 2009. The variety of data collected includes detailed geologic mapping, repeated and continuous water level measurements in over 75 wells, water chemistry, ground water age-dating, stable isotope measurements, precipitation sampling and monitoring, evaluation of stream flow, and detailed measurements of fracture patterns. These data provide a unique opportunity for a comprehensive review and interpretations of the ground water system in the southern Sacramento Mountains.

Currently, our findings suggest that the primary recharge area for aquifers in and surrounding the Sacramento Mountains is in what we have delineated as the high mountain aquifer system. Ground water in this area is recharged by infiltration of precipitation with subsequent "recycling" through springs and streams. From the high mountain region, most ground water flows east and south toward the Pecos slope aquifer and the Salt Basin.

SACRAMENTO MOUNTAINS WATERSHED STUDY

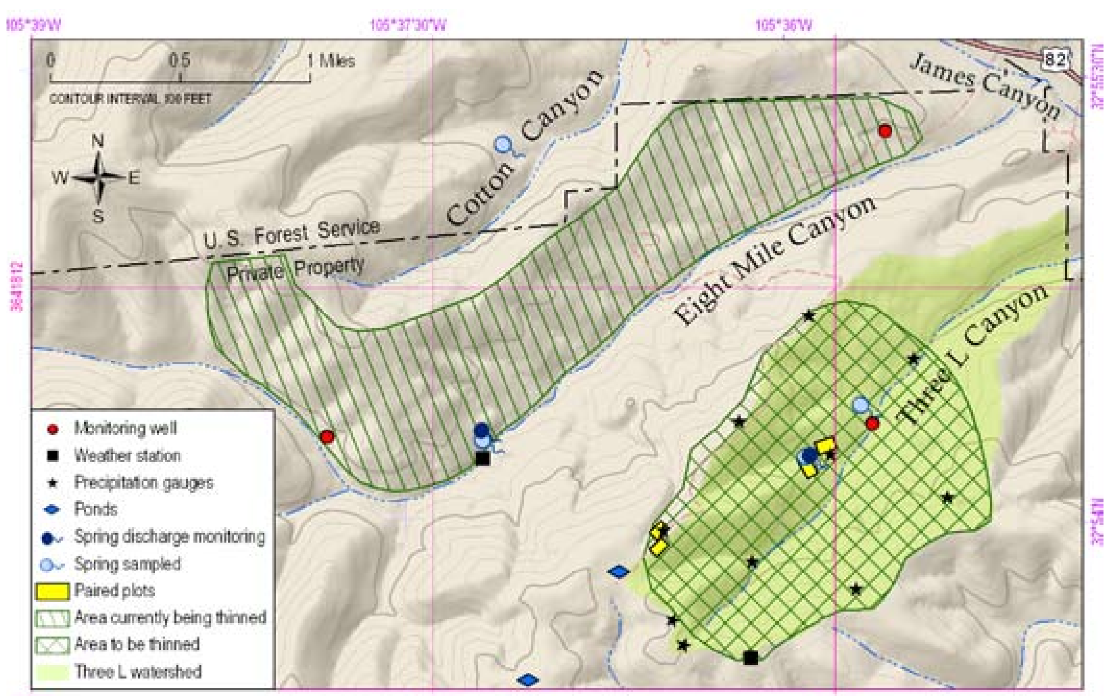
The primary goal of the Sacramento Mountain Watershed Study (SMWS) is to assess the effects of thinning trees in the mountains on a local hydrologic system. The study area (front page map) includes Three L, Eight Mile and Cotton Canyons. The focus of the SMWS is an experiment in Three L Canyon, a small watershed (~900 acres), that will utilize hydrologic, geochemical, and remote sensing techniques to examine how the inputs to and outputs from the local hydrologic system change after a large portion of the watershed is thinned. Baseline data are now being collected and tree thinning will begin in the area indicated on the map below in 2010. We will continue collecting data through 2012.

Other activities aimed towards evaluating the effects of tree thinning on the ground water and surface water systems include geochemical sampling, and measurement of ground water levels and spring discharge in areas that are currently being thinned in Eight Mile Canyon. Cotton Canyon is included as a control area, where no tree thinning will occur. We have installed instrumentation, that will help to estimate the different components of the watershed-scale water balance.

The map below shows the location of instrumentation and sampling points.

- Weather stations are measuring temperature, relative humidity, barometric pressure, wind speed and direction, precipitation, and solar radiation.
- Water levels and geochemistry are monitored in ponds located in small closed catchments on the ridge to measure runoff and infiltration on a smaller scale.
- Paired plot experiments will compare the plot-scale (30 by 30 meters) water balance for thinned plots to that of non-thinned plots. Each pair of plots is located on a different soil type and/or slope position.
- Precipitation volume is measured at several locations throughout the study area.
- Spring discharge is measured on an hourly basis in springs in Three L and Eight Mile Canyons.
- Ground water levels are monitored on an hourly basis in Three L and Eight Mile Canyons.

Our preliminary interpretations of these data are currently being improved as we revise and update our report for this project (New Mexico Bureau of Geology and Mineral Resources Open File Report 512 found at http://geoinfo.nmt.edu/publications/openfile/downloads/OFR500-599/500-525/512)



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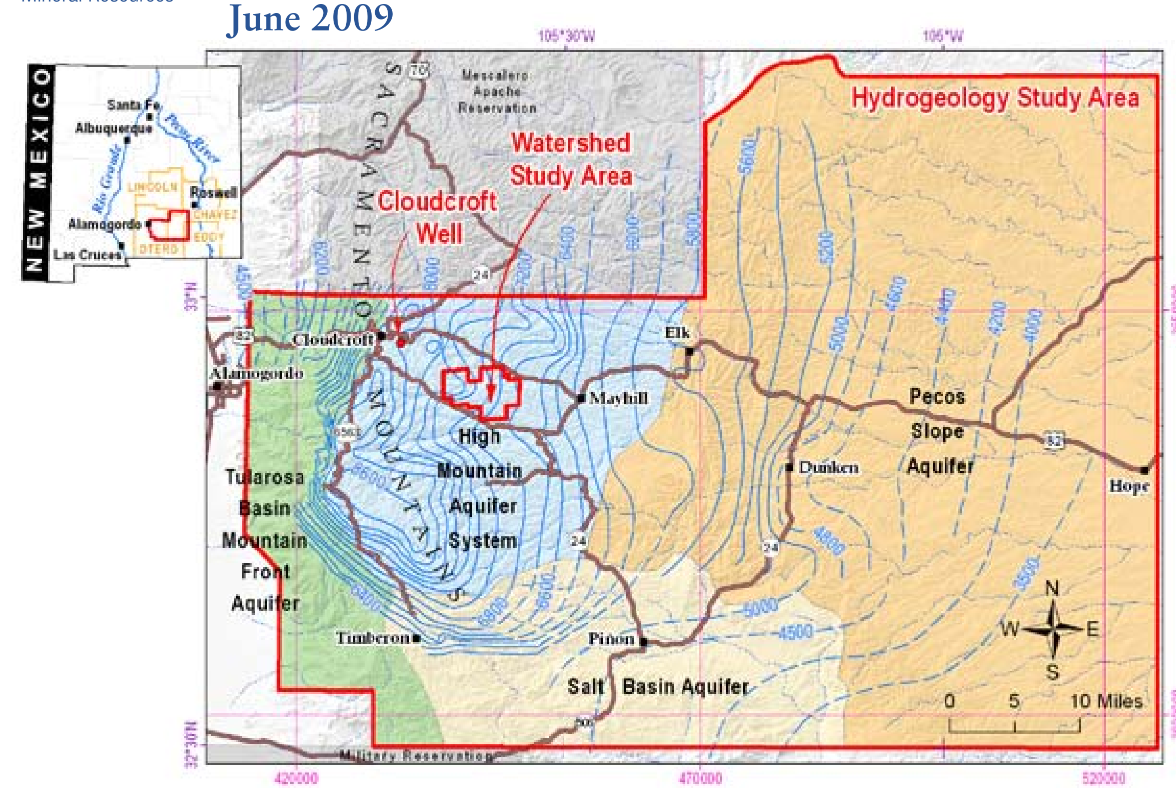
AQUIFER MAPPING PROGRAM

New Mexico Bureau of Geology and Mineral Resources

Sacramento Mountains Hydrogeology Study

June 2009



Study area map showing the regional aquifers and average water table elevation contours (in feet). Ground water flows from high to low elevations, and perpendicular to contours.

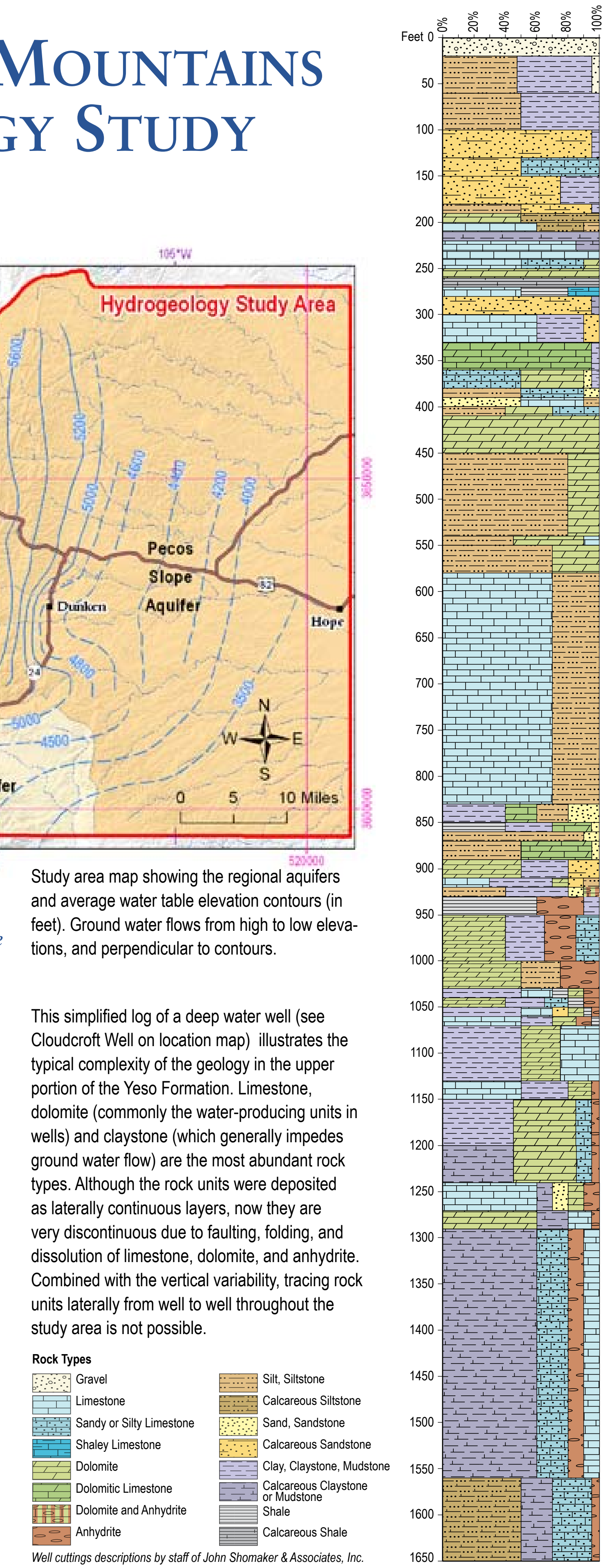
The southern Sacramento Mountains are an important source of recharge to the Roswell Artesian Basin and Salt Basin aquifers. This is an overview of progress to date of an ongoing, multi-scale study to understand the hydrogeology of the mountain aquifers, the relationship between surface water and ground water, and the effects of vegetation management and climatic variability on the local hydrologic balance. The project was initiated and is supported by the Otero Soil and Water Conservation District.

GEOLOGY

The main water-bearing units in the southern Sacramento Mountains are the Yeso and San Andres Formations. The Yeso Formation is the primary aquifer in the high mountain region. It is a complex geologic unit, as shown by the well log to the right. Ground water is stored in the Yeso Formation within fractures and pores in the limestone, dolomite, siltstone and sandstone. Most water discharging from springs and wells in the high mountains is associated with fractures and voids within limestone and dolomite units.

The San Andres Formation is more homogeneous than the Yeso Formation, and is composed primarily of gray limestone and dolomite. It is found on ridge tops and upper hill slopes in

This simplified log of a deep water well (see Cloudcroft Well on location map) illustrates the typical complexity of the geology in the upper portion of the Yeso Formation. Limestone, dolomite (commonly the water-producing units in wells) and claystone (which generally impedes ground water flow) are the most abundant rock types. Although the rock units were deposited as laterally continuous layers, now they are very discontinuous due to faulting, folding, and dissolution of limestone, dolomite, and anhydrite. Combined with the vertical variability, tracing rock units laterally from well to well throughout the study area is not possible.



Well cuttings descriptions by staff of John Shomaker & Associates, Inc.

the high mountain region. It is a dominant water-bearing unit only in the eastern parts of the Pecos slope region. However, it is the primary aquifer in the Roswell Artesian Basin.

GROUND WATER FLOW CONDITIONS

In general, most of the ground water flows eastward from the crest of the mountains towards the Pecos River Valley. Some water also flows southward into the Salt Basin. Regionally, the water level elevation throughout the study area is primarily controlled by topography. That is, the water table surface resembles smoothed topography. The elevation differences in the study area are what drive ground water flow. Steep gradients in the southwestern part of the study area (shown on front page map) reflect the steep mountain front topography. On a smaller scale, geologic features, such as rock types or geologic structures, can have an effect on ground water movement. In the high mountains, the position of limestone beds with respect to other rock types, as well as fractures in the rock, control where water discharges as springs. East of the McDonald Flats area, the gradient steepens across the Dunken-Tinnie structural zone, due to the dominant ground water flow direction being perpendicular to the faults and folds of this regional structure.

REGIONAL AQUIFERS

As shown on the front page map, the study area has been divided into four regional aquifers. The boundaries are largely based on topography (surface water drainage basins) and the water table map that represents the average surface of the water table on a regional scale. The boundary between the high mountain aquifer system and the Pecos slope aquifer is based on water chemistry and flow characteristics. It is approximately where the Yeso Formation dips below the ground surface.

Some of our preliminary interpretations of the southern Sacramento Mountains ground water system are depicted on the cross-section below. Interpretations were made from spring locations, well and water level data, water chemistry, stable isotopes and age-dating information.

High Mountain Aquifer System–The aquifer system in the high mountains is complex and variable. There are many wells and springs in this region, therefore it is an area where we have abundant data. The complex geology of the Yeso Formation results in a complicated hydrologic system. Perched aquifers associated with the multitude of springs are connected to each other by regional fracture networks and local stream systems. It is probable that a deeper continuous aquifer exists in the eastern portion of the high mountains that connects to the Pecos slope aquifer. The high mountain aquifer system recharges aquifers in the Roswell Artesian Basin and Salt Basin.

Stable isotope data for springs and wells suggest that water originates as local precipitation (primarily snow melt) and has undergone evaporation in mountain streams. Water discharging from perched aquifers and springs at higher elevations becomes part of the surface water system where it undergoes evaporation, but then recharges another shallow ground water system and discharges at a spring at a lower elevation. This cycle may happen several times before the water is deep enough below the ground surface that it cannot interact with the surface water system.

The chemistry of this aquifer system indicates this water has spent less time in the subsurface than water in adjacent aquifer. The high mountain aquifer system has a diamond shaped stiff diagram with relatively high calcium and bicarbonate. The primary water source in this aquifer system is local precipitation. As water percolates below the surface and moves through the ground water system, it acquires its chemical signature by dissolving limestone in the San Andres and Yeso Formations.

The relative age of this water compared with the other aquifer classes also supports the chemistry findings. On average, the water in the high mountains has the most tritium (3.4 TU, from 54 samples). These data suggest that it is a mixture of water that may be as young as 1–2 years old with older water that may be greater than 80 years old.

Pecos Slope Aquifer–The aquifer from approximately Mayhill towards the eastern study boundary is geologically simple relative to the high mountain area, though there are several faults and structural zones which may influence the ground water. Wells are completed in both Yeso and San Andres Formations and a few springs discharge from the Yeso Formation. Recharge to this aquifer occurs primarily from the high mountain aquifer system to the west.

The stable isotopic composition of ground water in this aquifer is fairly constant over a large area and is similar to that of springs and wells sampled at the eastern edge of the high mountain aquifer system. This trend is consistent with the interpretation that recharge to the Pecos slope aquifer comes primarily from the high mountain aquifer system.

The chemistry of this aquifer indicates that ground water has been in the subsurface for a longer time period compared to the high mountain aquifer system, and has higher electrical conductivity. The stiff diagram shows slightly elevated sodium, chloride, calcium and magnesium concentrations compared to ground water in the high mountain aquifer system. The main difference in the shape of the two stiff diagrams is the increase in sulfate in the Pecos slope aquifer which is likely a result of ground water dissolving gypsum in the Yeso Formation.

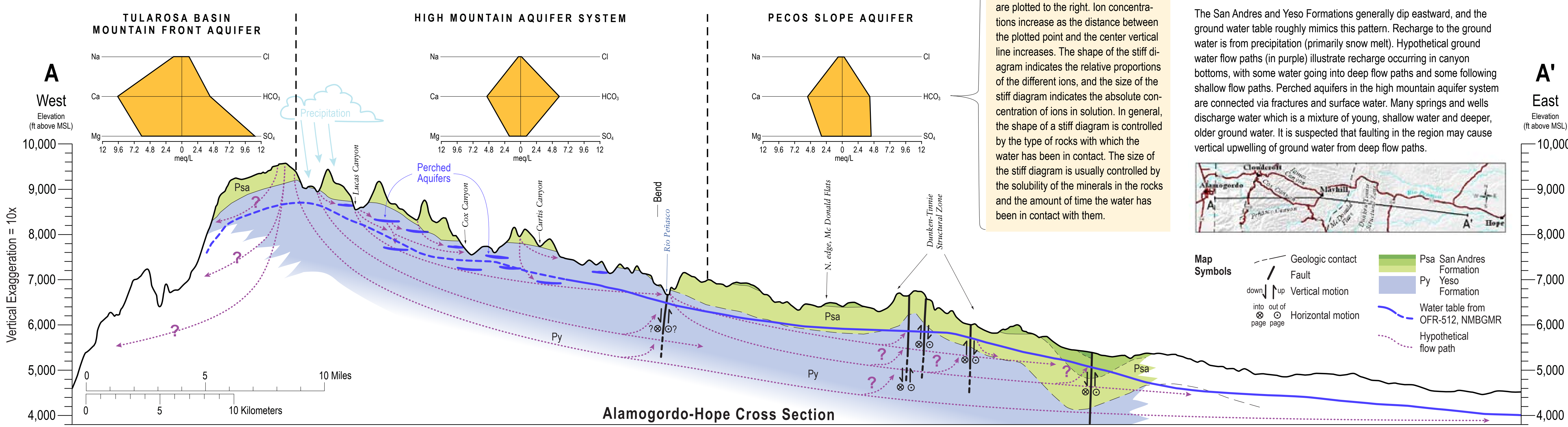
The relative age of the ground water in the Pecos slope aquifer is also older than other areas, with an average tritium concentration of 1.0 TU (from 30 samples). These data suggest that ground water is a mixture of a young component (less than 30 years old) with an older component (probably much greater than 80 years old). Also, the relative age of the ground water appears to get older towards the east.

Tularosa Basin Mountain Front Aquifer–The steep west side of the study area has very different geology and hydrologic characteristics than areas east of the range crest. The geology is complicated by mountain-front parallel faulting. There are several springs that discharge along the steep mountain front, and many wells throughout the area. We have collected minimal data for this area, but it does indicate that water is different from the high mountain aquifer system and other areas encountered in this study. (Our studies will focus on the northern Tularosa Basin in the next few years.)

Water chemistry is quite different than that of water from the high mountain aquifer system and the Pecos slope aquifer. The most striking observed difference when comparing average stiff diagrams is the size. The measured concentrations for most major ions are at least twice that of those measured for the other two aquifer systems. The shape of the stiff diagram is also different than that of the other stiff diagrams, indicating high sulfate waters which is probably a reflection of the different rock types that are present in this system.

STIFF DIAGRAM

Stiff diagrams are a way of plotting the general chemistry of water. Positively charged ions (sodium (Na), calcium (Ca), and magnesium (Mg)) are plotted to the left of the vertical line, and negatively charged ions (chloride (Cl), bicarbonate (HCO_3), and sulfate (SO_4)) are plotted to the right. Ion concentrations increase as the distance between the plotted point and the center vertical line increases. The shape of the stiff diagram indicates the relative proportions of the different ions, and the size of the stiff diagram indicates the absolute concentration of ions in solution. In general, the shape of a stiff diagram is controlled by the type of rocks with which the water has been in contact. The size of the stiff diagram is usually controlled by the solubility of the minerals in the rocks and the amount of time the water has been in contact with them.



The San Andres and Yeso Formations generally dip eastward, and the ground water table roughly mimics this pattern. Recharge to the ground water is from precipitation (primarily snow melt). Hypothetical ground water flow paths (in purple) illustrate recharge occurring in canyon bottoms, with some water going into deep flow paths and some following shallow flow paths. Perched aquifers in the high mountain aquifer system are connected via fractures and surface water. Many springs and wells discharge water which is a mixture of young, shallow water and deeper, older ground water. It is suspected that faulting in the region may cause vertical upwelling of ground water from deep flow paths.