APPENDIX F. Preliminary Lineament Analysis.

Introduction

A lineament is any naturally-occurring linear trend or feature that can be identified on an aerial photograph or satellite image of a particular area of interest for geologic exploration and mapping. Lineaments occur as a result of rock fractures or faults, and from differences in lithology, soil type, vegetation type, and other factors across linear or quasi-linear boundaries. These linear boundary trends very often are of geologic origin, and most often are invisible or indistinct even to trained geologists when working on the ground. However, at the "larger view" afforded by commonly available aerial photos and satellite images, lineaments often can be observed. This is particularly true of mountainous areas such as the Rio Grande County study area where bedrock formations outcrop and where erosive forces such as frost, wind, moving water, and daily and seasonal temperature extremes cause differential erosion: i.e. more rapid erosion of less-resistant formations, resulting in sharp and well-defined topographic differences from place to place.

It is well documented in the geologic literature that locations of faults and rock fractures, and particularly the intersections of faults and fractures at different azimuths (i.e. compass directions) in competent bedrock formations often have enhanced ground water movement and better yield to water wells, due to higher permeability in the fault or fracture locations than is the average permeability of the surrounding unfractured rock. As the geophysical and water chemistry work in the Rio Grande County Hydrogeology Study have shown, there is evidence of deep ground water circulation in the Conejos Formation that makes up the majority of the bedrock aquifer used by water wells in the mountainous areas of the County.

Accordingly, the study team performed a preliminary lineament analysis of Google Earth™ satellite imagery for the Rio Grande County study area as a test of concept to see whether any lineament trends are visible, and also to determine whether any observed lineament trends agree with, or enhance, the information from previous geologic mapping in the area. This preliminary analysis stops short of attempting to correlate water well depths or production rates, or hydrologic characteristics of fractures, with identified lineaments.

Method of Analysis

A member of the study team (HRS Water Consultants, Inc.) used easily available Google Earth satellite imagery for this preliminary lineament analysis. There are features in Google Earth that makes it particularly well suited for this type of analysis, including:

- The instant "zoom" and "rotate" capability of Google Earth, so that vertical downward-looking viewpoints from near the ground (larger scale) to far from the ground (smaller scale) could be viewed, and linear features at different scales could be compared and correlated.

- The instant availability of images from several different years and times of year between 1989 and 2011.

- The capability to view each image at different daylight hours (i.e. sun angles) between sunrise and sunset, thereby enhancing shadows – a valuable feature when viewing steep topography as is present in the study area.

This analysis was conducted without referring to the published geologic maps of the area (cited in the Rio Grande hydrogeology study) until after the lineament mapping was complete, with the expectation that a less-biased mapping of lineaments would result.

Google Earth images for the study area for several different months and years were studied, at varying scales from only a few thousand feet filling the computer monitor frame, to the entire study area filling the monitor frame. The procedure began by closely observing each mapped section (square mile of the Public Land Survey System) of land in turn, beginning in the northeastern sector near the Summer Coon Volcano (just outside of Rio Grande County to the north), and proceeding west, and then south, until the entire mountainous area of the county had been analyzed section by section. We then correlated and "connected" lineaments from section to section, by visually correlating and joining shorter linear features into longer ones where there appeared to be continuity from feature to feature. During this step we eliminated features that, upon closer inspection, appeared to be man-made features such as fence lines, trails, power line alignments, utility corridors, etc.

We then developed a KMZ file of the mapped lineaments. A KMZ file is a Google Earth – specific digital file of linear or polygonal features, precisely tied to particular locations on the ground. The next step was to overlay the mapped geology, and transfer the mapped faults from the geologic maps to Google Earth. This allowed a direct visual comparison between the mapped lineaments, and the faults and intrusive rocks (i.e. dikes or other igneous rocks emplaced by injection into the pre-existing bedrock) identified on published geologic maps (see Figure 1).

Results and Conclusions

Figure 1 shows the results of the preliminary lineament analysis. Lineaments identified from Google Earth images in the study area are shown in blue, compared to mapped faults (orange) and mapped intrusive igneous rocks (red). The comparison indicates generally good spatial correlation between observed lineaments and mapped faults, although many mapped faults are shown as longer continuous features than we were able to identify as lineaments on the satellite images.

Areas with a relatively high density of lineaments include the South Fork / Rio Grande Graben area near the western edge of the study area, the foothills area just west of Monte Vista, and an area of short, north-trending lineaments near the north-central edge of the study area, which are thought to be associated with dikes radiating outward from the Summer Coon volcano, centered just north of the Rio Grande County – Saguache County line. A relatively high density of short (less than one mile in length) lineaments was identified in the San Francisco Creek watershed. Relatively few lineaments were identified from the satellite images in the Old Woman Creek watershed, although this may be related to soil cover obscuring the view of the bedrock.

From this preliminary lineament analysis, we have arrived at the following conclusions:

- Lineaments with a dominant north-south or NNW – SSE orientation are common in many areas within the Conejos Formation in the Rio Grande County study area.

- Many of the lineaments are closely associated with mapped faults, indicating that lineament analysis almost certainly is a feasible means of identifying zones of enhanced permeability due to faulting or fracturing of competent Conejos Formation bedrock.

- The areas with the observed highest density of lineaments in the Conejos Formation generally correspond either to areas of steep topographic relief, such as the South Fork / Rio Grande Graben area, or are in areas with sparse tree cover and soil cover, such as the foothills west of Monte Vista.

- The areas with the lowest density of lineaments generally correspond to areas of heavy tree canopy, such as the south-central Rio Grande County study area, or to areas known to be covered by unconsolidated glacial outwash or alluvial deposits, such as the Rio Grande valley between Del Norte and South Fork.

- We tentatively conclude that north-south or NNW – SSW trending faults and rock fractures are very common in the Conejos Formation in most of the mountainous area of Rio Grande County. The difference in identified lineament density from place to place may be strongly related to the presence or absence of tree cover or of unconsolidated deposits overlying the bedrock.

- Based on this proof-of-concept preliminary lineament analysis, a more in-depth lineament analysis, in our opinion, would be helpful as part of a more in-depth hydrogeologic study. Further steps that should be taken in a complete lineament analysis include:

    - A more in-depth lineament analysis, using stereoscopic analysis of adjacent pairs of high-resolution aerial photographs, would help identify lineaments that may have been overlooked in this preliminary analysis.

    - Major lineament groups mapped from aerial imagery should be field-checked to identify particular characteristics such as the rock types involved, whether particular lineaments are associated with a fault or rock fracture; the fracture orientation (i.e. strike and dip); fracture aperture (i.e. average width of fracture openings in a given area), and whether any hydrologic features, such as springs, can be identified in association with the lineament.

    - Areas of anomalous ground water quality should be mapped and subsequently field-checked to see whether the anomaly may be related to an identifiable fault or fracture that allows deep circulation of ground water.

- Graphical and statistical methods of lineament analysis should be considered to allow better identification of particular areas of the County that may have an elevated risk of ground water contamination in water wells due to enhanced permeability in the Conejos Formation aquifer. These methods should include development of rose diagrams to show the relative frequency and length of lineament groups on a compass rose, or discrete fracture network (DFN) analysis, which is a stochastic approach to mapping fractures of similar characteristics.

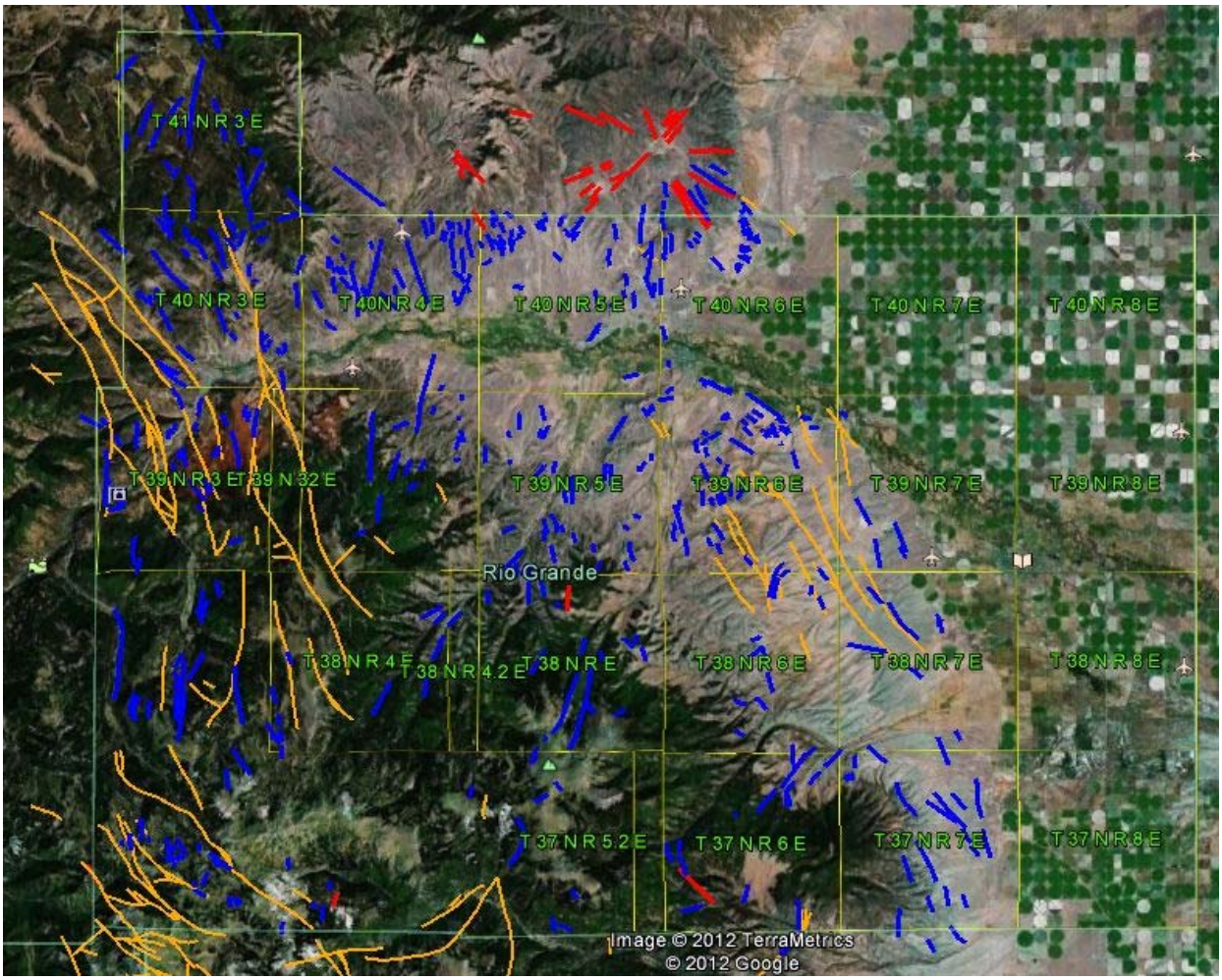

Figure 1. Screen-capture of identified lineaments (blue) and mapped faults (orange) and igneous intrusions (red) in the Rio Grande County hydrogeology study area.