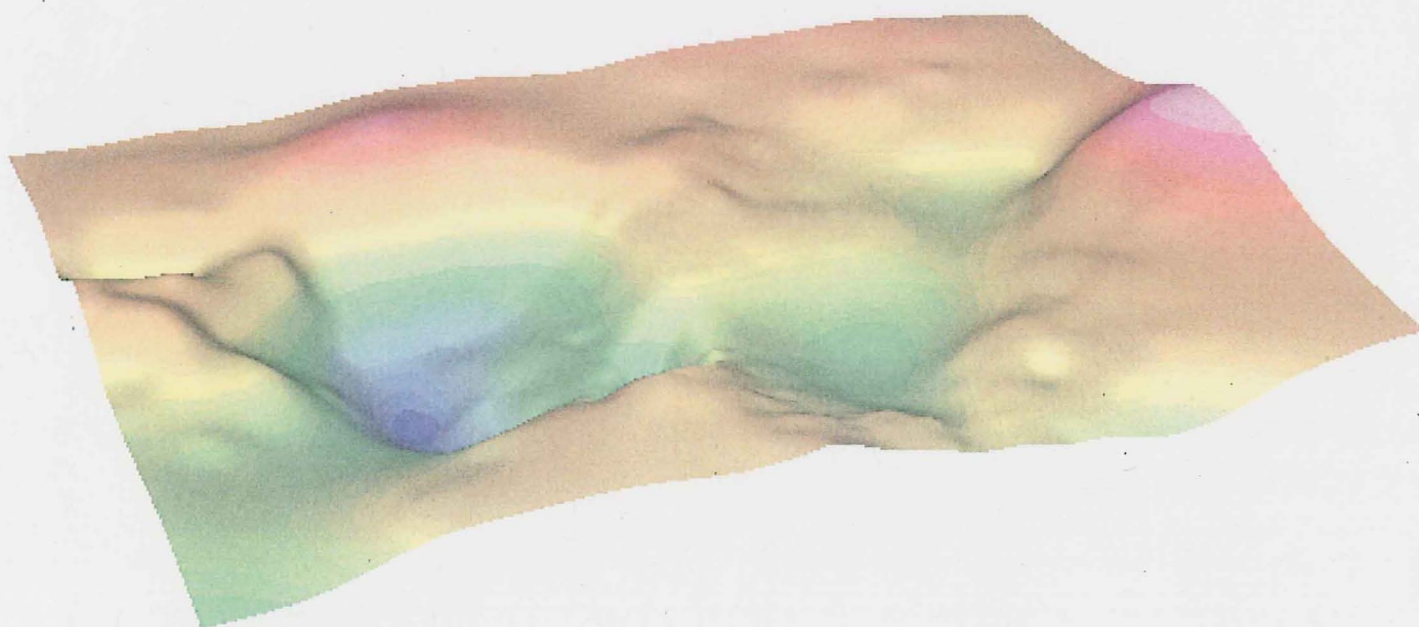# Gravity-based geologic modeling of the Central Truckee Meadows

Prepared for
The Central Truckee Meadows Remediation District
Washoe County Department of Water Resources
Reno, Nevada

By Michael Widmer

May 1, 2005

# TABLE OF CONTENTS

## LIST OF FIGURES AND TABLES

**Figure (follow text)**

1. Study area maps
    a.      Location map of study area
    b.      Study area overlain on Henry geologic map.
2. Complete Bouguer Gravity Anomaly contour of study area
3. Color Shaded Relief of CBA of study area
4. Partial Color Shaded Relief of Total Horizontal Gradient map of CBA
5. Color Shaded Relief of upward continued residual of CBA
6. Location map of geologic cross sections and linements overlain on Henry geologic map
7. South Reno geologic cross section with gravity
8. South Reno geologic cross section with gravity
9. South Reno geologic cross section with gravity
10. South Reno geologic cross section with gravity
11. Study area overlain on Henry geologic map with gravity contours, well locations and hydraulic barrier

**Tables**

## Introduction

Currently, an existing groundwater flow model of the Central Truckee Meadows is being re-evaluated within this office. A revised model will be used to improve the understanding and resolve existing PCE impacts to groundwater resources of the basin, delineate regional flow and solute transport characteristics, and be used in future groundwater management activities. One component of the conceptual model, upon which the groundwater flow model is based, is determining the bedrock configuration within the model domain. This report documents the acquisition, analysis and modeling of gravity data within a $150km^2$ ($60mi^2$) study area, encompassing the Central Truckee Meadows. The study area for this report includes land within the McCarran ring road and periphery as shown in Figure 1a. The interpretation of the data contained within this technical memorandum was supported, in part, by discussions with Gary Oppliger, Ph.D., Research Associate Professor of the Mackay School of Mines at the University of Nevada, Reno and Chris Henry, Ph.D., Research Geologist for the Nevada Bureau of Mines and Geology.

Geophysical methods can provide a useful image of subsurface geologic structure. These methods include seismic reflection and refraction, magnetic surveys, and gravity surveys. The interpretation of the gravitational field can be used to locate the subsurface alluvium-bedrock contact and the presence of high angle interfaces. This is done through a forward modeling process that involves constructing geologic cross sections, evaluation of their calculated gravity responses, and comparison to the actual measured data. The modeling of gravity responses is however, non-unique as two or more differing geologic models can describe the measured potential field data. The modeling of the gravity data in this study has been conducted in such a manner so that local features are consistent with current thoughts on regional trends in this area.

## Geologic Summary

Figure 1b is a portion of a larger geologic map, overlain on a digital elevation model (DEM), provided by Dr. Henry. It depicts the generalized geologic units and structures within the study area for this report. Other geologic "Quadrangle" maps of the study area, prepared by the Nevada Division of Mines and Geology (Reno, Mt. Rose NE, Vista, Steamboat), assisted in the geologic interpretation. Surprisingly, little is known of the geologic structure of the Central Truckee Meadows, at the juncture of the Basin and Range Province and the Sierra Nevada. The most prominent topographic features are the Carson Range in the southwest, the Virginia Range on the east and north, the Huffaker Hills on the south, and Peavine Mountain on the northwest. Elevations within the area of interest range from 1,340 meters (4,400 feet) at the eastern side of the basin to 1,550 meters (5,100 feet) on the flanks of Peavine Mountain. Elevations of the mountain ranges that ring the study area exceed 2,400 meters (8,000 feet). The Truckee River enters the study area from Verdi to the west and flows easterly to the lower Truckee Canyon (outside the study area) and Wadsworth. The Truckee River flood plain is the prominent flat lying region within the study area of Figure 1a, particularly at the east end of the basin. Alluvial fans are not easily discerned. The most prominent topography within the area of interest are pediments in Tertiary rocks that have been cut by the Truckee River and flank the Carson Range and Peavine Mountain within the western study area. Most of the valley fill area is relatively flat laying land that was formed from lacustrine and alluvial deposits.

1

Generally the study area can be described with five geologic units (Table 1), Cretaceous granodiorite, Mesozoic metavolcanics, Tertiary volcanics, Tertiary sediments, and Quaternary alluvium. The Henry geologic map does not distinguish between the metavolcanic and granitic units which are indicated by the "K" symbol on Figure 1b.

**Table 1.**
**Generalized geologic units and densities (g/cm$^3$)**

| Qal | Quaternary Alluvium | 1.97 |
|---|---|---|
| Ts | Tertiary Sediments | 2.07 |
| Tv | Tertiary Volcanics | 2.47 |
| Mzv | Mesozoic Metavolcanics | 2.67 |
| Kgr | Cretaceous Granodiorite | 2.67 |

The oldest, rocks exposed in the study area are the metamorphosed volcanic sediments of Mesozoic (Jurassic?) age. These are found in the north and eastern portions of the study area, largely on the flanks of Peavine Mountain. They can also be found at the east side of the valley where the Truckee River enters the lower Truckee Canyon. These rocks have been intruded by Cretaceous granodiorite associated with the Sierra Nevada batholiths. However, the exposed uplift has only recently occurred within the last 2-3 m.y. (Henry and Perkins, 2001).

Tertiary volcanic rocks (Tv) include the Alta Formation and the Kate Peak Formation (Bonham and Bingler, 1973). These rocks are primarily mafic to intermediate extrusives and volcanic detritus. Other less common Tertiary (Miocene age) volcanics include basalt to rhyolite flows, intrusives, and ash flow tuffs which are also mapped in other areas of Washoe and Storey Counties. These volcanic rocks are found on the flanks of the mountains outside the McCarran ring road.

Tertiary sedimentary rocks (Ts) are known as the Sandstone of Hunter Creek (Bonham and Bingler, 1973), but have also been termed the "Truckee Formation". The rocks can be found on the northern flank of the Carson Range and the southern flanks of Peavine Mountain. These rocks are largely sandstone, siltstone, and diatomite, forming 100-150 meter (300-500 feet) bluffs on the western side of the study area. These consolidated sediments are assumed to form the basal unit of the basin fill deposits that are unconformably overlain by the Quaternary alluvium (Qal).

Little is known of the geologic structure prior to Basin and Range tectonic events or the Sierra Nevada orogeny that occurred during the last 3-4 m.y. In northwestern Nevada, Basin and Range normal faulting created north-south trending mountain ranges comprised of granodiorite and volcanic rocks flanked by volcanic and alluvial filled basins. The left-lateral, strike-slip Olinghouse Fault that extends from the Walker Lane west-south-west to Reno along the Truckee Canyon (Sanders and Slemmons, 1979) is found beyond the eastern edge of the study area.

A N-S range front, normal fault structure is mapped on the Henry map along the base of the Virginia Range. Other north-south trending normal faults are mapped in the central part of the study area where horst and graben structure is inferred. Within the western portion of the study area, northeast-southwest to east-west trending strike-slip and normal faults are mapped. The Tertiary sediments dip towards the Truckee River on both the Peavine and Carson Range flanks indicating a synform.

The Moana Geothermal Area (MGA) is found in the southwest portion of the study area and is indicated, in part, by red-filled circles on the Henry Map (Figure 1b). The MGA is approximately 10 $km^2$ (4$mi^2$) in area. Another small geothermal system is found west of McCarran near Mogul. Space heating wells that tap the Moana system are the deepest wells in the area and range from 150 to 1,000 meters (500 to 3300 feet) deep. Existing "deep" water wells are also shown on the Henry map (blue-filled circles) and range in depth from 120 to 300 meters (400 to 1,000 feet).

**Discussion of Geologic Units and Structure**
The Quaternary unit (Qal) is a result of alluvial fan, fluvial, and lacustrine depositional environments. These unconsolidated sediments unconformably overlie the Sandstone of Hunter Creek (Ts). The sediments range from clay size particles to boulders. Thicknesses of this unit are not known, but probably vary from 0 to a few hundred meters. A density value of 1.97 gm/cc is estimated for this unit for gravity modeling purposes.

The exposed Tertiary sediments consist predominately of consolidated fine to medium grained sediments, with true thicknesses poorly constrained. Clays are reported in the Tertiary sediments from numerous well drilling reports, but fine grained sediments have also been described as diatomaceous siltstone and sandstone (Widmer, 1991; and as reported in the NBMG geologic quad sheets). Actual thicknesses of this entire mapping unit have been estimated at 760 meters or 2,500 feet (Trexler and others, 2000). Basaltic extrusives and conglomerates have also been mapped within this unit (ibid). The areal extent of this formation is also poorly constrained. The Henry geologic map and the NBMG geologic quad sheets indicate that this unit is extensive from Verdi to west McCarran. The formation can also be found on the western margin of the South Truckee Meadows. However, as one traverses easterly through the study area, the lateral extent of the formation is unknown as these sediments are covered by the Quaternary alluvium and only encountered in a limited number of wells. For the purposes of this analysis, the assumption is that the Tertiary sediments are the most significant sedimentary unit and underlie the entire study area. Whether or not this is true is not as important as the density value given to whatever sediments lie beneath the land surface for the purpose of gravity modeling.

The Sandstone of Hunter Creek mapping unit includes conglomerate, sandstone, siltstone, diatomite, and basaltic extrusives. Therefore the density of rocks in that unit varies from 1.7 to 2.5 gm/cc. For this investigation, a composite density value of 2.07 is used. Stratigraphy suggests (Cashman, 2004) that conglomerate and sandstone form the basal unit of the formation followed by less dense sediments including varying concentrations of diatomite in the sediments.

3

Following traditional facies theory, sediment size should also decrease towards the center of the basin.

The dominant crystalline rock units within the study area are Tertiary volcanics exposed as capping units in the mountain ranges surrounding the study area. Here again, the relative thicknesses of the volcanic units are subjectively modeled in order to render best fits to the gridded gravity data. Their physical properties are assumed to be constant but probably vary widely. Recent drilling in the South Truckee Meadows (Widmer, 2005) shows that volcanic tuffs are considerable in thicknesses. This makes estimating density values problematic again. The Cretaceous granodiorite and Mesozoic metavolcanics are considered basement rock as the Henry geologic map indicates. As with the Tertiary sediments the lateral extent of the metavolcanics is poorly understood, but appears to be coincident with the higher gravity anomalies.

Range bounding normal fault structures are mapped or inferred for both the Virginia Range and the Carson Range. These faults are interpreted to be steeply dipping towards the valley. There is speculation that a local east-west bounding fault occurs coincident with north McCarran along the flanks of Peavine Mountain (as mapped) eastward to east Sparks. The westerly projection of the Olinghouse strike-slip fault is poorly defined and not well understood within the Truckee Meadows.

Faults or other structural elements that can impede or enhance groundwater movement are important to the groundwater modeling effort. Such is the case for the horst and graben structures proposed in the Moana area. Indeed, one of the fundamental reasons for this investigation is to improve the understanding and location of an apparent groundwater flow barrier in this region that strikes from the Moana area to central downtown Reno. There is speculation that the Genoa Fault strikes northward through this study area and influences local structure in the Moana area. Dr. Oppliger has shown that fault structures influence the temperatures of shallow groundwater within the Moana area (personal communication). Omitted from the figures in this report are faults mapped by the NBMG, but are included in the analysis. They have been omitted from the figures only for clarity in the presentations. Those shown in the Henry geologic map are adequate for presentation.

**Gravity Data**
Gravity information was compiled from several surveys, but largely consists of surveys contracted by Washoe County. In January 2005, Washoe County contracted Tom Carpenter, Consulting Geophysicist, to complete a gravity survey in which 125 sites were measured (Carpenter, 2005) to augment an existing data set. The data were collected using a LaCoste and Romberg Model G-230 gravimeter with a precision of 0.01 mGal. Positions were located by rapid static GPS survey methods using a WILD GPS – System 300 manufactured by Leica. The elevation accuracy is believed to be better than ±20cm. The International Gravity Reference Network base at the James G. Scrugham Engineering Mines Building at the University of Nevada, Reno served as the local reference gravity value. The measured data were reduced to Complete Bouguer values using 2.67 g/cm$^3$ as the slab density. Oppliger compiled other data

sets and processed the entire data set as one using the same terrain correction model. The compiled surveys include over 3,000 data points and cover southern Washoe County and this investigation is a sub-set thereof.

**Potential Field Maps**
Figure 2 is a contoured grid of the Complete Bouguer Anomaly (CBA) gravity data overlain onto the Henry geologic map and a DEM. Also plotted are the gravity stations. The gridding was accomplished with a minimum curvature routine (Geosoft, 1999). The contours are of the gravity anomalies (0.5 mGals interval). The total range of gravity anomaly variation within the study area is -166 to -198 mGals or 32 mGals, common for basin and range structure adjacent to the eastern Sierra Nevada. In eastern and central Nevada, variations in gravity anomalies can be as high as 60 mGals in basins as deep as 3,000 meters (10,000 feet).

This figure shows that the low gravity anomalies are generally coincident with the lower topographic elevations and high gravity anomalies correlate with the high topographic elevations. This is expected as the lower density anomalies represent thick, low-density sediments. The steep gravity gradients correspond to strong density contrasts between "hard" and "soft" rock units and are assumed to represent thickening alluvium overlying normal faults. Figure 3 is a color shaded relief map of the CBA where the low gravity anomalies are coincident with relatively deep alluvial basins. From these figures it is clearly seen that the Central Truckee basin is really comprised of four basins. An apparent sub-surface ridge transects the basin in a north-south orientation of which the southern portion maps onto the "horst and graben" fault structure noted in the geologic summary section above. The largest gravity anomaly "highs" map onto the Mesozoic metavolcanic unit (Bonham and Bingler, 1973; Bell and Bonham, 1987).

Figure 4 is a partial, color-shaded relief map of the total horizontal gradient of the gravity data. The total horizontal gradient is the maximum horizontal rate of change in the strength of density contrast anomalies (first horizontal derivative of the gravity field). It is a useful analytic tool to determine where gravity slopes have their maxima. Fault structures offsetting rocks of different density can be inferred to exist where gravity gradients reach their maxima. Figure 4 illustrates this with the steepest rate of change in gravity delineated with red lines parallel to these trends. The lineations are good indicators of basin boundary faults and are so inferred here. Of note is the west-east lineation that plots along northwest McCarran, coinciding with the mapped fault on the Henry geologic map (discussed above). Figure 5 is a color shaded relief map of the gravity data 'upward continued" 350 meters and subtracted from the CBA. This has the effect of amplifying the lateral geologic density boundaries in the upper 350 m while suppressing expression of the deeper changes. From this Figure a more complex basin structure is seen.

**Modeling Approach**
Potential fields modeling is non-unique. By changing the density of lithologic units, the model thicknesses of these units will change. The practice of the present modeling effort was to keep the density values constant within a given unit. Table 1 lists the major lithologic units found in the study area and their associated density used in the geologic modeling. Densities values for the granodiorite and metavolcanics are reported from rocks measured in the Sierra Nevada

Carson Range, Washoe County, Nevada, approximately 6-8 miles to the southwest (Skalbeck, 1998). The alluvial values of density are assumed to be within the range of water saturated alluvium. Of note is the diatomite, diatomaceous sandstone and diatomaceous siltstone ubiquitously found in the Sandstone of Hunter Creek Formation. These rocks most likely range from 1.7 to 2.2 g/cc in their density values depending upon the amount of diatomite contained in these sediments and their degree of water saturation.

Potential fields modeling was accomplished using the software package GM-SYS$^{TM}$ (Northwest Geophysical Associates, 1996). The gravity data were formatted for modeling using Oasis Montaj$^{TM}$ software (Geosoft, 1999). Coincident line data were used for the gravity and topographic elevation data. Data sets for each were gridded and coincident profiles were generated. The elevation data came from the 30-meter USGS Digital Elevation Model. Mapped surface geology was strictly honored as control for each model cross section. The "gradient lineations" were mapped onto the profiles with the assumption made that they represented basin boundary faults. Where possible, lithologic data from water well drilling was also used in constraining the modeling. It should be re-emphasized that the purpose of the modeling was to configure a bedrock structure model. Consequently, the results should be considered "best-fit" models where importance was placed in the mapped geology and lithologic well logs and then the gravity data. Cross section orientation was chosen perpendicular to gravity gradients to maximize lithologic density contrasts.

**Model Results**
Figure 6 shows the locations of the four geologic cross sections modeled. The cross sections were located to obtain roughly perpendicular traverses to gravity gradients of interest. Modeling a cross section that parallels a gravity gradient creates much more uncertainty to the model section because of the lack of lateral density contrast. Figure 6 also shows the locations of available lithologic logs (well drilling reports) and the lineations as derived from the total horizontal gradient map (see Figure 4). A listing of logs can be found in the appendix.

Figures 7-10 illustrate the geologic cross sections based upon the gridded gravity data and these lithologic logs. The gravity curve (top section) plots the observed data (dots) and the calculated (solid line) data based upon the geologic model found in the lower section. A distance scale is at the bottom and will be referred to in the discussion for each cross section. Please note the vertical exaggeration and scale. The tick marks located on these figures indicate l for lineament, derived from Figure 4; f for a mapped fault; and s for a mapped fault splay. The derrick with a number indicates a well lithologic log where the total depth of the well is also shown. A listing of these wells can be found in the appendix for each cross section. Geologic units and their densities are also shown on the figures.

<u>NW-SE Reno</u>
Figure 7 shows a geologic model across the northwestern and southeastern portion of the study area. This cross section traverses three gravity low anomalies. The interpretation of the gravity and geologic data incorporates two distinct basins separated by a high gravity anomaly with an included small, low gravity anomaly. The west side of the basin could be interpreted with basin

6

bounding faults that coincides with two lineaments (see Figure 4). This interpretation has a volcanic unit (Kate Peak) adjacent to granodiorite. The western basin, for this report, is termed the West Reno basin and is approximately 1,600m (5,250ft) thick based upon this model. This anomaly is bounded on the east by a lineament and inferred, steeply dipping (70°), normal fault.

The most complex portion of the study area is found in the center of this cross section where horst and graben structure is interpreted to exist. Of note is the proposed double faulted wedge of sediments to account for the low gravity anomaly found within the Moana Geothermal Area (see Figure 6). It is proposed (Henry, personal communication) that the structure was initially down-dropped to the west, and then this fault was terminated by an east-dipping fault to form the sediment wedge. The structure would be the result of a "pull-apart-basin" as can be seen from its rhombohedral form (see Figure 6). Gravity lineaments are coincident with mapped faults. This feature is also largely consistent with that proposed by Abbott and Louie (2000). The steeply dipping normal faults were inferred from the Henry map and range in dip from an estimated 60° to 70° (±10°). A horst structure is proposed for the apparent north trending ridge, bounded on the east and west by mapped faults. Further investigation of this area is likely to prove that the details of this interpretation are lacking. However, this figure does illustrate the structural complexity of this area and that further refinement may be warranted.

To the east, a second basin is apparent. This basin is termed the SE McCarran basin and is bounded on the southeast by an inferred fault indicated by a lineament (see Figure 4). The Huffaker Hills are translated a few hundred meters and located on the Figure at the east end with a small alluvial deposit. This model includes granodiorite at depth, but could also reasonably include the Mesozoic metavolcanic unit as well, particularly at the east-side of the valley where it has been mapped at the surface (see above discussion on this unit).

E-W Reno/Sparks
Figure 8 shows a geologic model for the central portion of the study area. It continues the structure interpreted from Figure 7 with west and steeply dipping (60° to 80° ±10°) normal faults. This section shows the West Reno basin sediments at 1,200m (4,000ft) thick. The basin continues easterly with two down-dropped blocks with inferred faults from the mapped lineaments (see Figure 6). The eastern boundary of the West Reno basin is bounded by an inferred fault coincident with the very high gravity gradient. The lineament represents the fault mapped to the south and seen in Figure 7. The high gravity anomaly to the east can be interpreted as either granodiorite or metasediments. However, the density was increased to 2.77 in order to better fit the measured gravity gradient. Consequently, a density contact between the Mesozoic metavolcanics and Cretaceous granite at depth is arbitrary and was chosen at the high angle inferred fault.

The model then includes a ramp like structure of sediments that dips to the east, terminating at the Virgina Range and possible west-dipping, basin bounding fault. Due to the lack of gravity data and lithologic control in this area, the inferred fault is represented at a relatively low angle despite the very strong gravity gradient. The apparent basin is termed the East Sparks basin, estimated at 400m (1,300ft) thick. Lithologic control on the thicknesses of units in this area is

7

lacking. Well logs that are shown apparently do not penetrate the Tertiary sediments. Gravity data are very sparse to the north and east of the McCarran ring road and therefore do little to help constrain this model.

<u>W-N Reno</u>
Figure 9 shows the geologic model for a portion of west-to-north Reno. This section is interpreted as a broad, northerly thinning basin with normal (?) basin bounding faults. The basin fill is estimated at 1300m (4,300ft) and agrees with the estimate modeled in the NW-SE Reno and West-East Reno/Sparks sections. West dipping, high angle (60-70°), normal faults are also interpreted at two locations and are consistent with the previous sections discussed above. These faults are interpreted on the total horizontal gradient lineations from Figure 4. The basement rock on the right half of the section could consist of either Mesozoic metasediments or Cretaceous granodiorite. Granodiorite is mapped three miles to the north of this section and metasediments are mapped three miles to the west (not shown on Figure 1b).

<u>N-S Reno</u>
Figure 10 shows the geologic model for a north-south section through the study area. The section, from the left of the figure, follows the "North McCarran" high gravity anomaly southward where another basin develops (SE McCarran basin). The section terminates near the Huffaker Hills where the sedimentary units "pinch out". This basin is estimated at 770 m thick (~2,500 ft). Once again there is no lithologic control on this section.

Reviewing Figures 3, 4 and 5 shows that east-west faulting could exist within the area of interest. One location is suggested on the north boundary of this basin, coincident with N. McCarran Blvd. This would be an extension of the lineament and fault trace shown on the Henry map west of N. Virginia Street. The suggested fault can also be interpreted coincident with N. McCarran near Pyramid Way such that the North McCarran high gravity anomaly over-prints this trace. The second east-west fault is suggested at the midpoint of I-80 and S. McCarran where a gravity trend is shown on Figure 5. Figure 10 shows this "suggested" fault at ~6500m on the distance scale. If these faults do exist, they may pre-date the north-south faulting that is prevalent in the Basin and Range province.

**Model Accuracy**
It is important to note that the depth of the sediments modeled in these cross sections is highly dependent upon the density contrast between the alluvium and the igneous rocks. Absolute density values assigned to the different lithologies are not as important as the contrast between them. For example, if the contrast between units is modeled at 0.3 g/cm$^3$ but physically is 0.1 g/cm$^3$, then the relative thickness would actually be 1/3 less. Likewise, if the contrast is actually 0.4 g/cm$^3$, but modeled at 0.3 g/cm$^3$ the relative thickness would actually be greater. Therein lies the uncertainty of the modeling results.

In order to resolve this issue, a number of boreholes drilled to bedrock would be needed to confirm the actual sedimentary thickness. Few wells have been drilled to confirm alluvial thickness and those are located exclusively in the Moana Geothermal Area. These wells have

8

been used in the modeling effort. The gravity data strongly support the modeled basin structure. Therefore, it is felt that an accurate model of the basin structure has been developed and that the modeled lithologic thicknesses are reasonable, probably within 30%. At intersections of the different cross sections, lithologic thickness differences between model interpretations were mostly between 0 and 100 meters. The thickness of the Tertiary volcanics for the intersection of the Central and South Reno sections differed by 150 meters. The thickness between the NW and Central sections for this unit differed by 265 meters.

**Discussion**
Constructed geologic cross sections are consistent throughout the study area with minor differences. Actual depths to bedrock are uncertain and can only be verified through drilling or perhaps seismic methods. Accurate density contrasts between the sediment and bedrock units, which vary both horizontally and vertically, are not available and therefore average density values must be used. To compensate for the natural increase in density with depth in the alluvial sequence a second sedimentary unit with a 10% increase in density would be justified. Differentiation of volcanic units was not possible and was not within the scope of this study, but mapped units were recognized. The contact between the basement granodiorite and the volcanics is subjective. The gravity gradient lineaments were considered to represent normal fault structures and this interpretation was mostly successful.

The gravity data are complementary and consistent with the surface geology and topography. The gravity data displayed in Figures 2-6 defines basin structure where gravity gradients highlight the steep and west dipping normal faults that define basin structure. The use of the total horizontal gradient map gave good insight on the presence and location of basin boundary faults that were consistent with mapped faults. This interpretation was useful in the geologic cross section modeling effort. A better structural presentation on fault mechanics as applied to the Moana area is warranted. The model of Figure 7 is more a presentation of the complexity of the area rather than a "true" structural representation.

It is interesting to study Figure 11 with respect to the overall structure of the Central Truckee Meadows. The eastern half, east of Virginia Street, appears structurally "quiet" other than range front faulting along the Virginia Range. Between the inferred range front fault on the Henry map and the gravity gradient lineament, a high volcanic platform is suggested that includes the Huffaker Hills (dated at 7 Ma). To the immediate west of the lineament, two basins have formed, but lack evidence of being formed from faulting. In the north of the study area, the dominant feature is the somewhat pyramidal form of the N. McCarran high gravity anomaly. This is interpreted to be composed of either Cenozoic granodiorite or Mesozoic metavolcanics, but certainly granodiorite at some depth.

West of Virgina Street, west dipping, normal faulting dominants the area. The West Reno basin is of relatively great depth for such a small area. The "pull-apart" inferred in the Moana Geothermal Area probably provides the crustal weakness for geothermal fluid migration. The faulting in this area could be part of a more regional fault structure, known as the Genoa Fault, that can be traced from the Carson Valley and suggested to bound the west slope of the

Steamboat Hills (discussions from Henry, Oppliger and Widmer). The section of this projected fault traverses the Mt. Rose alluvial fan (or alluvial veneered pediment) and provides a barrier to groundwater movement (Widmer, 1991). The fault is also coincident with an offset in water levels observed in monitor wells in the Central Truckee Meadows. This has been represented as a barrier to flow in the existing groundwater model as shown in Figure 11. This flow barrier is also coincident with other faulting and the apparent bedrock ridge that traverses northerly from the Moana Geothermal Area to the N. McCarran high gravity anomaly.

**Future Work**
A thorough survey and more detailed measurement of density values of the Sandstone of Hunter Creek needs to be implemented before any other work. The measurements should be taken at intervals where the length of the stratigraphy sequence is greatest. This will help constrain the modeling to date and any future modeling. The cost of this work is minimal.

Additional gravity should be collected north of N. McCarran Blvd and in the eastern edge of the Central Truckee Meadows. Approximately 100 – 200 gravity stations would define bedrock structure in these areas to further constrain the geologic models. The cost of this survey would be approximately $10,000, which includes processing. An additional fourteen man-days of geologic modeling would provide for a detailed bedrock elevation map. However, the structural analysis will continue to suffer from a lack of subsurface lithologic control.

Geologic models have been constructed for Washoe Valley, Lemmon Valley, Cold Springs Valley and the Verdi/Mogul area. Soon, the South Truckee Meadows (and further refinement of Washoe Valley) will be complete. At that time it is recommended that a structural model be constructed. This will provide a basis for working out more detailed bedrock elevation models for use in groundwater flow analysis.

**Acknowledgements**
The author thanks Dr. Gary Oppliger for his generous sharing of geophysical processing, interpretation skills and geologic insight. The author wishes to thank Dr. Chris Henry for use of his "generalized" geologic map and geologic discussions. The author also wishes to thank Tom Carpenter for his diligence in obtaining gravity measurements throughout southern Washoe County. It is hoped that future work will include these respected professionals. Without their contributions, much of this work would not have been undertaken.

**References**
Abbott, Robert E. and Louie, John N. 2000. Depth to bedrock using gravimetry in the Reno and Carson City , Nevada area basins: Geophysics, vol. 65, pp. 340-350.
Bell, John and Bonham, Harold.1987. Geologic map of the Vista quadrangle. Nevada Bureau of Mines and Geology. Map number 4Hg
Bell, John and Garside, Larry., 1987. Geologic map of the Verdi quadrangle. Nevada Bureau of Mines and Geology. Map number 4Gg.
Bonham, Harold and Rogers, David.1983. Geologic map of the Mt. Rose NE quadrangle. Nevada

Bureau of Mines and Geology. Map number 4Bg

Bonham, H.F. and Bingler, E.C., 1973. Geologic map of the Reno quadrangle. Nevada Bureau of Mines and Geology, Reno, Nevada.

Carpenter, Thomas. 2005, Gravity data acquisition and processing, Central Truckee Meadows, Washoe County, Nevada. Consultant report prepared for Washoe County Department of Water Resources, Reno, Nevada.

Cashman, Patricia. 2004. Personal communication. Research Associate Professor, Mackay School of Environmental and Earth Sciences, University of Nevada, Reno.

Geosoft, Inc.,1999. Oasis Montaj, data processing and analysis system for earth science applications, Version 4.3. Geosoft, Inc. Toronto, Ontario.

Henry, Chris and Perkins, . 2001

Henry, Chris. Personal communication. Research Geologist, Nevada Bureau of Mines and Geology. University of Nevada, Reno.

Northwest Geophysical Associates, 1996. GM-SYS, Gravity and Magnetics Modeling for Windows. Version 4.00. Northwest Geophysical Associates, Corvallis, Oregon.

Sanders, Chris and Slemmons, David. 1979. Recent crustal movements in the central Sierra Nevada-Walker Lane region of California-Nevada: Part III, the Olinghouse Fault Zone. Tectonophisics, vol. 52, pages 585-597.

Skalbeck, John D., 1998. Measurement of Physical and Paleomagnetic Properties from Rocks in the Steamboat Hills and Carson Range, Washoe County, Nevada. Unpublished report prepared for Washoe County Department of Water Resources, Reno, Nevada.

Trexler, J. H., Jr., Cashman, P. H., Henry, C. D., Muntean, T. W., Schwartz, K., TenBrink, A., Faulds, J. E., Perlins, M., and Kelly, T. S., 2000, Neogene basins in western Nevada document tectonic history of the Sierra Nevada - Basin and Range transition zone for the last 12 Ma, *in* Lageson, D. R., Peters, S. G., and Lahren, M. M., eds., Great Basin and Sierra Nevada: Boulder, Colorado, Geological Society of America Field Guide 2, p. 97-116.

Widmer, Michael C., 1991. Mt. Rose Fan Exploratory Drilling. Unpublished report prepared for Washoe County Department of Water Resources, Reno, Nevada.

Widmer, Michael C., 1995. Southwest Pointe Exploration and Well Construction Report. Unpublished report prepared for Washoe County Department of Water Resources, Reno, Nevada.

Widmer, Michael C., 2005. ArrowCreek Exploration and Well Construction (#4 and #5). Unpublished report prepared for Washoe County Department of Water Resources, Reno, Nevada.
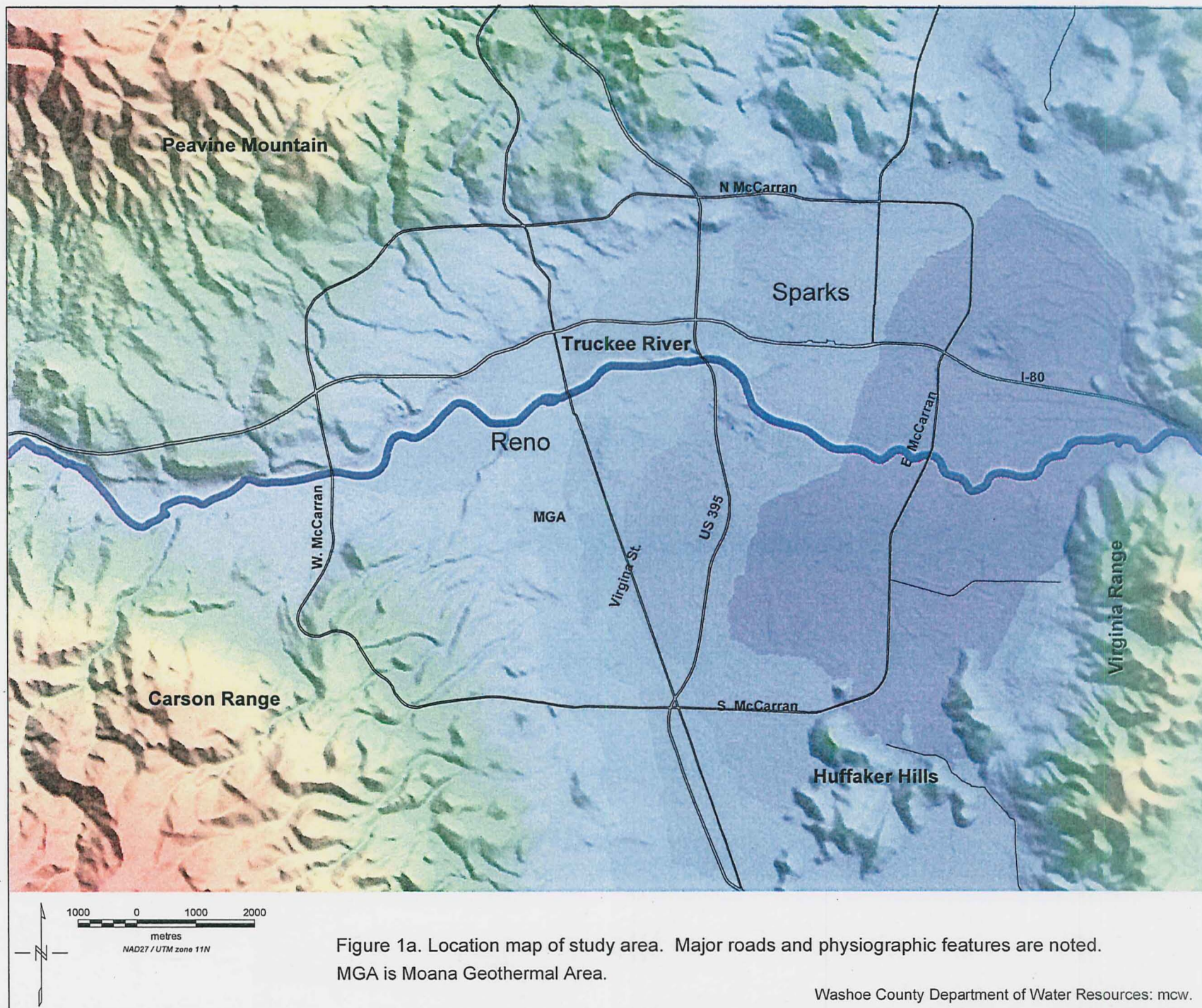
Peavine Mountain

N McCarran

Sparks

Truckee River

Reno

MGA

US 395

I-80

E McCarran

W. McCarran

Virginia St.

Carson Range

S. McCarran

Virginia Range

Huffaker Hills

1000    0    1000    2000
metres
NAD27 / UTM zone 11N

Figure 1a. Location map of study area. Major roads and physiographic features are noted.
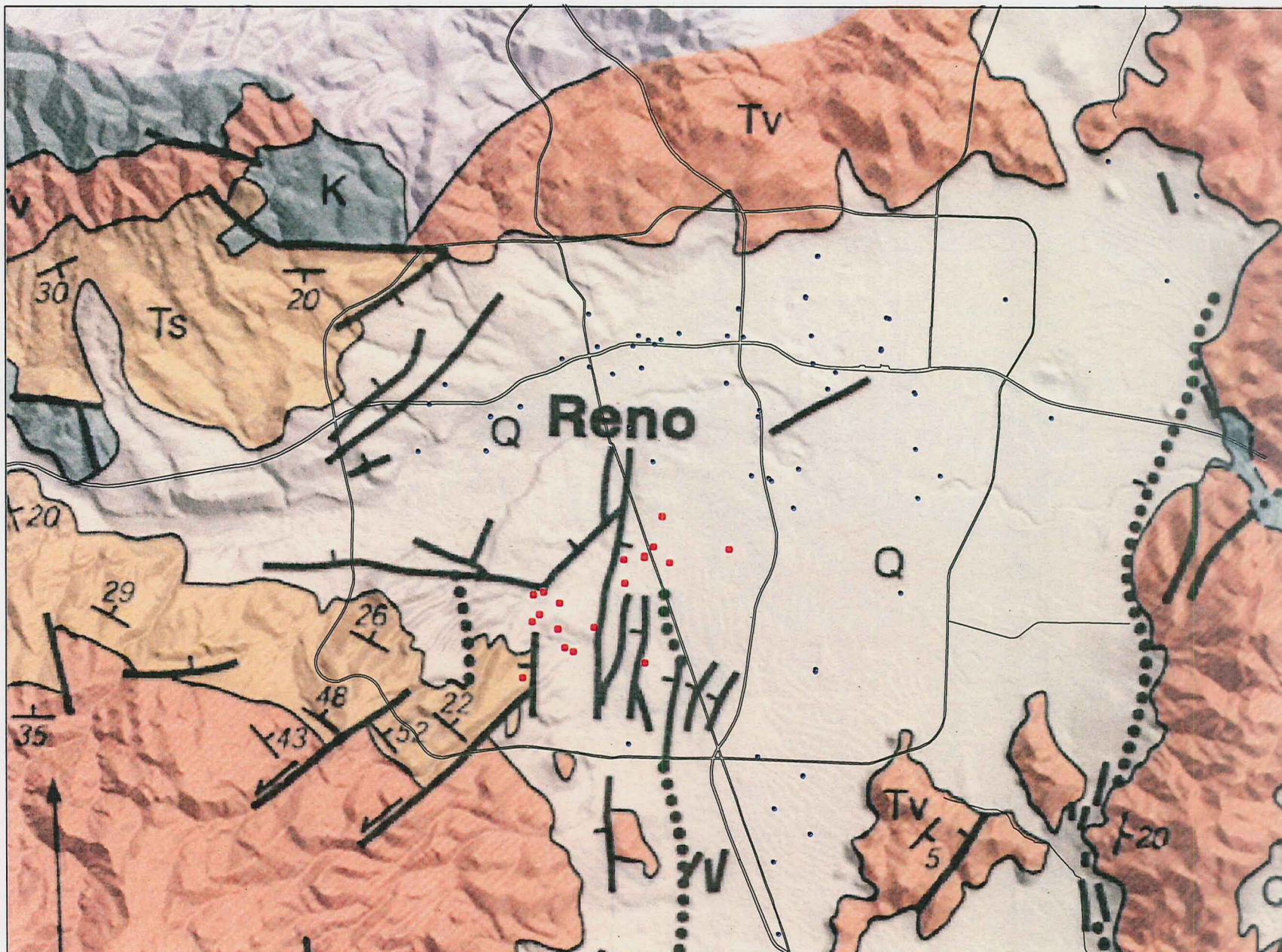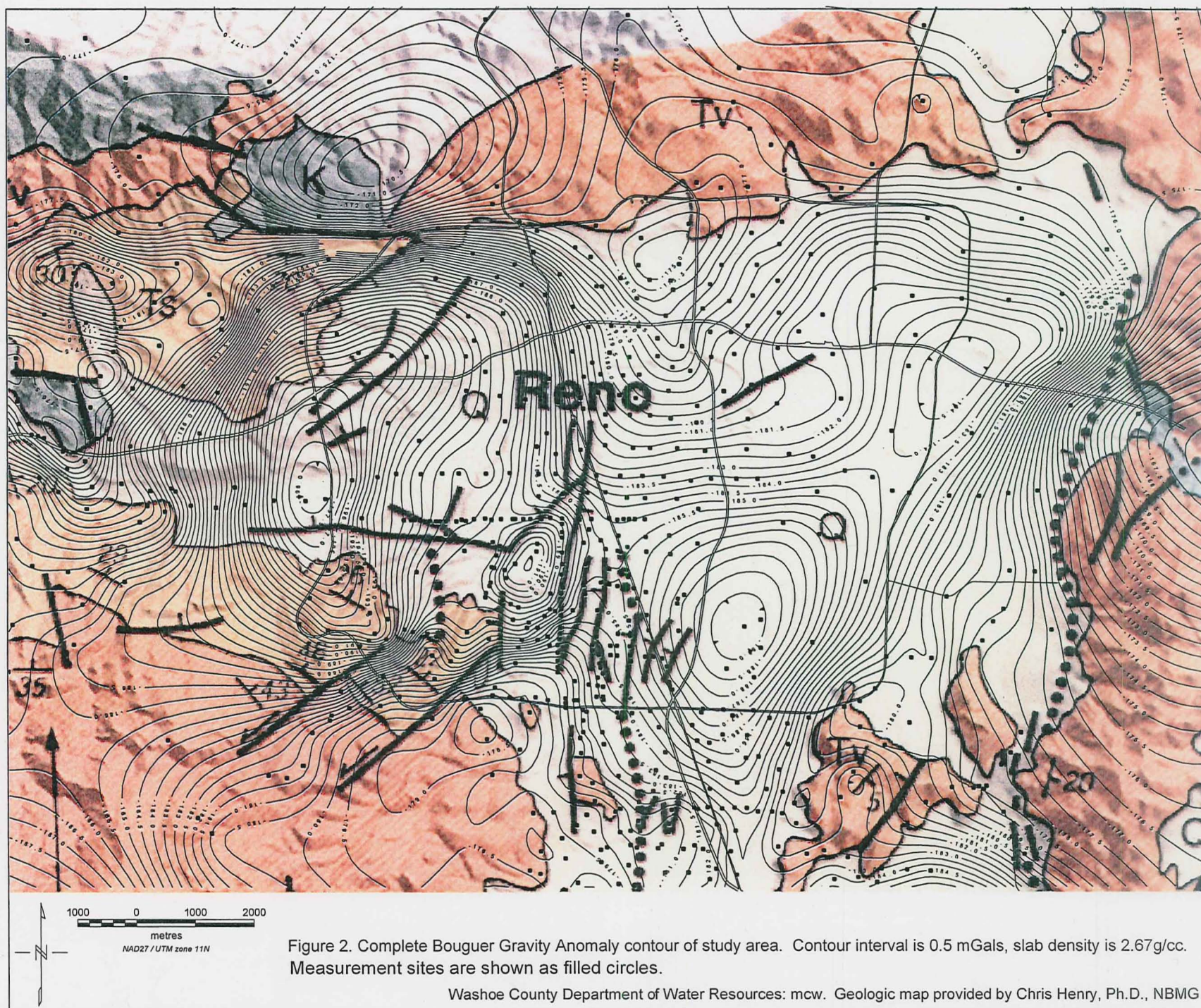MGA is Moana Geothermal Area.

Figure 1b. Study area overlain on Henry geologic map. Shown are major roads and lithologic log locations. (red = geothermal wells, blue = water supply and monitor wells).

Washoe County Department of Water Resources: mcw. Geologic map provided by Chris Henry, Ph.D., NBMG

Figure 2. Complete Bouguer Gravity Anomaly contour of study area. Contour interval is 0.5 mGals, slab density is 2.67g/cc. Measurement sites are shown as filled circles.

Washoe County Department of Water Resources: mcw. Geologic map provided by Chris Henry, Ph.D., NBMG
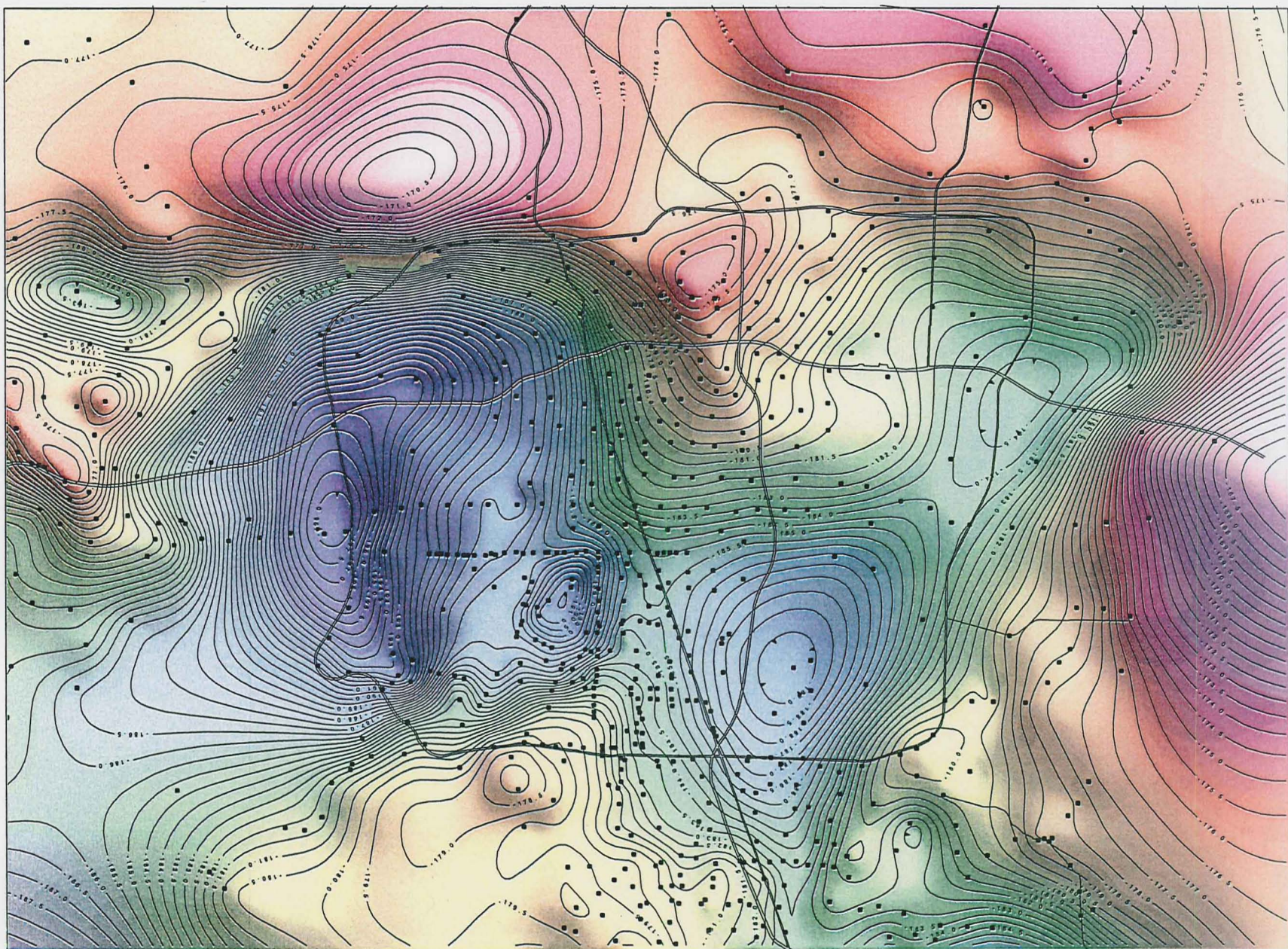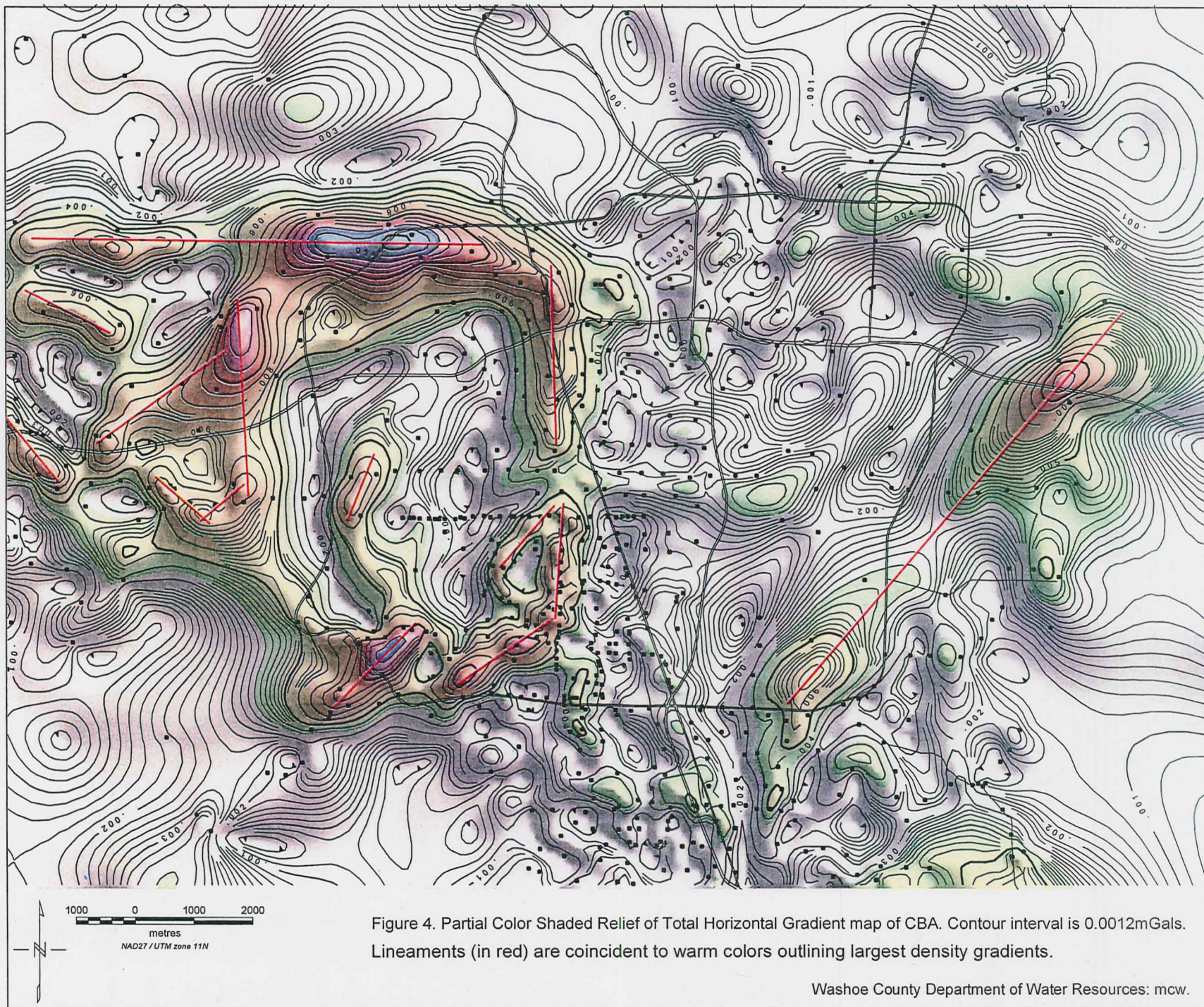
Figure 3. Color Shaded Relief of CBA of study area. Contour interval is 0.5 mGals. Cool colors are low anomalies and warm colors are high anomalies.
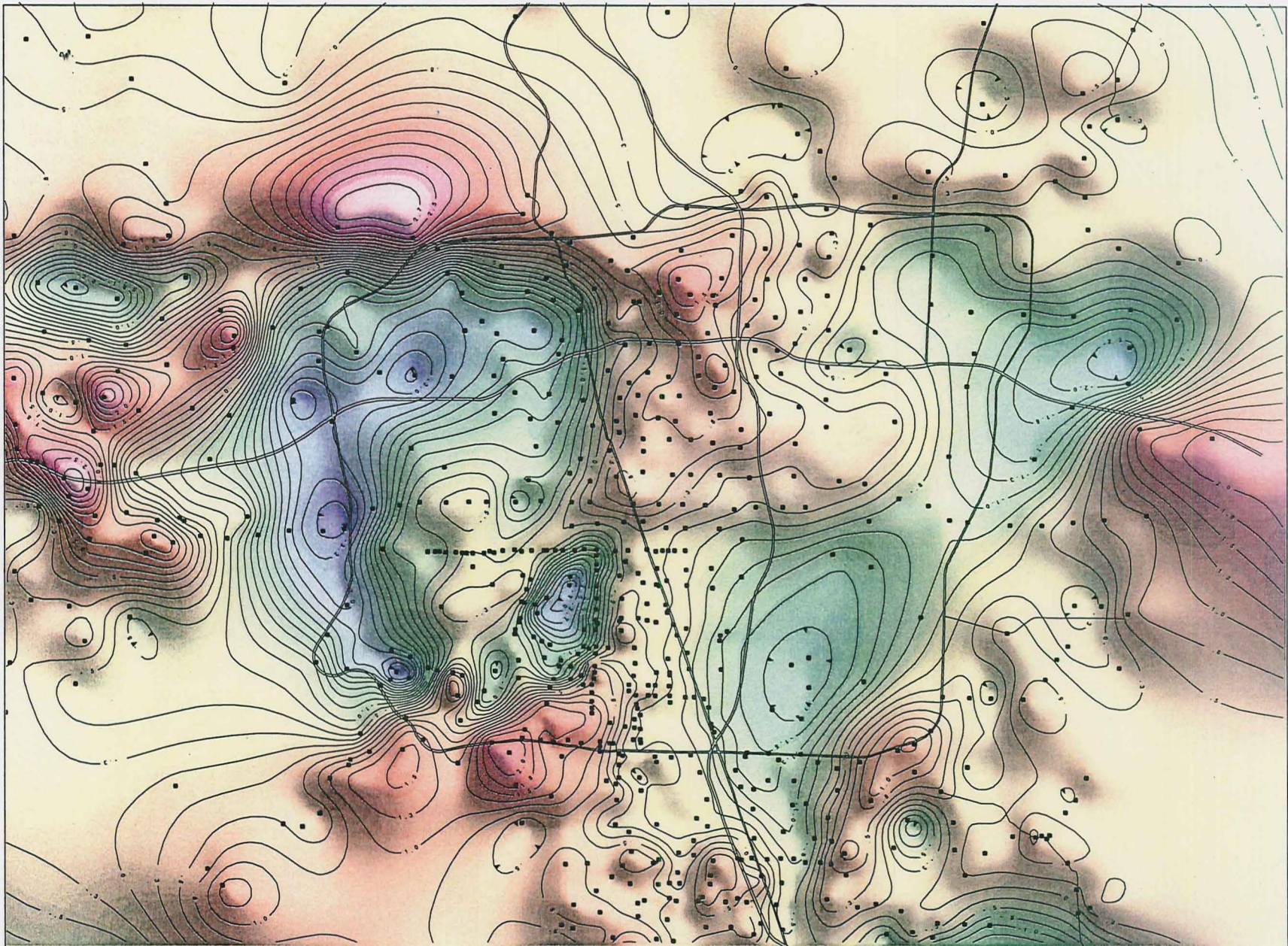
Washoe County Department of Water Resources: mcw. Geologic map provided by Chris Henry, Ph.D., NBMG

Figure 4. Partial Color Shaded Relief of Total Horizontal Gradient map of CBA. Contour interval is 0.0012mGals. Lineaments (in red) are coincident to warm colors outlining largest density gradients.

Washoe County Department of Water Resources: mcw.

NAD27 / UTM zone 11N

metres

1000    0    1000    2000

Figure 5. Color Shaded Relief of upward continued (350m) residual of CBA. Contour interval is 0.03 mGals.

Washoe County Department of Water Resources: mcw.

1000    0    1000    2000
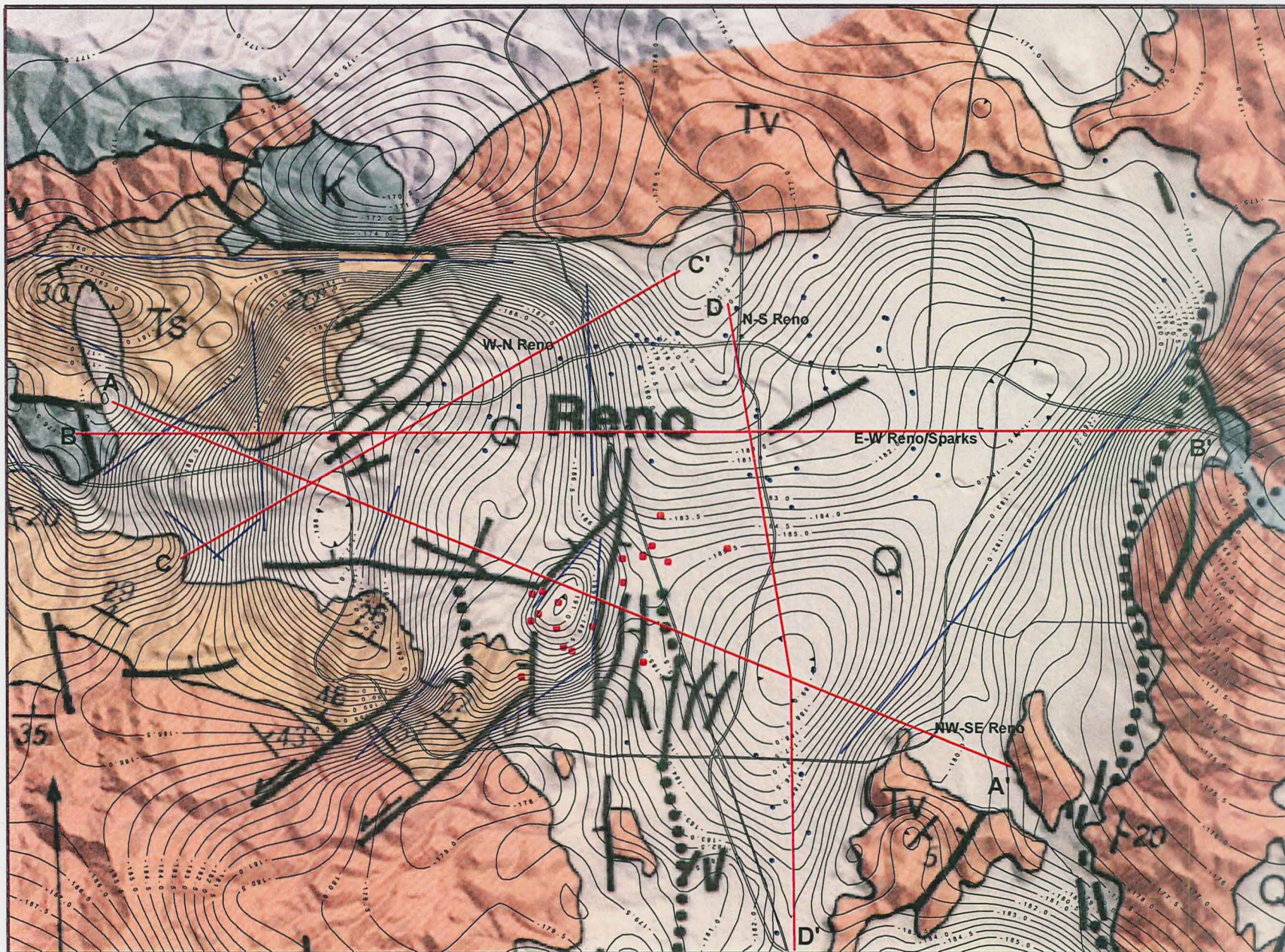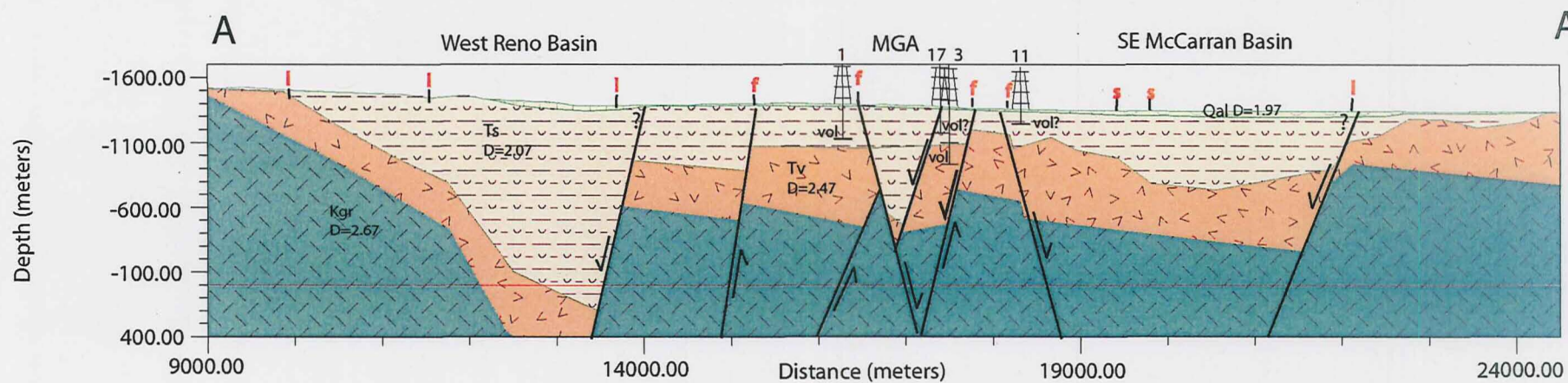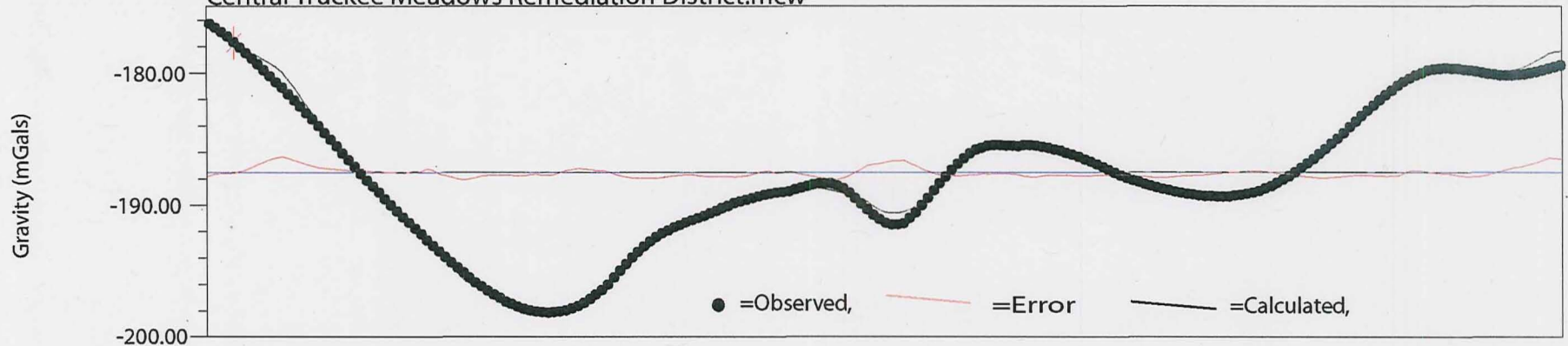metres
NAD27 / UTM zone 11N

Figure 6. Location map of geologic cross sections and lineaments overlain on Henry geologic map.
Filled circles are locations of lithologic logs used. Contours are of 0.5 mGal Complete Bouguer Gravity Anomalies.

Washoe County Department of Water Resources: mcw.  Geologic map provided by Chris Henry, PhD, NBMG

# Figure 7. NW-SE Reno geologic cross section with gravity

Central Truckee Meadows Remediation District:mcw

Thu Mar 24 14:46:01 2005



● =Observed,  ____ =Error  ▬▬ =Calculated,

A    West Reno Basin    MGA  17 3    11    SE McCarran Basin    A'

1

Ts
D=2.07

Tv
D=2.47

Kgr
D=2.67

vol?    vol?    vol?

vol

Qal D=1.97

Scale=75000
V.E.=1.5

1

⬚ derrick and depth symbols indicates well log location used in model and
number indicates log found in appendix for this cross section

I tick mark indicates location of:
f = mapped fault
l = gravity gradient lineation
s = mapped fault splay

# Figure 8. E-W Reno/Sparks geologic cross section with gravity



Central Truckee Meadows Remediation District:mcw

Fri Mar 25 11:20:53 2005

Scale=88000
V.E.=2

derrick and depth symbols indicates well log location used in model and
number indicates log found in appendix for this cross section

tick mark indicates location of:
f = mapped fault
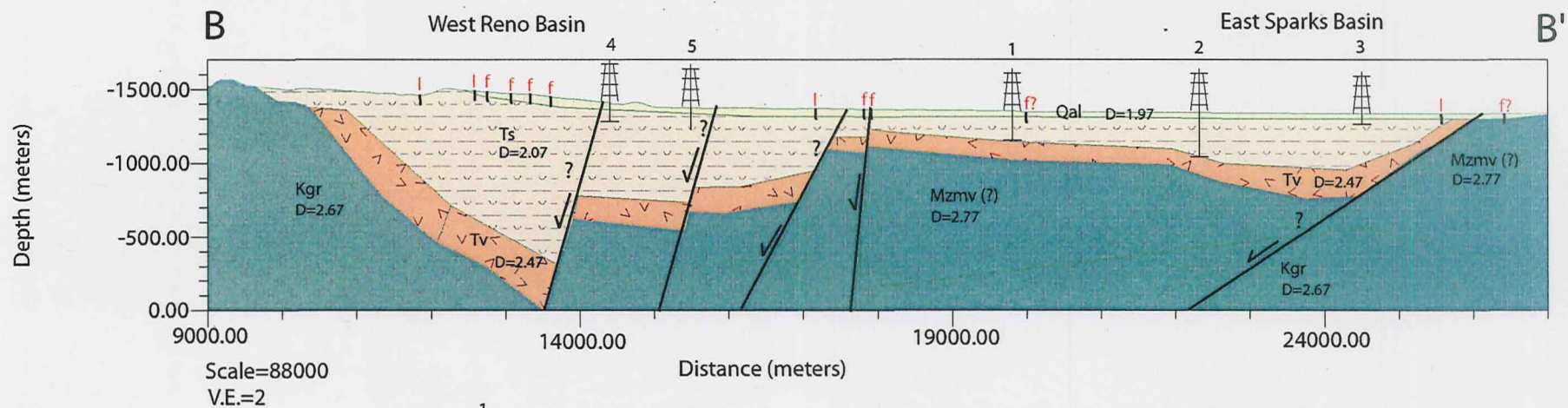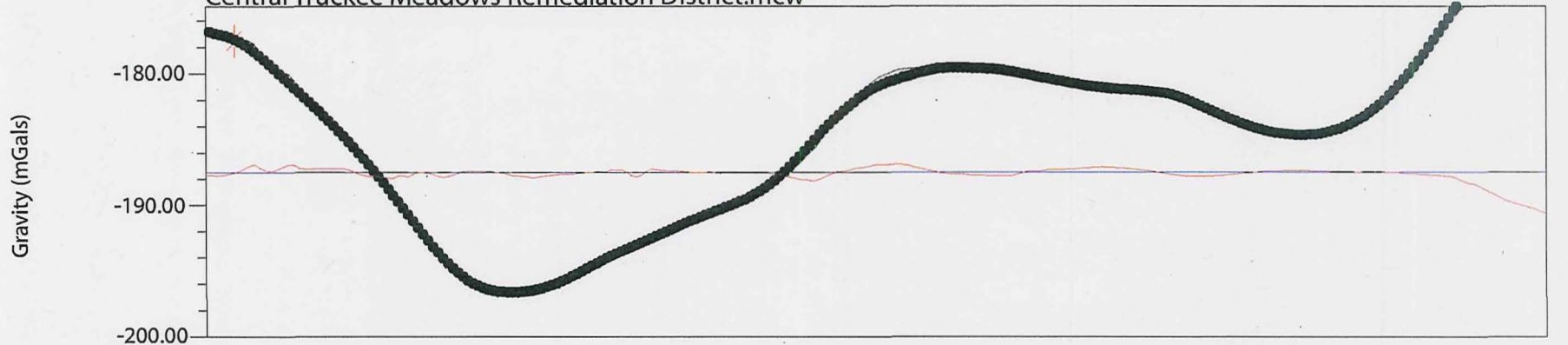l = gravity gradient lineation
s = mapped fault splay

# Figure 9. W-N Reno geologic cross section with gravity

Central Truckee Meadows Remediation District:mcw

Fri Mar 25 13:10:21 2005



Scale=44000
V.E.=1

derrick and depth symbols indicates well log location used in model and
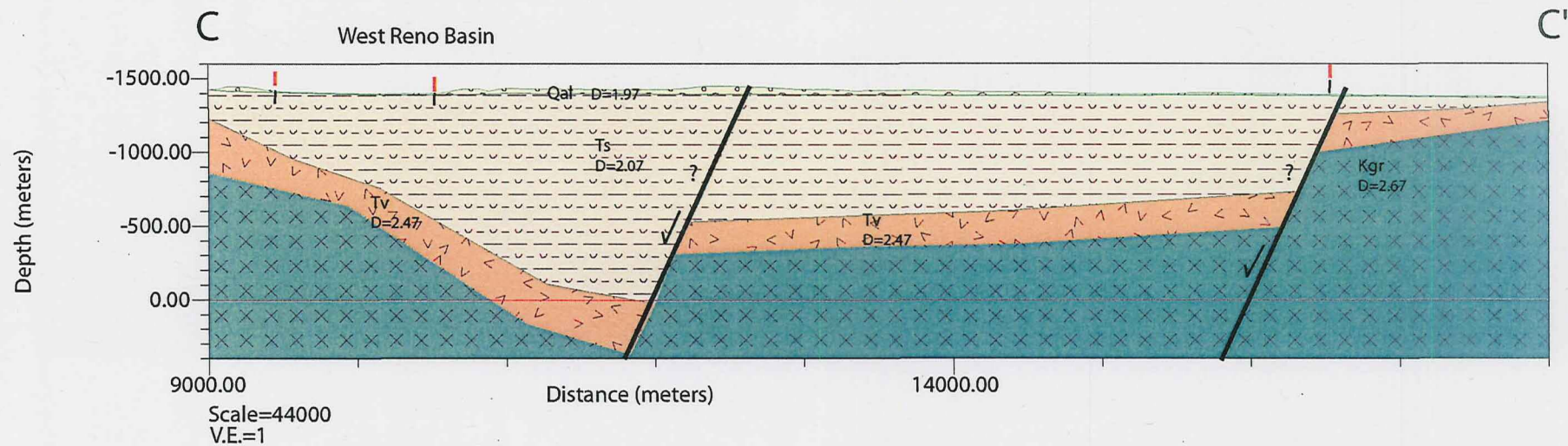number indicates log found in appendix for this cross section

tick mark indicates location of:
f = mapped fault
l = gravity gradient lineation
s = mapped fault splay

# Figure 10. N-S Reno geologic cross section with gravity



Central Truckee Meadows Remediation District:mcw                     Fri Mar 25 16:29:31 2005
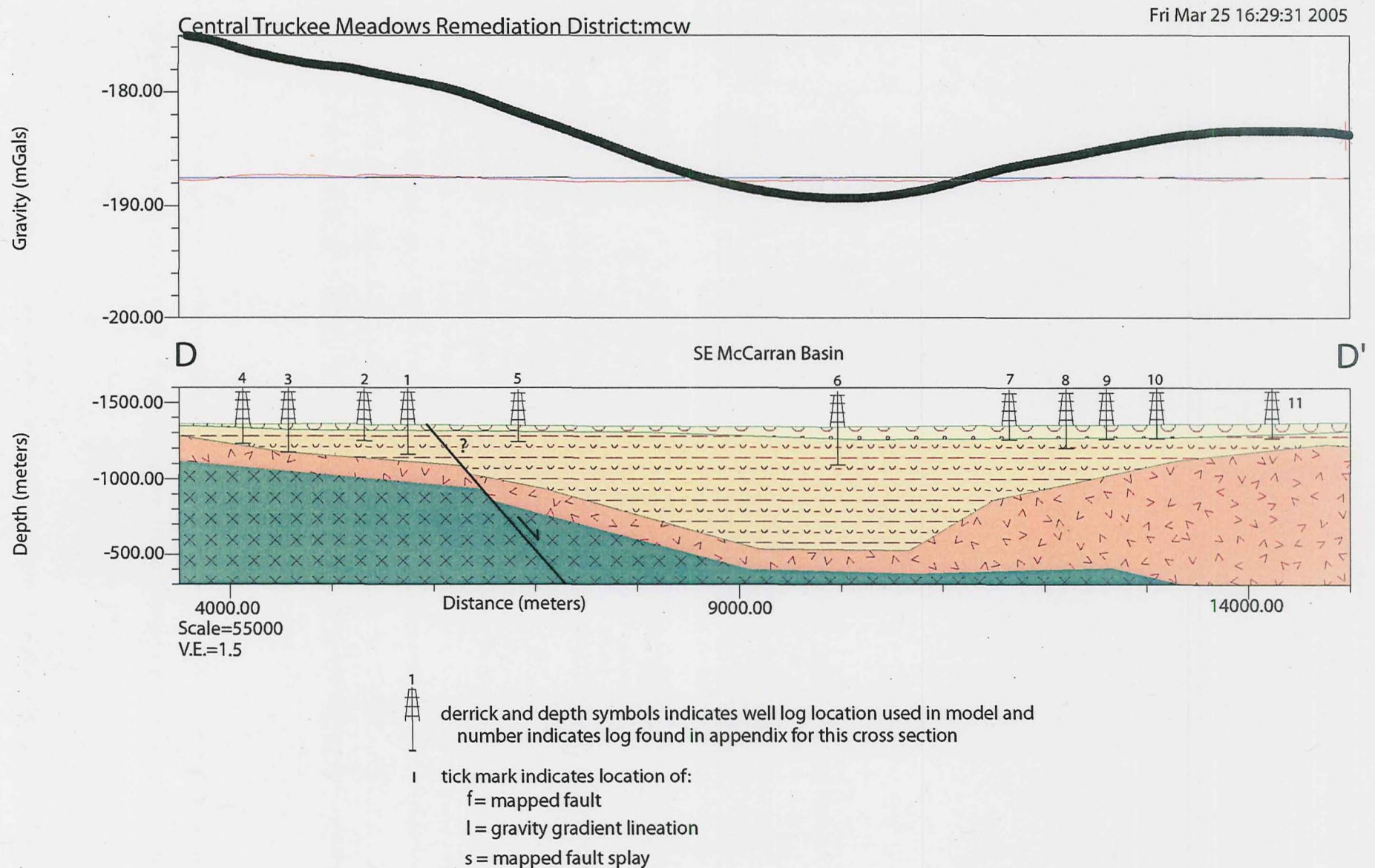
derrick and depth symbols indicates well log location used in model and
number indicates log found in appendix for this cross section

tick mark indicates location of:
f = mapped fault
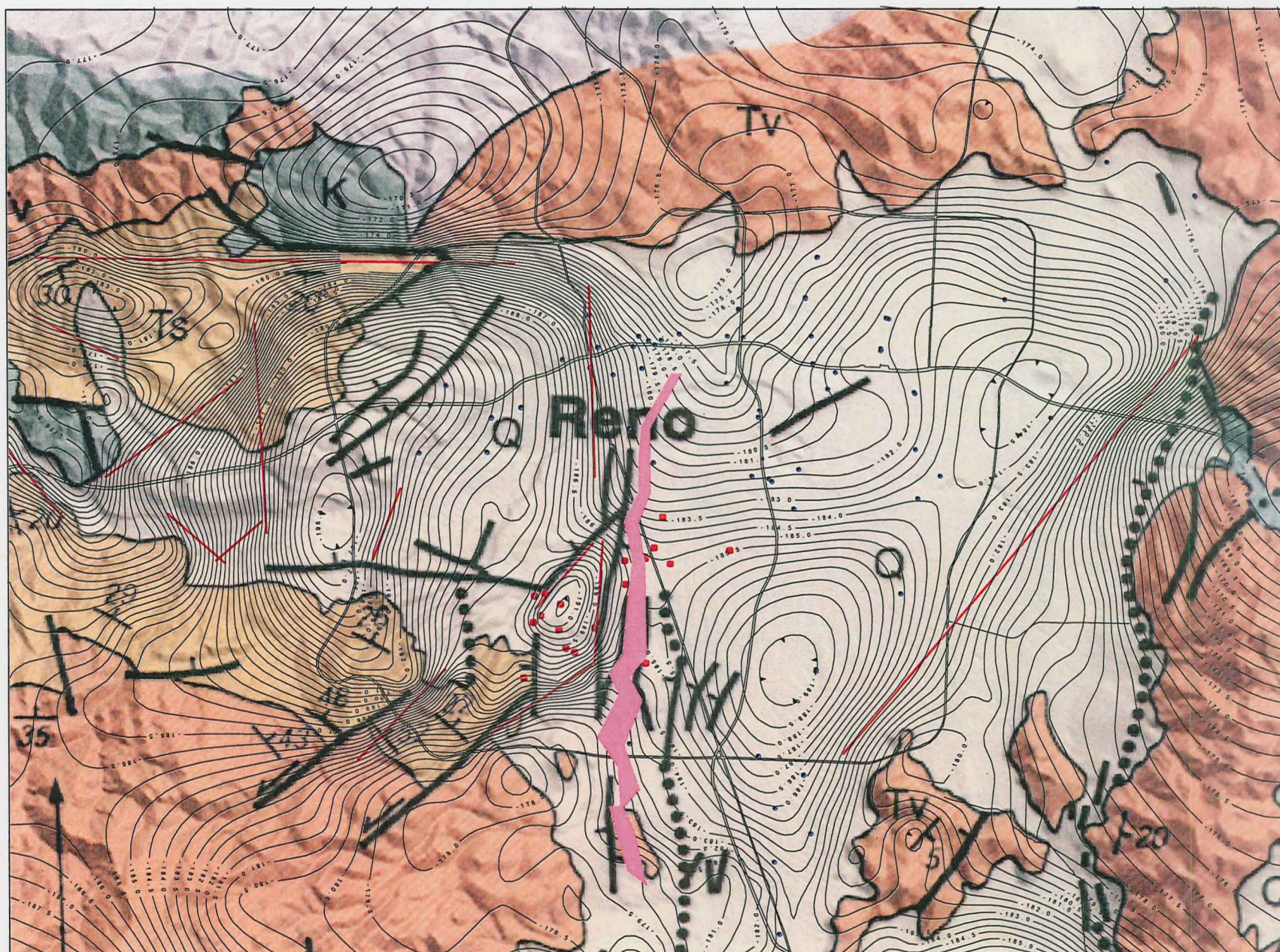l = gravity gradient lineation
s = mapped fault splay

Figure 11. Study area overlain on Henry geologic map with gravity contours, well locations, lineaments and "aquiclude". (red = geothermal wells, blue = water supply and monitor wells).

Washoe County Department of Water Resources: mcw. Geologic map provided by Chris Henry, Ph.D., NBMG

1000   0   1000   2000
metres
NAD27 / UTM zone 11N

| name | NAD27 zone11 | | total depth | depth to bdrx | total depth |
| --- | --- | --- | --- | --- | --- |
| | X | Y | (m) | (m) | (ft) |
| **"hot wells"** | | | | | |
| Bantz | 257167.9 | 4375847 | 275 | 267 | 902 |
| Hydrothermal Energy | 258622.7 | 4376035 | 245 | * | 803.6 |
| Hydrothermal Energy | 258609.6 | 4376417 | 450 | 283 | 1476 |
| Peppermill | 259334.4 | 4376368 | 230 | * | 754.4 |
| Peppermill | 259334.4 | 4376368 | 1000 | 343 | 3280 |
| Virginia Lake Town | 259078.9 | 4376625 | 365 | * | 1197.2 |
| LaCasa Arms | 260285.6 | 4376583 | 155 | * | 508.4 |
| Nv. Lakeshore | 258932.8 | 4376452 | 340 | * | 1115.2 |
| Nv. Lakeshore | 258935.3 | 4376472 | 300 | * | 984 |
| Mark Twain | 259218.6 | 4377116 | 311 | * | 1020.08 |
| Earth Science | 258939.8 | 4374755 | 120 | 115 | 393.6 |
| Earth Science | 257555 | 4375299 | 244 | 213 | 800.32 |
| Warren Estates | 257263.6 | 4375533 | 445 | 315 | 1459.6 |
| Pennington | 256992.7 | 4374520 | 375 | 150 | 1230 |
| Carabine | 257800.8 | 4374937 | 200 | * | 656 |
| Hilts | 257331.8 | 4375889 | 255 | * | 836.4 |
| Hartwell | 258131.5 | 4375328 | 215 | 215 | 705.2 |
| Carsoli | 257583.4 | 4375715 | 200 | * | 656 |
| Allen | 257147.2 | 4375417 | 220 | 205 | 721.6 |
| Stern | 257665.3 | 4375000 | 152 | * | 498.56 |
| | | | | | |
| **"cold wells"** | | | | | |
| 4th st | 260285.6 | 4379569 | | | 430 |
| Kietzke | 260361.5 | 4379111 | | | 618 |
| G&M | | | | | 350 |
| Mill | 260615.8 | 4377928 | | | 660 |
| Corbett | 260761.6 | 4376833 | | | 368 |
| Peckham | 261495.6 | 4373724 | | | 826 |
| P23 | 261297 | 4372058 | | | 315 |
| S. Virginia | 260835.3 | 4371520 | | | 504 |
| Longely | 261403.8 | 4371111 | | | 310 |
| Huffaker | 260819.2 | 4370663 | | | 315 |
| Holcomb | 260894.7 | 4369493 | | | 336 |