Runoff Processes and the Evolution of Water Chemistry in the Saguache Creek Watershed of the Upper Rio Grande

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Abstract:

Snowmelt is a significant source of recharge in the Upper Rio Grande of southern Colorado. However, the runoff processes that control the partitioning of water during snowmelt are poorly understood. These mechanisms need to be represented correctly so that distributed models such as tRIBS can accurately simulate and predict mountain front recharge in these high elevation headwater catchments. The ultimate objectives of this research are to use stream and groundwater chemistry to understand runoff processes, residence times, and flowpath length distributions in the Upper Rio Grande. The research plan was initially divided into three distinct steps: to develop criteria through which a representative sub-catchment of the Upper Rio Grande was selected or rejected, to instrument the selected catchment with water quality sondes in order to acquire a long-term high-resolution signature of stream chemistry, and to perform groundwater dating analyses.

The first step of this research plan was initiated in September 2005 and was completed in 2006. The Saguache Creek watershed located in the northern San Luis Valley was selected for our research plans. This watershed met all criteria, including good accessibility to stream and springs by forest roads and trails, presence of stream gauging stations, presence of SNOTEL and/or snowcourse sites, low population density, topographical and geological similarity to the Rio Grande headwaters, type of land-use, length and completeness of hydrological records, and desirable patterns of stream chemistry. The historical hydrological dataset for Saguache Creek catchment has been utilized to compare the hydrological processes of this stream to the Upper Rio Grande as measured at Monte Vista, CO, and to the Conejos River in the southern San Juan Mountains. Several hydrological characteristics, including normalized streamflow, baseflow contribution, snowmelt flux, and snow water equivalent, were compared between these streams and the results indicate that there is a strong similarity between the Saguache Creek and the Upper Rio Grande. In addition, samples of snow, snowmelt runoff, streamwater, and spring water have been collected and analyzed from the Saguache Creek watershed. Preliminary data show encouraging trends in the chemical evolution of groundwater and stream water from high to low elevations. The distribution of springs with respect to elevation in the catchment will also prove useful in groundwater dating and in the determination of residence times in the watershed. Thus, the next step of our research is to instrument the stream with a water quality sonde. Ideally, we would prefer to purchase two water quality sondes: one for the lower reaches of Saguache Creek and one for one of the headwater streams. This methodology would provide both a temporal and spatial pattern of the evolution of stream water chemistry. These long-term, high-resolution stream chemistry signatures would be very beneficial in understanding the partitioning of water especially during the transition from baseflow dominance to snowmelt dominance during the spring runoff and then back to baseflow dominance during the late summer to early autumn months.

Introduction:

The Saguache Creek watershed is located in the headwaters of the Rio Grande and recharges the northern San Luis Valley aquifer. It has a basin area of approximately 1641 km^2 and is almost entirely contained within Saguache County (Figure 1). Site selection for this study was critical. Therefore, there was a need to minimize anthropogenic effects due to development, housing, and recreational areas, such as large RV parks and camping sites that are found in other San Juan Mountain watersheds. According to

U.S. Census Bureau Quickfacts, Saguache County had a population of 7,031 in 2005, and consequently, the population density was less than 2 persons per square mile (http://quickfacts.census.gov/qfd/states/08/08109.html). Agriculture is the predominant land use, and grazing land is common throughout the watershed. Much of the watershed is accessible by Forest Roads and/or trails except during winter when these roads and trails are closed. The backcountry areas are typically accessible from May to early November.

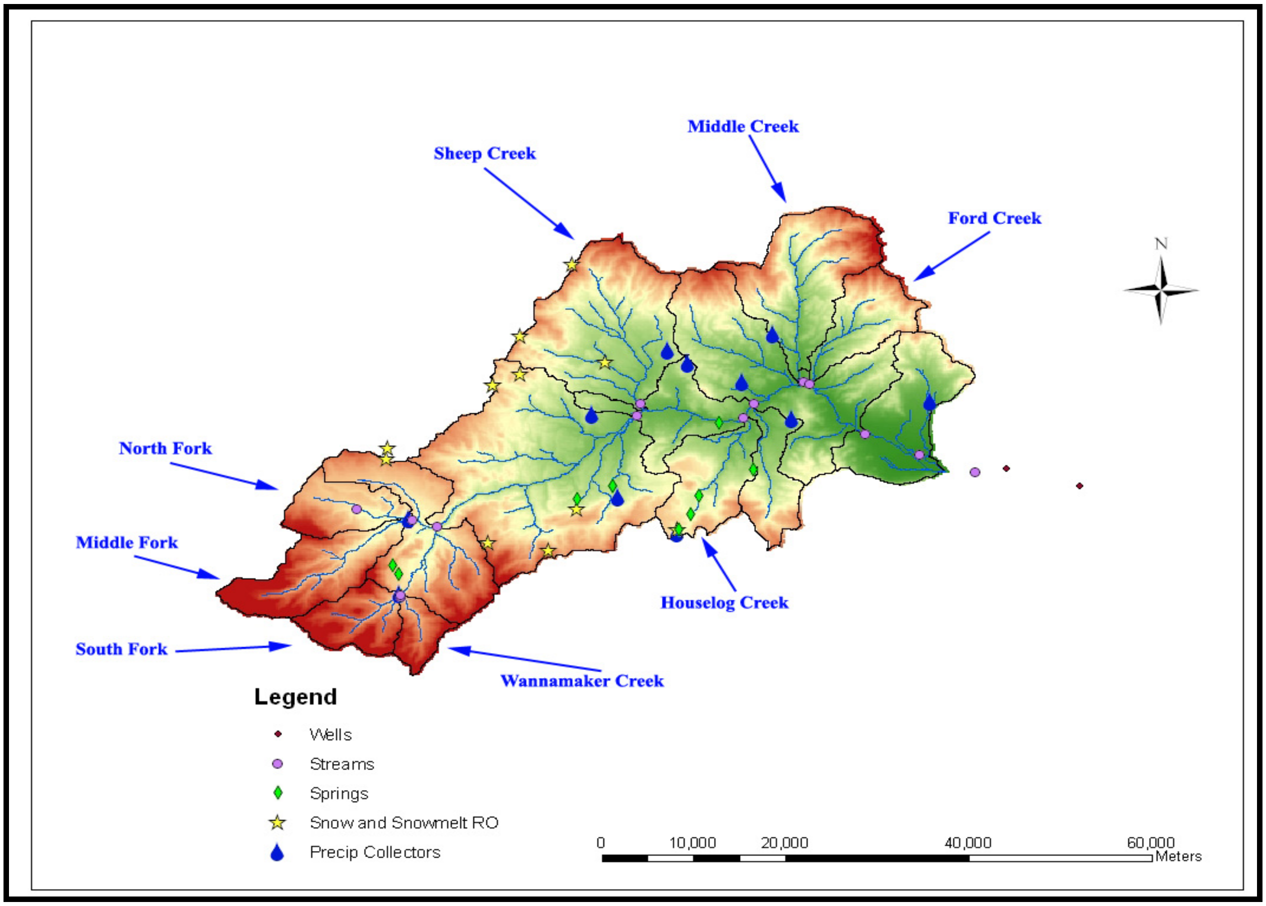

Figure 1

Saguache Creek is a perennial stream that has eight major tributaries: South Fork Saguache, Middle Fork Saguache, North Fork Saguache, Wannamaker Creek, Sheep Creek, Middle Creek, Houselog Creek, and Ford Creek (Figure 1). The overall average streamflow in Saguache Creek from 1929 to 2004 is 62.6 cfs (1.78 m^3/s), and this discharge is exceeded 27 percent of the time, according to flow duration curves. The minimum streamflow on record is 7.0 cfs (0.20 m^3/s), and the maximum streamflow on record is 678.0 cfs (19.2 m^3/s). The overall average annual unfrozen precipitation is 7.74 inches (19.7 cm), the minimum annual precipitation is 1.24 inches (3.2 cm), and the maximum annual precipitation is 16.22 inches (41.2 cm). Snow depth and snow water equivalent (SWE) are typically at a maximum on April 1st (this is true 75 percent of the time based upon the snow course record from 1949 to 2004). Average April 1st snow depth and average SWE during this record are 24 inches (60.9 cm) and 5.8 inches (14.7 cm), respectively. The minimum April 1st snow depth on record is 0 inches, and the maximum April 1st snow depth and SWE are 38 inches (96.5 cm) and 10.1 inches (25.7 cm), respectively.

Elevation ranges from 2310 m to 4269 m, and the average elevation is 2967 m. These data are very comparable to the Upper Rio Grande (URG), where the URG is defined as that portion located upstream of Monte Vista.

Knowledge of the geology of the SCW is important if the evolution of water chemistry and flowpaths are to be understood. The headwaters and high elevations are characterized by tertiary ash flow tuff between 26 and 30 MY (Fish Canyon and Nelson Mountain tuff sequences), and these tuffs are rhyolitic to dacitic in composition. Mid elevations are characterized by rhyolitic tuffs overlying andesitic lavas. Finally, low elevations are characterized by tertiary pre-ash flow andesitic lavas, breccias, tuffs, and conglomerates between 30 and 35 MY (Conejos Formation). Several low elevation springs emerge either in the Fish Canyon Tuff or at the contact between the lower Fish Canyon Tuff and the upper Conejos Formation. Other San Luis Valley deposits such as Redbed layers are thought to extend beneath the San Juan Mountains. All rock types appear to be heavily fractured near the soil surface, and the degree of fracturing appears to decrease with increasing depth below the soil surface (personal observation). Shallow subsurface deposits of fractured rhyolitic tuff are present in many of the hillslopes and may exert some control over short time scale runoff from the watershed. Faults are not common in the watershed, and a newly revised geologic map of the area is scheduled for completion in the near future (personal communication with William “Bill” McIntosh, New Mexico Bureau of Geology and Mineral Resources and Peter Lipman, USGS).

Other significant geologic units located in the headwaters of South and Middle Fork Saguache include quaternary landslide deposits in the form of talus, rock glacier deposits, and colluvial deposits and quaternary glacial drift deposits of Pinedale and Bull Lake glaciations. In general, areas above 3049 m (10,000 feet) in elevation contain evidence of a past glacial history. Terminal and lateral moraines are present at these altitudes and may be important storage elements in the headwaters of the watershed. Field reconnaissance in the headwaters of South and Middle Fork Saguache Creeks has determined that springs emerge from the base of some of these moraines. Hydraulic conductivity and other soil parameters of these moraines are not known at this point but the presence of perennial spring flow from the moraines may suggest that these are important storage elements in the headwaters of the basin.

Methods:

A structured sampling regimen was designed in May 2007 to accomplish multiple tasks, including investigating the spatial and temporal trends in streamflow chemistry, investigating the spatial and temporal trends in stable isotope composition, and investigating scale dependency of stream chemistry and isotope composition. Only the chemical trends will be discussed in this report since the WRRI funding was used to purchase equipment to monitor stream chemistry. A total of 27 stream and spring sites and 11 precipitation gauges were sampled on a monthly schedule during 2007. Chemistry and isotope data exist for stream and spring sites at a much coarser sampling regimen for 2005 and 2006. Chemistry and stable isotope data for snow and snowmelt were obtained during the snowmelt seasons of 2006 and 2007. Sodium and calcium concentrations were measured on all samples using the ion-selective electrodes purchased with WRRI funds.

Equipment was also purchased from WRRI funds to provide high resolution time series of stream chemistry at a site on Saguache Creek. This equipment included a sonde capable of monitoring electrical conductivity, pH, temperature, and chloride. A second sonde was constructed that was capable of monitoring sodium and calcium concentrations in streamflow. Finally, a pressure transducer was purchased to provide a high resolution series of stage measurements that will be used to construct stage-discharge curves and later to construct solute yields from the watershed. These instruments have been installed in the stream but data is not yet available from these instruments.

Results of Preliminary Research:

Sodium and calcium concentrations in stream water were plotted against subwatershed area or accumulating watershed area moving downstream. These plots seem to indicate that stream chemistry is more temporally and spatially variable in the headwater and low elevation tributary subwatersheds than it is in the main channel of Saguache Creek (Figures 2 and 3). This is especially true in subwatershed areas greater than approximately 367 km^2. Prior to the peak snowmelt pulse, which occurred in mid-May 2007, the stream chemistry of these subwatersheds was somewhat similar. However, after snowmelt commenced, the stream chemistry became much more scattered in the headwater and tributary subwatersheds (Figures 2 and 3). In contrast, it is interesting to note the development of linear trends in stream chemistry in the main channel of Saguache Creek at an accumulated watershed area of approximately 367 km^2. The exact reason for this behavior has not been determined although several explanations are being investigated. For example, the stream chemistry at accumulated areas less than 367 km^2 could be controlled by local to intermediate flowpaths at the hillslope scale; whereas, deep regional flowpaths could become more important to streamflow generation at areas greater than 367 km^2. Thus, the steep topography of the headwater subwatersheds may be conducive to shallow runoff, which samples a wide range of flowpaths as the vadose zone expands and contracts during snowmelt. In comparison, discharging groundwater to the stream at larger accumulated areas may be sampling a relatively stable distribution of flowpaths. Again, this question is currently being investigated.

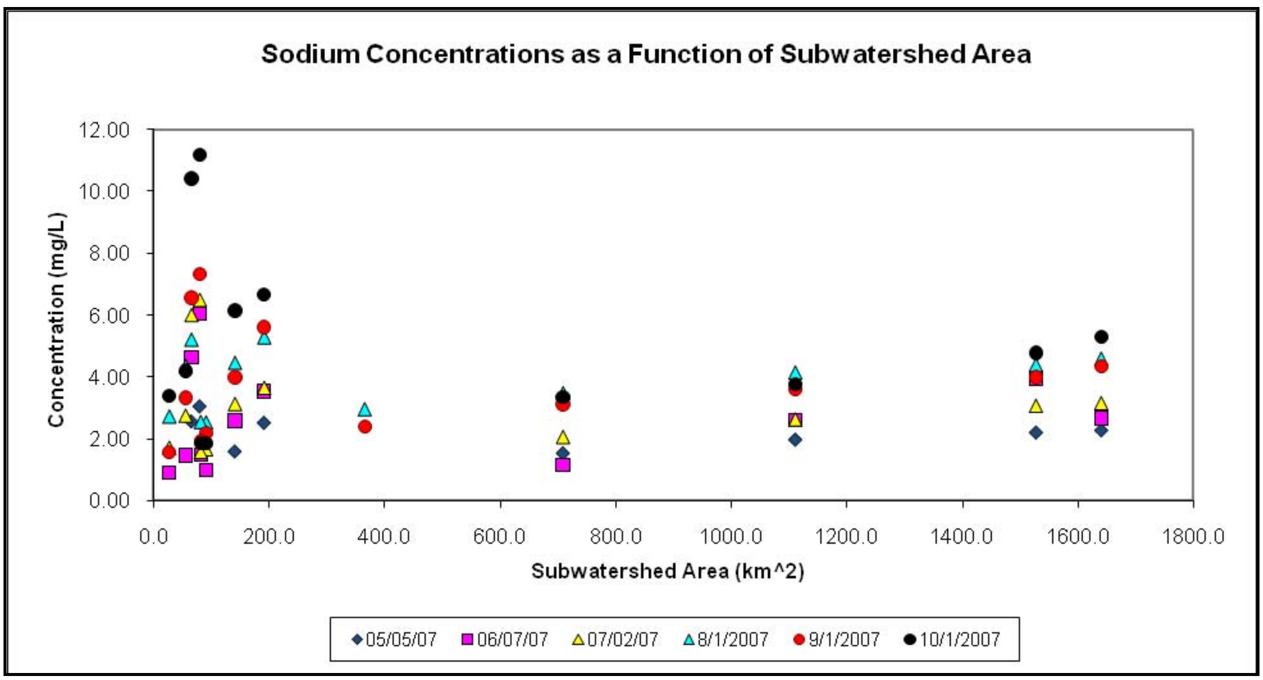

Figure 2

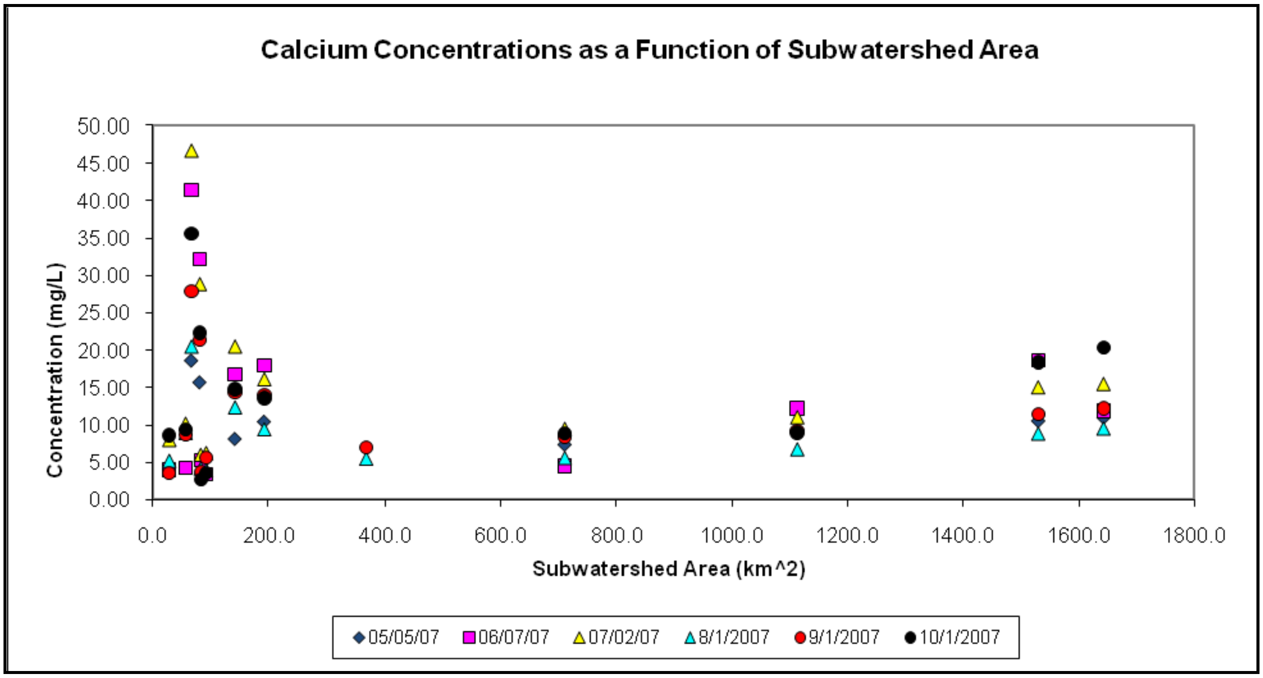

Figure 3

Sodium and calcium concentrations in spring flow were plotted against the elevation at which the spring emerges (elevation of the spring orifice). The plot of sodium concentration as a function of elevation indicates that the sodium concentrations generally increase with decreasing elevation, and there appears to be minimal temporal variability at individual springs (Figure 4). The exceptions to the latter observation are the springs located at elevations of 8200 ft. and 9000 ft., respectively. The spring that emerges at 8200 ft. flows from fractured andesite in the upper Conejos Formation, while the spring that emerges at 9000 ft. flows from the contact between the upper Conejos Formation (andesitic) and the lower Fish Canyon Tuff (rhyolitic). These two springs are thought to represent the oldest waters in the watershed, and the temporal variability may be a consequence of enhanced sodium dissolution due to increased contact time for rock/water interactions. In comparison, the other springs may represent younger waters which have limited rock/water interaction time (the contact time is much shorter than the kinetic weathering rate). This may be a consequence of their position in the landscape, that is higher elevations may be younger than the older water at low elevation springs. Future modeling efforts and age dating of spring waters will help address this question.

Calcium concentrations in spring water were also plotted against spring elevation (Figure 5). It is interesting to note that calcium concentrations are both temporally and spatially variable. Initially, one might infer from the geologic sequences in the watershed that calcium supply would be limited for some of the higher elevation springs since they are thought to be confined within rhyolitic tuffs. However, as illustrated in Figure 4, sodium concentrations in these springs are rather small in comparison to the calcium concentrations. This again may be related to the different kinetic weathering rates between calcic plagioclase minerals relative to sodium rich minerals (see Goldich weathering sequence). Again, the correlation of future modeling efforts with chemical kinetics will help explain these apparent trends.

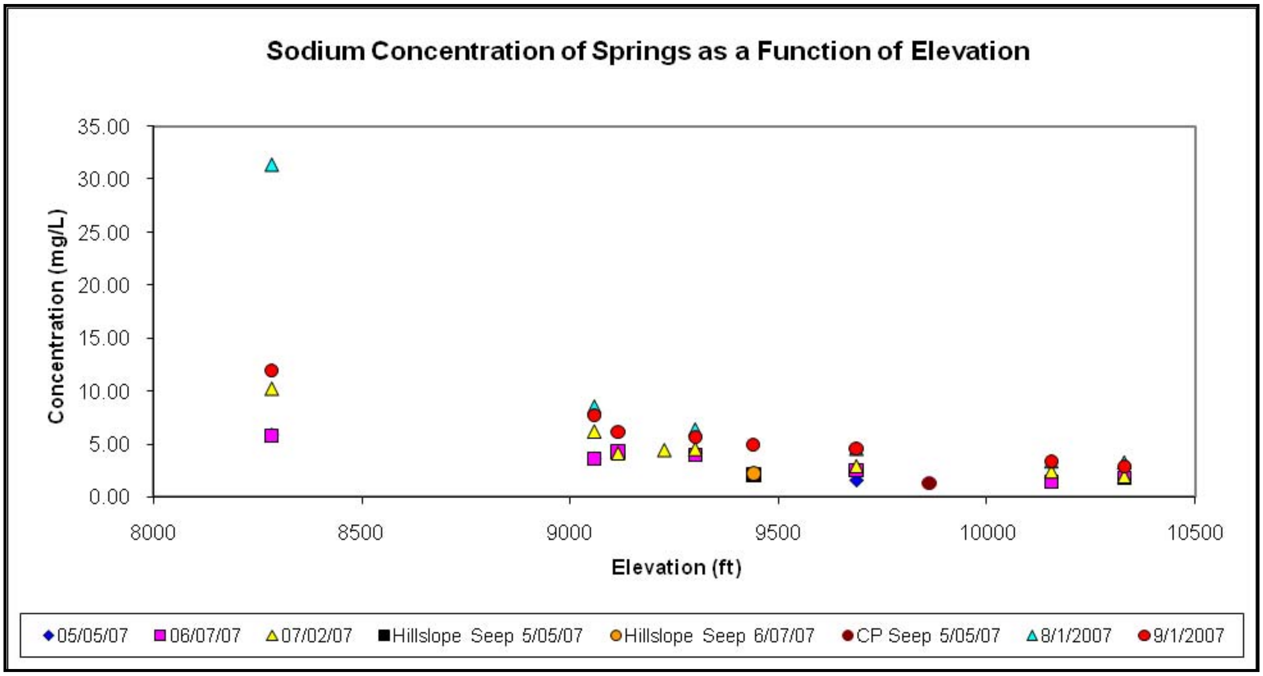

Figure 4

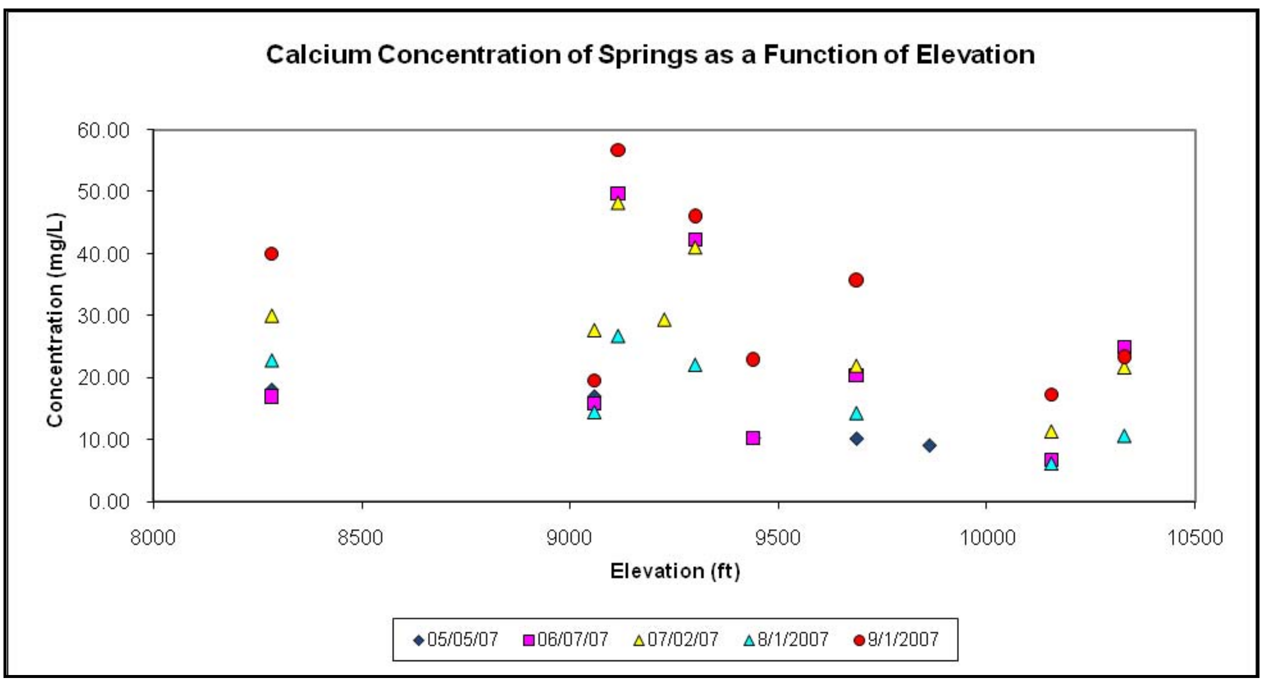

Figure 5

Preliminary Conclusions and Future Work:

Initial research into the chemical trends of streamflow in the Saguache Creek watershed suggests that there may in fact be an accumulated watershed area at which spatial and temporal variability in streamflow chemistry decreases. Beyond that point, streamflow chemistry may become somewhat similar or it may show strong linear increases in chemical constituents. In either case the degree of scattering will be reduced. The exact explanation for this will be investigated with the aid of high resolution water quality sondes which have been installed in Saguache Creek.

The research has also given us some insight into the kinetics that appear to control spring chemistry. Again, we are currently investigating these trends, and results will be published in the near future. Thus far, the equipment purchased through the support of NM WRRI has proven useful, and the data obtained from this equipment will be critical in constraining the chemical kinetics responsible for both spring and stream chemistry.

I'd like to take this opportunity to thank NM WRRI for the research grant. The questions that we are addressing through this research will be very beneficial to the watershed hydrology community and for future water resource planning in the Rio Grande valley. The support of NM WRRI will be fully acknowledged in my PhD dissertation and in any publications directly related to the water chemistry aspects of this research. This research has been covered in NM WRRI's *Divining Rod* as well as in the Socorro El Defensor Chieftain. This work has also been presented in 3 posters listed below, one of which was awarded a first place poster award.

Posters:

"Origin of the Chemical Composition of Springs in the Saguache Creek Watershed of the San Juan Mountains in Colorado", New Mexico Geologic Society Annual Spring Meeting 2007, Socorro, NM (April 2007)

"On the Selection of the Saguache Creek Watershed for Catchment Scale Hydrological Investigations Part 1: Hydrological Processes", SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) 6th Annual Meeting, Scottsdale, AZ (October 2006)

"On the Selection of the Saguache Creek Watershed for Catchment Scale Hydrological Investigations Part 2: Preliminary Hydrochemistry", SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) 6th Annual Meeting, Scottsdale, AZ (October 2006)