APPENDIX 7-60

LITTLE BEAR SPRING STUDY (EXPANDED STUDY, 1999)

AQUA TRACK

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File Mill Fork Lease 2820-4

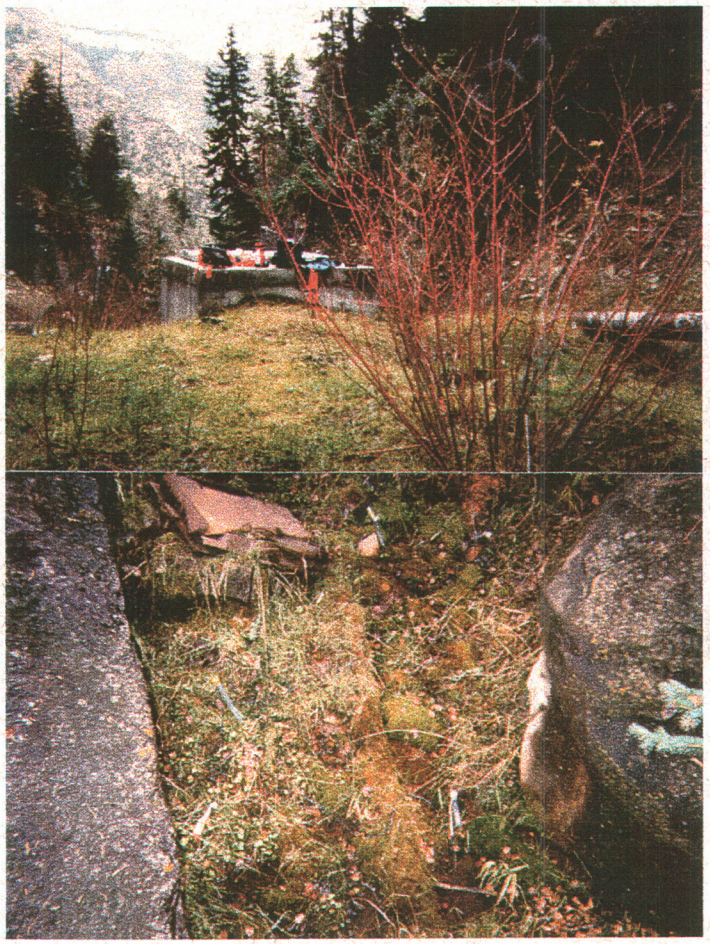
Jeff DeFreest
Return to Carter

1999

AquaTrack Survey

Little Bear Springs Study

Huntington Canyon, Utah



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AquaTrack

AquaTrack uses electromagnetic energy, injected into the groundwater being investigated, to map water and related geologic structures. More specifically the technology can be used to map, track, and monitor; groundwater, groundwater channels, groundwater structures, subsurface pollution plumes. It can also be used to map interconnected fracture or porous zones, map leaks in earthen dams, and maps leaks in drain fields. The technology will also monitor changes in subsurface water flow, changes in ion concentration in groundwater, progress of in situ leaching solution, movement of heap leaching solutions, changes in subsurface redox or reaction fronts, underground chemical reactions, and subterranean bio-reactions. AquaTrack can also be used to check other subsurface waters and related geologic structures. It works best for tracking long continuous conductors of any kind and in the ground this usually is the path of water but underground pipes and wires are known to cause interference problems.

COMPANIES AND GOVERNMENT AGENCIES WE HAVE WORKED WITH:

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CH2M HILL
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Bureau of Indian Affairs
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Salt Lake Co. - Flood Control
UT Div. of Oil Gas and Mining
INEEL - DOE - Idaho
Los Alamos - DOE - N.M.

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AQUATRACK

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SURVEY OBJECTIVES

Personnel from Water Technology and Research, Inc. (WTR) conducted an AquaTrack survey in Little Bear Canyon, Mill Fork Canyon And on top of the ridge that divides the two canyons. The purpose of the survey was to map the subsurface-water feeding Little Bear Spring in Little Bear Canyon. The goal of the survey was to follow the structure paths feeding Little Bear Spring, and to determine if the path of the ground water source intersected Mill Fork Canyon. In this regard, WTR was asked to provide the information on the following:

1. Expand the map of subsurface flow paths in the vicinity of Little Bear Spring. By Surveying a "U" shaped line the profile wrapped around the south, west and north sides of the 1998 survey area and Little Bear Spring.
2. Continue in identifying the path or route of the groundwater feeding Little Bear Spring.
3. Identify the structure that is controlling the water feeding Little Bear Spring.
4. If possible determine what the source might be that is feeding the spring.
5. If possible find the source of the water that replenishes the spring every year.
6. Find where the structure feeding Little Bear Spring crosses Mill Fork Canyon

CONCLUSIONS:

The results obtained from the AquaTrack data procured during the course of this investigation are summarized below.

1. The expanded survey area in the vicinity of Little Bear Spring is shown along with the results for Little Bear Canyon and Spring on the map of Figures 5, 6 pages 12-13 and Figure 15. Page 25. A cross section profile along the fault controlling the water feeding Little Bear Spring is shown in Figure 19 Page 30.

2. From the 1998 survey the path of the groundwater was found to be following a fault line. Along this fault the data indicates that the groundwater has hollowed out caverns or cave like structures creating a cistern like system in the mountain range south of Little Bear Spring. In the 1999

The use of the words "caverns or cave like" in this report do not reference the large open system seen in limestone formations. They refer to what develops along a fault such as gaps or spaces between the fault planes, small pockets created by dissolving the calcite between sand grains to form pockets of sand. These sand pockets would be about the same size and shape as the pockets seen in the cliffs in this area.

survey the data upheld this conclusion indicated water is following this fault and structures related to this fault. This was verified by the data from all three areas studied in this years survey, first Little Bear Canyon, second the ridge between Little Bear Canyon and Mill Fork Canyon, and third Mill Fork Canyon.

A secondary structure was also identified which connects Mill Fork Creek water to the dominating fault that controls the Little Bear Spring water system. This secondary structure creating a leg extending from sinks in Mill Fork Canyon to an area under the ridge where the two structures join, see the combined interpretation and Figure 15 Pages 24-25. The first indication of this secondary structure was identified in the ridge top survey. It is expressed as the right leg of the inverted "Y" on Figure 8 Page 15.

3. There is one main fault line that the groundwater is following.

- In Little Bear Canyon the fault line was found to continue south and north of the 1998 survey area see Figure 6, page 13.
- On the ridge top this fault line was identified in the profiles station 5, Figure 9 Page 16. The small leg connects to the fault in this area adding water to the Little Bear Spring system, see Figure 8, page 15.
- In Mill Fork the controlling applicable fault line was identified at station 44, see Figures 11, thru 14 and the accompanying explanation pages.18 thru 23.

For a complete map that is a composite of all three survey areas see Figure 15 page 25.

4. From the 1999 data it was possible to identify a *portion* of the water that yearly replenishing the groundwater. This water source was Mill Fork Creek. This is probably not the main source of water feeding Little Bear Spring, but this water source adds to the total of water coming from Little Bear Spring.

The water enters the system where the water disappears into small sink holes in the bottom of Mill Fork Creek near station 21. These sinks were used as the contact points of electrode 2, see Mill Fork Canyon Interpretation and Figures 11-14 pages 18-23. This is where the data indicates that there is a connection from Mill Fork Creek to the Little Bear Spring groundwater system. The data indicates this leg connects to the Little Bear Spring system under the survey area on top of the ridge. The path for this leg and for the main fault line can be seen in Figure 15. The data still indicates that a *portion* of the water is from sources that fills the fault line south and possibly north of Mill Fork Canyon.

> The Small sinks are not the giants that occur in limestone formations. The sinks visible in Mill Fork Creek bottom are about two to three feet in diameter, about a foot deep, and a sorted sand forms the bottom.

5. The groundwater feeding Little Bear Spring comes from multiple sources. The primary direction of flow is probably to the bottom of the syncline of which is Little Bear Canyon's axis.

- First, The part of the water feeding the Little Bear Spring system is one or more unknown sources south of Mill Fork Canyon.
- Second, a portion of the water in the Little Bear Spring system is from Mill Fork Creek. The data indicates that this water is entering the system by small sinks in the bottom of Mill Fork Canyon. The water that enters these small sinks eventually connects to and enters the dominating fault structure that controls primary groundwater feeding Little Bear Spring.
- Third, there is a small possibility that some of the water could be coming from north of Little Bear Spring along this same fault system. The data indicates that the fault structure continues to the north. Two caveats; First, north of the springs, in the direction of the fault, the slope is primarily down gradient except for one short section. Second, because Little Bear Canyon is located on the axis of a syncline that short section of the fault system that is up gradient is immediately north of Little Bear Spring on the north side of Little Bear Canyon. This could be why so much water exits from the fault system at the location of Little Bear Spring. However, the trend of the gradient past this point is down gradient because of the angle of the fault.

6. The dominant fault in the Little Bear Spring system crosses Mill Fork Canyon at our 1999 survey Mill Fork Canyon station 44 seen on Figure 14 page 22. The data indicates that the fault crosses at this point and that there is water in the fault system. This location was identified during the interpretation process, after the field work had been concluded. Thus, no additional data was collected around Mill Fork Canyon station 44. Thus the data does not indicate if water is entering the Little Bear Spring system at this point or if it is just passing under Mill Fork Canyon at this location.

Additional analysis of the data collected in Mill Fork Canyon around station 44 indicates that the underground water surface at station 44 is possible 100 to 200 feet below the surface, see Figure 16 and its explanation on Page 26.

7. A composite of the AquaTrack survey results and Huntington Mine #4 supplied by Utah Oil, Gas, and Mining indicate that the water feeding Little Bear Spring is below the mine workings, see Figures 17-18 Pages 27-29.

INTERPRETERS NOTE

This section has been included for disclosures and clarification on terms used in this report.

The station spacing used in this survey was either 50 feet or 100 feet, thus the accuracy of any point located by the data taken during this survey is ± half the station spacing. This implies that the error in locating the channel center is ± half the station spacing with a maximum error in the width of the channel of the ± station spacing.

Survey lines' (SL), are lines of data collection in the survey area. Profiles are the survey lines' data after mathematical corrections have been made for objects that influence the data such as power lines and known utilities. Line is a survey line of data stations referring to as a profile or SL. Station refers to a point on a survey line where that data were collected. Channel(s) are paths of current flow that can result from groundwater, utility lines, soil disturbed by past trenching or abandoned manmade structures such as old underground flews, etc.

The coordinate system used in this report defines north and east as positive numbers and south and west as negative numbers. The numbers along the bottom of the profile charts are in hundreds of feet so the distance between -2 and +1 would be 300 feet. For all the profiles the observer is looking west or north. In the case of the east/west profiles the observer is looking north.

BACKGROUND:

Little Bear Spring is the largest spring in Huntington Canyon and is used to supply culinary water to Huntington City and other surrounding towns. Coal mining in the area could disrupt the source of water feeding or replenishing the spring. It is important to both the water users and the coal mining companies to know the source of water and also to know the source replenishing Little Bear Spring. The continuation of the field survey for Little Bear Spring was conducted in August and early September of 1999. The last of the wire was picked up October 1 1999. Data reduction and modeling were done in September of 1999, and the interpretation and report was written in October of 1999.

TECHNOLOGY USED- AQUATRACK, How it Works:

AquaTrack uses electricity to follow the groundwater and map its subsurface paths. The best conductors in the ground are water, ore bodies and manmade structures like metal pipes or buried wire. AquaTrack works by directly energizing the groundwater in question. In this survey this was accomplished by energizing Little Bear Springs and using the water in Mill Fork Creek to

complete the circuit. The electricity flowing in the groundwater generates a magnetic field. By mapping the magnetic field, the flow of electricity in the ground is mapped. The map of current flow thus generates a map of the groundwater.

For a more detailed explanation refer to the appendixes.

EQUIPMENT AND SETUP:

The AquaTrack survey requires the establishment of an electrical circuit which includes the groundwater to be mapped. In this case that was Little Bear Spring on one end and water in Mill Fork Canyon on the other end of the circuit. The current takes the best path (least resistance and generally the shortest) to the return electrodes, completing the circuit. Most surveys, excluding this one, utilize only one direct contact point with the water being surveyed. However, in this survey an attempt was made to energize both ends of the water. For the 1998 survey Little Bear Springs was energized and the ground was in Huntington Creek. This electrode arrangement did not provide a signal that would reach Mill Fork Canyon. The first electrode setup in Mill Fork Canyon used the re-emergence of Mill Fork Creek as the ground point. Using the first electrode system the survey was unsuccessful in locating where the Little Bear Spring system crosses Mill Fork Canyon. For the second electrode arrangement in Mill Fork Creek a series of small two to three-foot in diameter and a foot deep sinks were used where Mill Fork Creek disappeared into the ground. This second electrode arrangement was located where the Little Bear Spring system crossed Mill Fork Canyon.

Survey Area

The survey area first extended the coverage around Little Bear Spring in Little Bear Canyon; second, it covered a small area on the ridge between the two canyons; and third, several profiles in Mill Fork Canyon were surveyed.

The survey line in Little Bear Canyon was "U" shaped, see Figure 1. The line starts north of the spring extended toward the west around the base of the valley and up a ridge on the

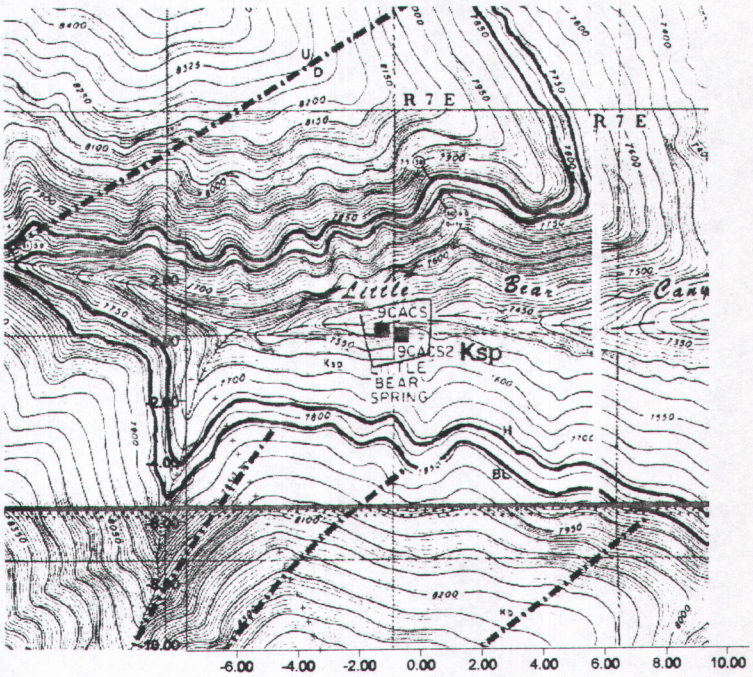


Figure 1 Map for 1999 stations in Little Bear Canyon.

south side of Little Bear Canyon. New data stations are shown with respect to the location of Little Bear Spring, see the blue "+" in Figure 1.

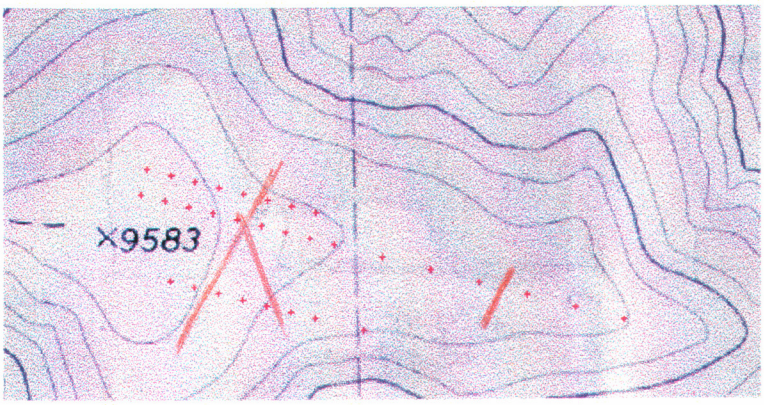


Figure 2 Station on top of the ridge.

On the ridge top three lines were surveyed. The main line started west of the fault line that was thought to be the structure feeding water to Little Bear Spring, and continued to the east to the ridge point. This line was used to determine if the structure could be identified at the top of the ridge. If it could be identified, then what is the depth of the water in the structure. Once the structure was identified, two shorter lines were surveyed to determine trends and direction of the water structure, and how it runs under the ridge. Data station locations are shown on top of the ridge in Figure 2 as red "+".

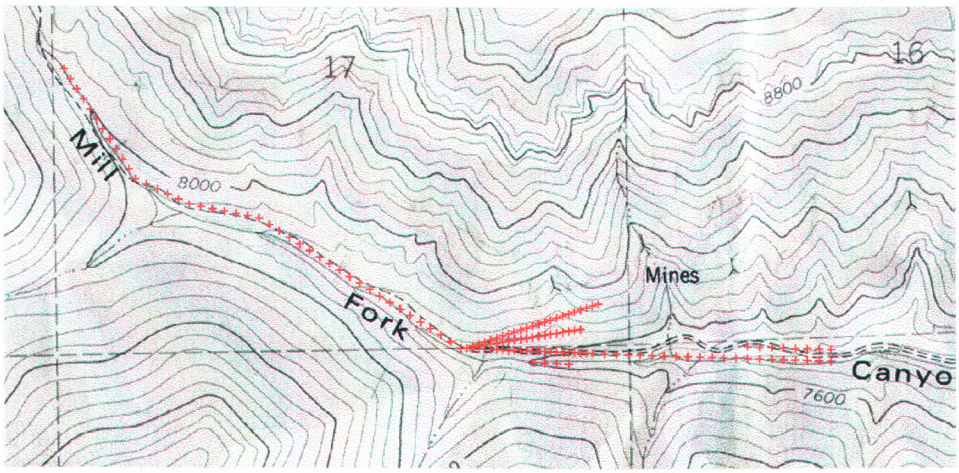


Figure 3 Stations for 1999 in Mill Fork Canyon.

Mill Fork Canyon is the farthest south profile in this survey. In Mill Fork Canyon there were two electrode set ups. The first electrode was set up where the water in Mill Fork Creek started to flow again. The second electrode setup was where the Mill Fork stream disappeared into the ground. Some survey stations were measured twice in Mill Fork Canyon using the different electrode arrangement. Figure 3 shows station locations in Mill Fork Canyon as red "+" .

Electrode Placement

Four electrodes were placed into the water around Little Bear Spring. Return or ground electrodes where placed in Mill Fork Creek to completes the circuit. The connecting wire was run down Little Bear Canyon across Huntington Creek then under the road through a drain pipe to the east side of the highway. The wire was then laid out along the highway to Mill Fork

Canyon where it was again put through a drain pipe to go under the highway. The wire then crossed the river and continued up Mill Fork Canyon to where the electrodes were placed in Mill Fork Creek. The wire was placed on the east side of the highway because there were no campgrounds or pull offs on that side of the highway, so that the likelihood of a camper or fisherman tripping on the wire was minimized. A map indicating wire position is shown as Figure 4.

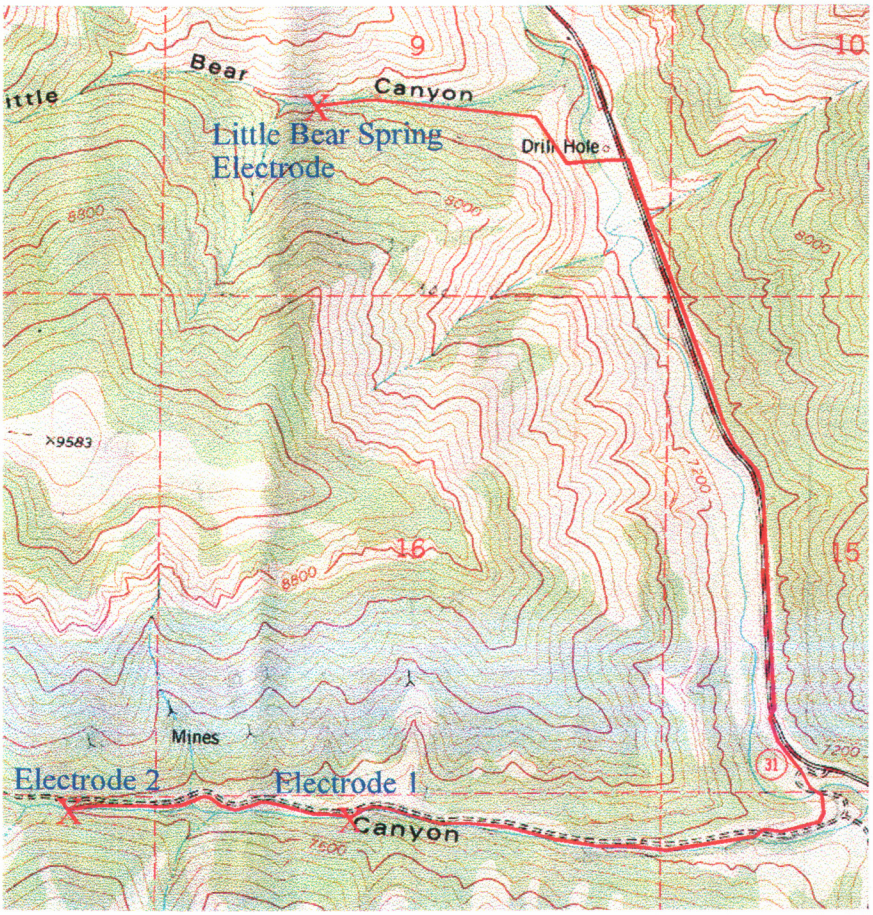


Figure 4 Location of electrodes and wire connecting the electrodes.

The return electrodes were placed in Mill Fork Creek to avoid the problem discovered in the 1998 survey where the signal bled off into Huntington Creek before it reached Mill Fork Canyon. The route described above posed the best antenna to see if the ground water source for Little Bear Spring intersected Mill Fork Canyon.

The first electrode setup in Mill Fork Creek was where the creek starts running again. It was thought that this is where the water resurfaced from where it disappears underground further up Mill Fork. The results of this survey indicated otherwise, and there were some anomalies in Mill Fork Canyon that needed further investigation. A second electrode configuration was needed, thus, the return electrode was moved up the Mill Fork Canyon about 1500 feet to where the water in Mill Fork Creek disappears into several small sinks.

The stations along the main survey line on Mill Fork Canyon road and trail were then re-occupied to obtain a second set of data, using the second electrode configuration, that could be compared to the data from the first electrode arrangement. Using this second set of data or readings, survey lines on the north and south side of the Mill Fork Canyon road were surveyed to obtain additional information about the primary anomalies in Mill Fork Canyon. It was

discovered after the data was reduced that the anomaly defining the main Little Bear Spring Structure was overlooked during the field survey. However a secondary source and possibly the only Mill Fork Canyon connection to Little Bear Spring was identified.

Grid Location

Because of the terrain a regular grid was impossible to establish. Lines were positioned where the terrain would permit. Whenever possible the lines were kept 100 feet apart. Near the end of the survey a couple of intermediary lines were run to better define the subsurface system. The station spacing was 50 feet along the line. The base station was located at the beginning of the lines in each canyon and on top of the ridge and then repeated as often as the survey permitted, usually at the beginning and at the end of the day. The station locations are superimposed on topographic maps shown in Figures 1, 2, and 3.

SURVEY RESULTS:

At each survey point, data was taken to allow the magnitude and direction of the magnetic field produced from the transmitter and antenna to be calculated. The data was analyzed using several techniques. The magnitude of the magnetic field is used to produce a contour map. The profiles were analyzed individually to gain additional insight into the subsurface channel configuration. The groundwater channel centers are obvious in this data, however in contour data, edges are a little more difficult to identify. The center and edges of groundwater channels are easier to determine on the profile.

Because of the overall area covered by the survey, there are three main areas that will be discussed individually; first, Little Bear Canyon; second, on top of the ridge; and last is Mill Fork Canyon. In each area the discussion will focus first at the contour data and subsequently the profiles and then vector models if used. The two or three types of interpretation will be used to corroborate each other and help the reader follow the interpretation process. The final map will be a composite of the information obtained from all forms of analyzing the data.

Contours

The contour maps used in this report are based on the maximum horizontal field. A standard contouring program, "Surfer" was used to generate the map. This program utilized a method known as "Kriging." Stations are marked with a small "+". Computer programs yield ambiguous results where there is no definitive data. Often it is best to ignore the contours in such areas. On the maps used in this report these contours have been removed.

Profiles

The profile interpretations in the report were created from the data set and do not indicate what order or how the data was gathered. The profile order is arbitrary, and was chosen to provide the details for the structures that needed to be studied. In the following sections the profiles are analyzed from north to south starting at Little Bear Spring.

The different colors used on the line or profiles in the maps that follow are to assist the reader. By using the different colors the various profiles can be individually identified where they overlap. On the maps data stations are generally shown in red "+". The exception is Little Bear Canyon where the 1998 stations are in red "+" and the new 1999 stations are in blue "+".

Little Bear Canyon

For additional data in Little Bear Canyon one "U" shape line was proposed for the 1999 survey. This line would cover area farther north, west and south of the 1998 survey. The positions on the map of the new 1999 survey stations can be seen in Figure 1 as blue "+". The positions of new stations in relation to last years stations can be seen on the contour map Figure 5 and on Figures 6 and Figure 15 with blue "+' for 1999 stations and red "+" for 1998 stations.

Figure 5 is the contour map of the results obtained in Little Bear Canyon when both surveys are combined. This map shows that the anomaly structure is trending in a southwest direction along the same course as indicated in the 1998 survey interpretation. The profile added in 1999 indicates that the anomaly to the north of the spring trends toward the northeast so that the continuation of source structure is a northeast direction instead of a northwest direction that the 1998 survey data indicated. The earlier interpretation was incomplete due to the inefficient data to the north. So the anomaly and structure to the north of Little Bear Spring is a

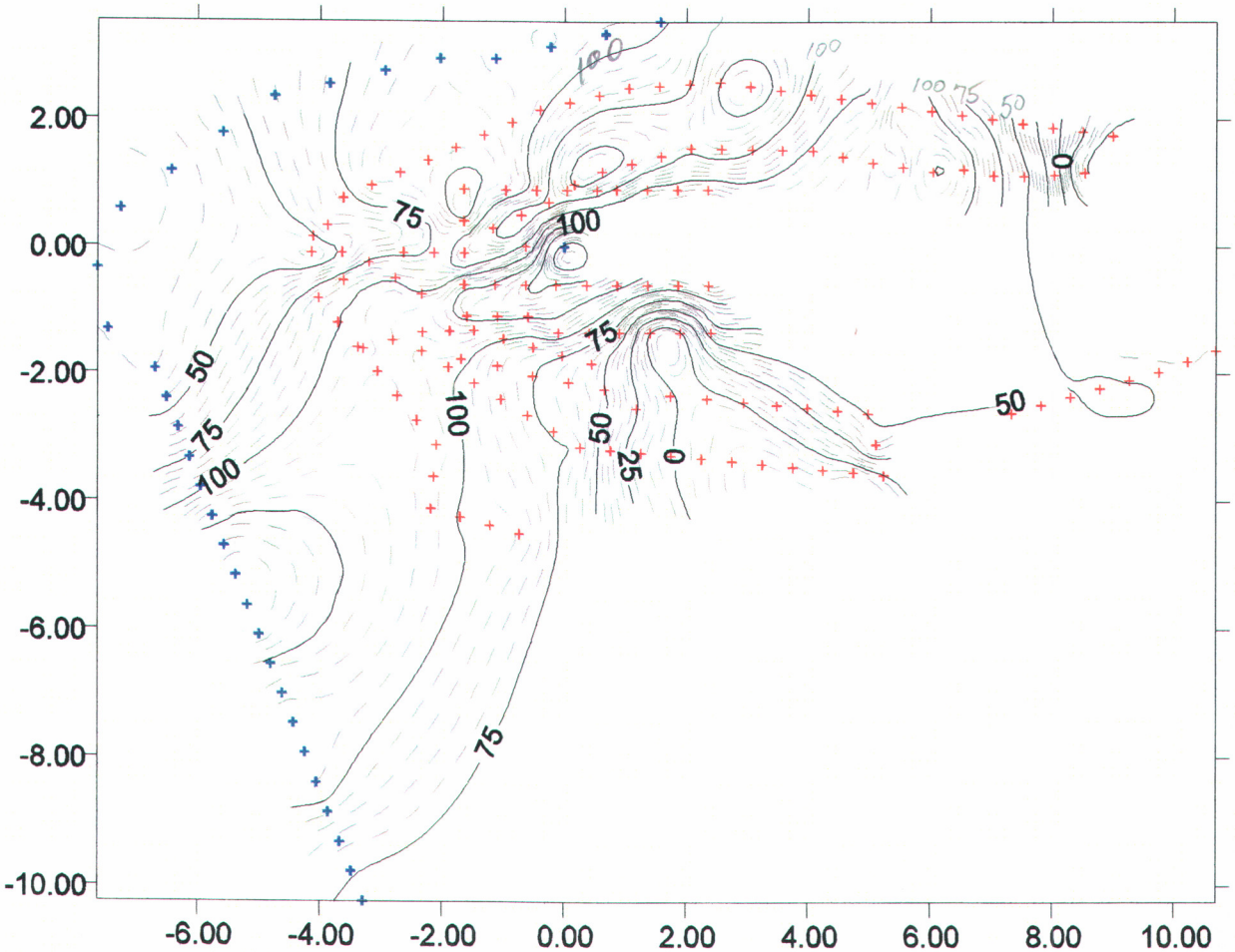


Figure 5 1999 Contour map of Little Bear Canyon. 1999 stations are blue. 1998 stations are red "+".

continuation of the anomaly and structure to the south of Little Bear Spring. Meaning that all the water in the system might not be coming out at Little Bear Spring. Some could be moving farther north along the fault system. An alternative possibility is that south of Little Bear Spring groundwater is moving north to the spring, and north of Little Bear Spring ground water is moving south towards the spring. However, elevations of structures and formations in the area tend to negate this second hypothesizes. The one sure fact is that Little Bear Springs water is coming from the fault system and associated underground structures shown in the final interpretation map at the end of this report.

Figure 6 shows the interpretations of the contour map and the profile data in the immediate vicinity of Little Bear Spring. The yellow dotted line is the projected line of the fault that the groundwater feeding Little Bear Spring is following. The center of the anomaly outlining the groundwater is shown with a dark blue line. The area affected by the groundwater is shown in blue with the affected edges outlined with purple dotted lines. The black dotted lines are the fault lines indicated on geologic maps. The grey lines on Figure 6 are formation contacts. These are used as reference points since they are found on geologic maps and are referred to in the 1998 report. The light brown areas are tight formations with no water. These areas are discussed in the 1998 report.

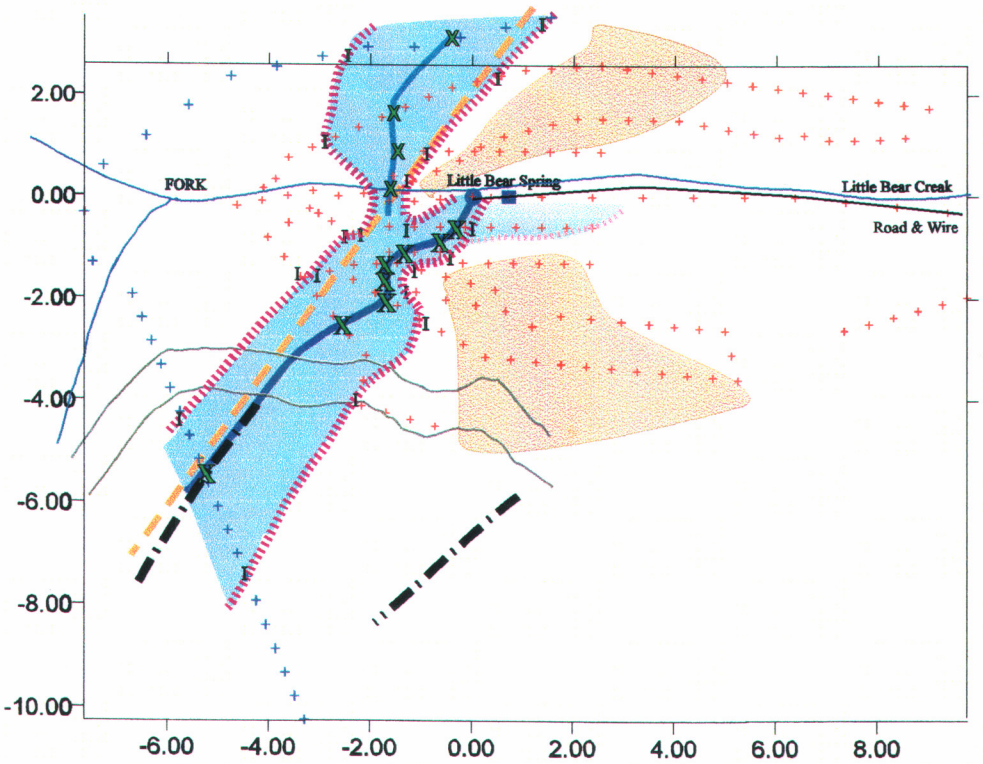


Figure 6 Interpretation of Little Bear Canyon Contour map.

Shown in Figure 6 is the center of the anomaly mapping the groundwater (dark blue line) which follows the fault line projection (yellow dotted line), with the exception of the area around the spring. There is a little detour in the path of the water where the path turns to the east and flows towards the spring.

West of the spring some of the groundwater could turn north and continue along the line of the fault projection. The least likely possibility is that groundwater is feeding Little Bear Spring from both the south and the north, that all the water from both directions comes out of the spring.

Figure 7 is the "U" line profile in Little Bear Canyon. This line starts on the north side of Little Bear Canyon with station 0. The line continues westward to Little Bear Creek. It then crosses ~~across~~ the creek and proceeds up the hill toward the southeast ending at station 22 on the south side of Little Bear Canyon, see Figures 1 and 7. Little Bear Creek is located between stations 9 and 10. This profile shows anomalies in two places. The south side anomaly is between stations 14.5 and 18. The readings show no anomaly to the west of the spring supporting the data gathered in the 1998 survey and the conclusion that none of the water from Little Bear Spring is coming from Little Bear Creek. On the north side of the "U" the readings increase again showing another anomaly. However, when the new data is added to old data, the trend of the anomaly and fault controlling the groundwater on the north side of Little Bear Canyon is in a northeast direction, instead of trending in a northwest direction as the 1998 data indicated. The 1998 data only identified a local structure north and west of the spring. With the addition of the 1999 data, the trend is that the groundwater both north and south of Little Bear Spring is associated with and controlled by a long fault. The southern extent of this fault was previously mapped on the surface. The northern extent of the fault has not been mapped on the surface. It could be that the fault has only a weak surface expression north of Little Bear Spring or the geology has not been mapped in detail north of Little Bear Spring. Thus indications are that primarily the groundwater feeding Little Bear Spring is controlled by a single fault line trending from the north east to the south west. The projected continuation of the fault line through the canyon is shown in Figure 6. The line indicating the center of the anomaly defining Little Bear Spring feeder system overlay the fault zone both in position and direction.

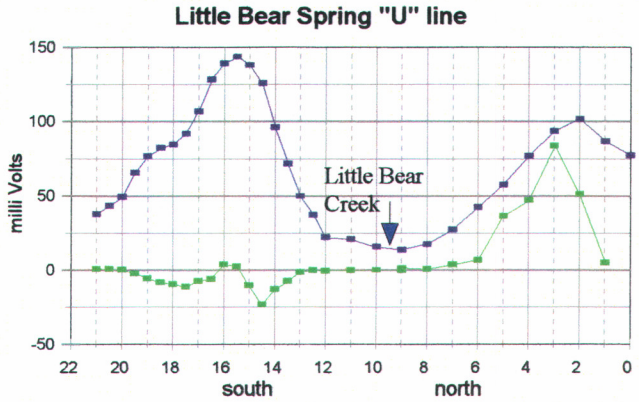


Figure 7 Little Bear Canyon "U" line/profile.

Top of Ridge

Figure 8 is the contour map of the data collected at the top of the ridge in 1999 between Little Bear Canyon and Mill Fork Canyon. The yellow dotted lines in Figure 8 identify the centers of the anomalies. Meaning that at those points the electrical current is flowing directly below these survey lines. There is one main anomaly on the contour map with two additional smaller anomalies. The strengths of the anomalies are partially controlled by where our return electrode was placed. The largest anomaly on this map is the leg of the upside down "Y" starting at station 6 on the bottom of Figure 8. This anomaly trends to where the water disappears into a series of small sinks in Mill Fork Creek. This is the strongest anomaly on this contour map because the return electrode was probably connected to a collateral groundwater source that is feeding Little Bear Spring. This will be further explained in the Mill Fork Canyon interpretation.

The second largest anomaly, by the magnetic reading, is the long leg in the "Y" anomaly in Figure 8. This leg, alines with the mapped fault line indicated in 1998 survey and now in the 1999 survey as the structural source primarily feeding groundwater to Little Bear Spring. This is easily seen on the final interpretation map at the end of the report. On the final interpretation this fault system and the groundwater system feeding Little Bears Spring is indicated by a pink dotted line that traces the fault line. The data defines this path as the main source of the water feeding Little Bear Spring.

The third anomaly is over to the east, starting at station 14 on Figure 8. This anomaly is a separate water feature from the Little Bear Spring. This anomaly is also associated with another mapped fault line. This anomaly has weak magnetic readings indicating it is small, but there is enough current accumulating in this structure from current leakage through the ground that there is some water or moisture associated with this fault.

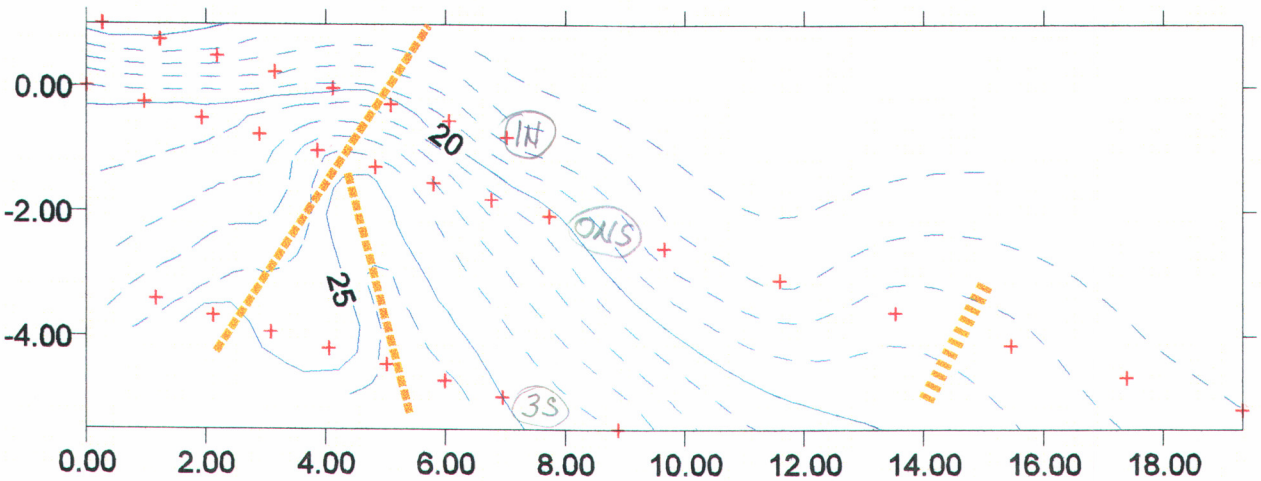


Figure 8 Contour Map of the top of the ridge between Little Bear Canyon and Mill Fork Canyon.

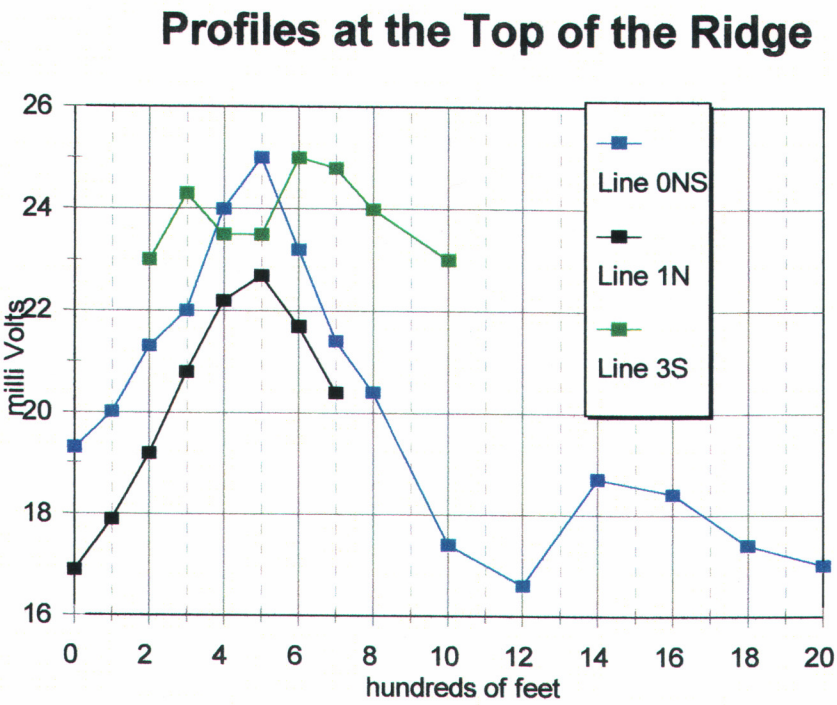


Figure 9 Top of ridge profiles.

Figure 9 is the graph for the profiles on top of the ridge. This graph indicates that on line -3N there are two anomalies close together. One at station 3 and the other between stations 6 and 7. Line 0NS the graph shows two anomalies, however the larger anomaly centered at 5 covers the same area as the two anomalies on line -3S. This anomaly is larger than each of the two on line -3S, this indicates that the two anomalies have become one anomaly at this point. This supports the data seen in the contour map of the "Y" shaped anomaly and gives an angle of the leg of the anomaly at stations 6 and 7 on Line -3S.

The second and smaller anomaly on Line 0NS centered at station 15 lines up with a mapped fault line and shows no indication of being connected to the Little Bear Spring anomaly.

Line 1N supports the conclusion that there is only one anomaly in the area between stations 2 and 7 centered at station 5. One anomaly in this area indicates that the two anomalies in line -3S did merge into one anomaly and that both are feeding groundwater to Little Bear Spring.

Figure 10 is the vector model for the data from on top of the ridge. There

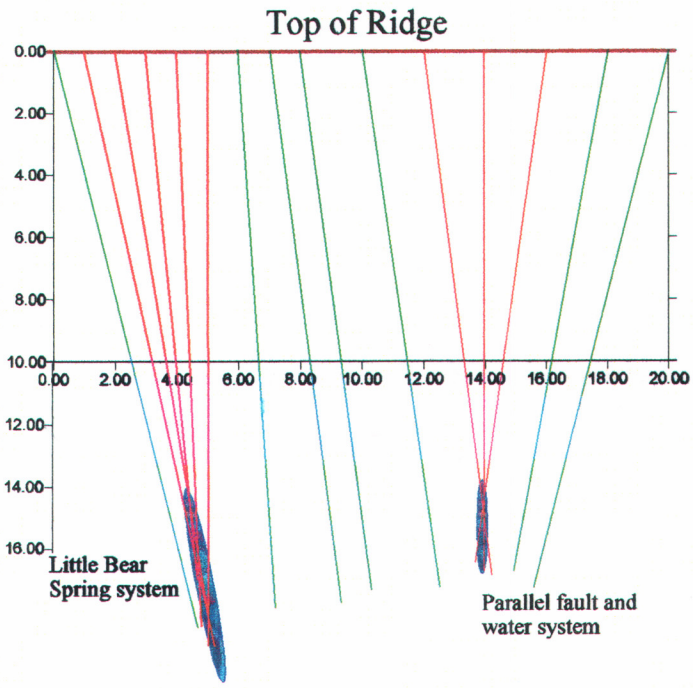


Figure 10 Vector models for the top of the ridge.

was little elevation change along the profile, and the anomalies on top of the ridge were distinctive enough that they lent themselves to vector modeling. This vector model was included in the report to support the profile data that the two fault systems are separate and that the small anomaly seen on line 0NS at 14 is not connected to the large anomaly at station 4, which is the structure feeding Little Bear Spring, in this area of the survey. The vector models also indicate approximately how deep the anomalies are. The top of the ridge is about 9400 feet. The highest point at which the vectors cross on the Little Bear Spring system is 1650 feet below the surface or at an elevation of about 7700 feet. Moving away from the center vector, the other vectors continue to indicate closure at ever increasing values. The range where the vectors cross is between 1650 and 1850 feet, that puts the top of the water just between about 7500-7700 feet in elevation. It should be pointed out that the vector models will indicate an average ~~the~~ depth for structures that are planer in nature, and usually yields values that slightly are deeper than the top of the water. Thus, the depth to the top of the water could be as high as 7800 feet.

Mill Fork Canyon

The data for Mill Fork Canyon was measured using two separate electrodes. The reduction of the data involved two extra mathematical steps so the two sets of data would be compatible. This section will explain each of the procedures and what they were designed to compensate and model.

The first correction is a standard correction that is applied to all data. This correction is to account for the fall off of current as it spreads out from an electrode. In a homogeneous earth the current would spread out evenly and as it is spreading from a point its effect is circular. The larger the circle the more the current is diffused. Thus, to ascertain the true nature of the medium, a circular correction must be made. The circumference of the circle is 2π times the radius. Since the factor 2π is a constant, it does not change regardless of how big the circle is, but the radius is larger for larger circles. Thus, the current is less by a commensurate amount. Therefore, to correct for the spread of the current from a pole, the magnetic field measured at the station must be multiplied by a factor related to the distance the station is from the pole. This is a standard correction that is applied to all such data.

The second and third corrections are only used to combine and correlate data collected at the same stations using two or more separate electrodes. The second correction can be best explained by visualizing what would happen if a current carrying wire was not covered with insulation and was laying on the ground. The electrical current would gradually leak off to the ground. Because the wire is a better conductor, the current does not leak all at once, but rather it would gradually leak off along the length wire until it crossed a good conductor in the ground. At the good conductor all the current would be shorted to ground.

This is what happened in Mill Fork Canyon. The first electrode in Mill Fork Creek was placed in that part of the creek where the water starts to flow again after disappearing under ground further up the canyon. This electrode position is labeled electrode one. It was determined by reducing the data from the electrode one, and during the field survey, that the current from electrode one energized a groundwater for a system that is different than the Little Bear Spring system. However, part of the current followed the groundwater in Mill Fork Creek up the canyon to where it reached a connection with the Little Bear Spring system, so only part of the Little Bear Spring system was mapped. The location of this connection is the small sinks where Mill Fork Creek disappears into the ground. Thus, a second electrode position was established in Mill Fork Creek in these sinks that are about two to three-foot in diameter and about a foot deep where the water disappears into the ground. This electrode setup is and has been referred to as

electrode setup two. Electrode two turned out to be in a secondary interconnection to the Little Bear Spring system. The effect of current flowing from these connections is analogous to the bare wire analogy above, and the corrections that need to be made to the data for this situation are straight forward. The correction is the slope of the signal fall off as measured in the data. This represents the rate at which the electrical current is being bled off from the current flowing up Mill Fork Creek's groundwater system. A simple straight line approximation of this slope was thus subtracted from the data to make the second correction see Figure 11.

Figure 11 has been corrected for the radial effects as explained above. The corrections needed for the current bleed off are shown in this figure as sloping lines paralleling long strings of data for both electrode one and electrode two in Mill Fork Canyon. The downward slope of the readings from right to left is caused by signal bleed off. The orange line for electrode two and the brown line for electrode one show the area that needs to be corrected for the far field bleed off effects. The red line on electrode two and the grey line on electrode one show the area where corrections are needed for the near field bleed off. The near bleed off is the area between the electrode and a certain point where the current bleed off is high. Once the current reaches that zone the amount of current bleeding off changes. The current loss is less under these conditions when measured over a given length or distance. The point at which the bleed off changes from near to a far field bleed off is usually associated with an anomaly that represents a high conductive zone.

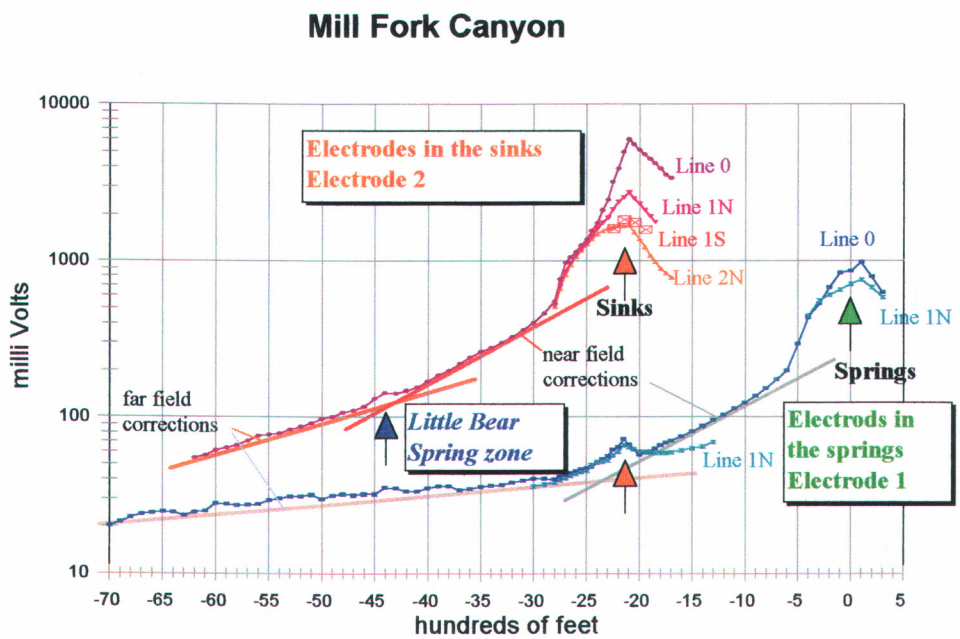


Figure 11 Radial Corrections for Electrode setups 1 and 2.

Figure 12 is the data interpretation for the electrode one setup showing the progression of data as the corrections have been made for the near and far field current bleed off. The electrical current bleed off is the second correction made to data that is explained above. Electrode one

setup is when the electrodes were placed in Mill Fork Canyon where the water resurfaced in Mill Fork Creek. All three lines in Figure 11 show the same set of data readings, but are for different corrections; the radial correction, the far fields bleed off correction and the near field bleed off correction.

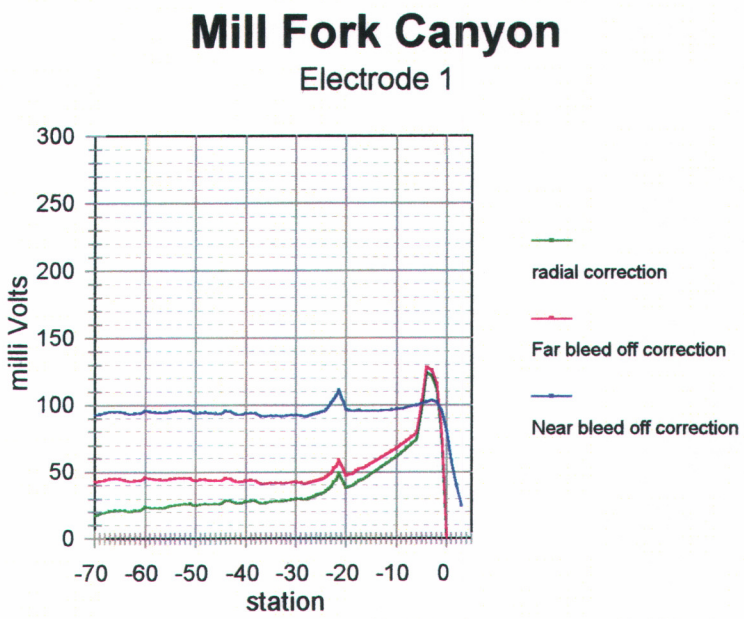


Figure 12 Electrode 1 setup Mill Fork Canyon data

There are two anomalies seen on Figure 12 the first is at station 3. Notice how once the near field bleed off is corrected for, the anomaly centered at station four nearly disappears. This indicates that this anomaly is not part of the Little Bear Spring system. It still is an anomaly / water source, but if it had been connected to the Little Bear Spring system it would not have drastically changed once the data had been corrected for a near field current bleed off.

The second anomaly shown for electrode 1 in Figure 12 is a smaller anomaly at station 21. This anomaly is directly connected to the Little Bears Spring system. This is evident in that it did not disappear or decrease in size with all the corrections made. This anomaly is located where the electrodes were moved to for the second electrode setup.

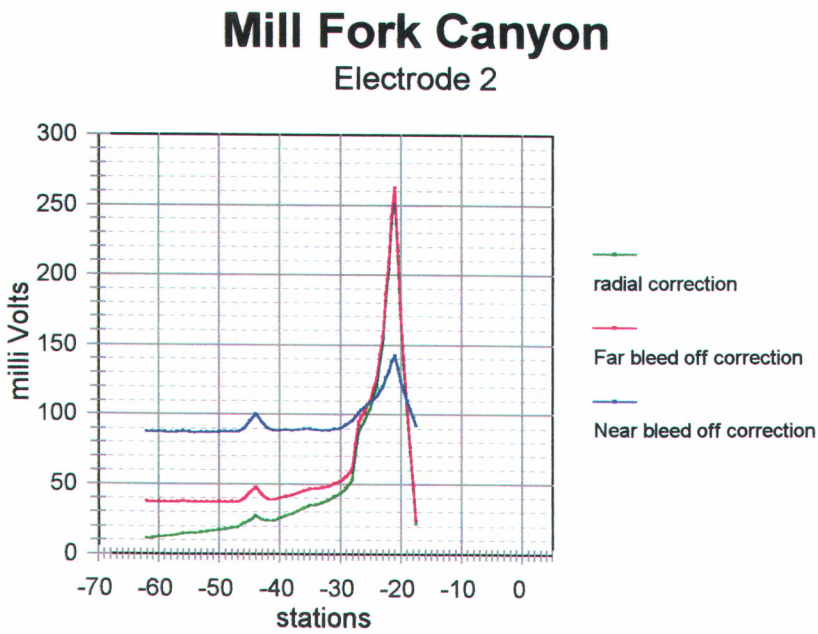


Figure 13 Electrode 2 setup Mill Fork Canyon data

Figure 13 is the data interpretation for the electrode two setup showing the progression of data as the corrections for the near and

far current bleed off have been applied. Electrode two setup is where the electrode was moved about 1800 feet west, up Mill Fork Canyon to where the water disappeared into some small sinks in the Mill Fork Creek.

There are two anomalies for the Electrode 2 setup, however there is only one anomaly that is the same from one electrode setup to the next. That anomaly is located at station 21. This anomaly is where Mill Fork Creek disappears into some sinkhole and stops flowing along the creek bed. This anomaly is directly connected to the Little Bear Spring system. This location is the only sure connection that is indicated by the data where Mill Fork Canyon water is feeding Little Bear Spring. However, it is not the only anomaly indicating the system that is feeding Little Bear Spring on the Mill Fork Canyon profiles.

The second anomaly seen in Figure 13 for the Electrode two setup is the Little Bear Spring System. The data indicates two ways that this anomaly is the Little Bear Spring System. The first indication is that this anomaly does not disappear or decrease in size with the bleed off corrections. The second, is that this anomaly lines up on the map with the fault line that is feeding Little Bear Spring.

This smaller anomaly at station 44 indicates where the fault defining the Little Bear Spring System is energized by electrode two. This anomaly was energized by two round-about ways. First, by current leaking through the ground, and second, current following the creek from electrode two through the water to where the smaller anomaly at station 44 connects to the Little Bears Spring system or fault structure. Substantial water may be entering the Little Bear Spring system at or near station 44, or it may not be entering at that point. The fault system is close to the surface but the stream does not stop flowing. There may be only thin cracks or breaks in the rock that impede the flow of water but still sufficient to establish an electrical connection.

The fault system feeding Little Bear Spring is connected to Mill Fork Creek at one known point. This connection is directly under the top of the ridge. This connection point can be seen in the top of the ridge profiles Figure 9 and on the top of the ridge contour map Figure 8.

The third correction had to do with relative signal strength. This was calculated by comparing the maximum signal measured at station -19, the main survey line running along the road of Mill Fork Canyon, for both electrodes after the first two corrections were made. The difference between these two readings was applied as a normalizing factor for the third correction. This normalizing factor was applied to all the data measured in Mill Fork Canyon. This type of correction is referred to in the literature as normalizing. The data values shown in Figure 14 are

for the Mill Fork Canyon lines subsequent to the above corrections,

Figure 14 shows only the data along the center profile in Mill Fork Canyon for both electrodes one and two after the normalized correction. Notice that the first unconnected anomaly at station 3 still appears but it is very weak.

In order to normalize the data from electrode one to electrode two the average background value of both profiles had to equal zero. Then a multiplication factor that would make the value of station number 22 for electrode 1 equal to the value of station 22 for electrode 2. This factor

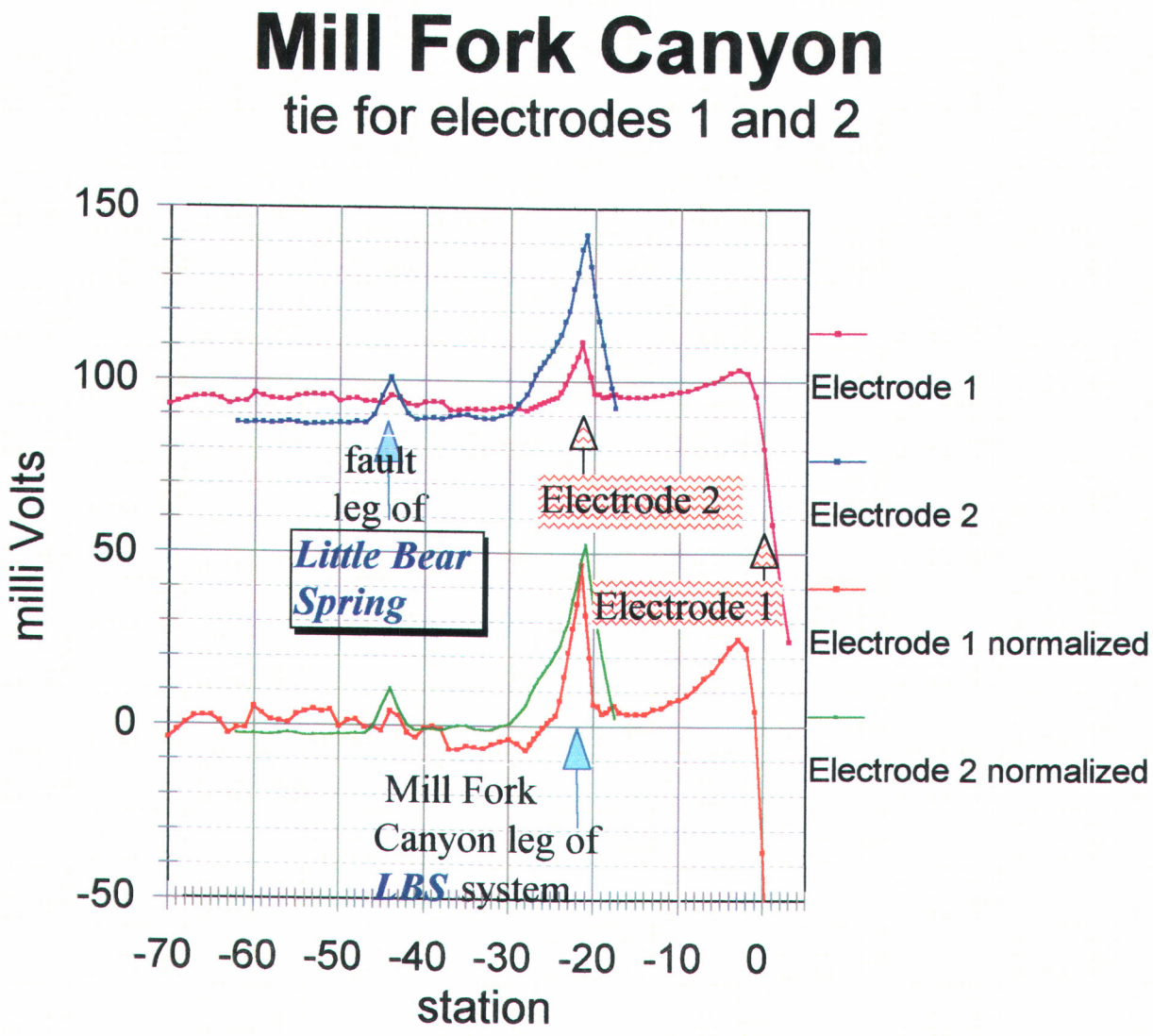


Figure 14 Data normalized for Electrodes setup one and two in Mill Fork Canyon.

was found to be 2.7, which indicates that electrode two has about three times better connectivity to the Little Bear Spring System than electrode one. This would indicate that electrode setup two was connected directly into the Little Bear Spring system where electrode one was not directly connected to the Little Bear Spring system by dispersed groundwater.

The connection of the small sinks in Mill Fork Canyon to the Little Bear Spring system is very strong in both electrode setups. This is because it is possibly the only direct connection in Mill Fork Canyon to the Little Bear Spring system. From the topographic map the elevation of the small sinks in Mill Fork Canyon are about 7600 feet, and the elevation of Little Bear Spring is about 7475 feet.

The normalized data still indicates on Figure 14 the fault controlling the groundwater for Little Bear Spring crosses the Mill Fork Canyon profile at station 44. The data does not indicate a direct connection to Mill Fork Creek at this location. The elevation of Mill Fork Creek where the Little Bear Springs controlling fault crosses at this location is about 7800 feet.

Combined Interpretation

Figure 15 is the interpretation map of all three survey areas combined, Little Bear Canyon, the top of the ridge, and Mill Fork Canyon. Seen on this map is the projected line of the fault that is the dominant and controlling structure for the groundwater feeding Little Bear Spring. This projected line is a dotted pink line which continues past the mapped fault line to the north and follows the fault line to the south. This line indicates where the fault and the Little Bear Spring feeder system passes through Little Bear Canyon, the ridge top, and Mill Fork Canyon.

In Little Bear Canyon this structure is the main water conduit for the spring. The 1999 data supports and strengthens the 1998 data and interpretation. The data collected in 1999 indicates that the fault line continues past Little Bear Spring to the north east. The new data strengthens the hypotheses that this fault structure forms the small cavities, gaps, and other opening along this fault that controls and channels groundwater to Little Bear Spring.

The data taken on the top of the ridge indicates that this fault system is still the primary structure for the groundwater moving to Little Bear Spring. However, there is another structure interconnecting with the fault structure under the ridge that adds groundwater to the Little Bear Spring system. This side leg combined with the main fault structure is seen on Figure 15 as a pink dotted line. Based on anomaly strengths and trend directions, there is a high probability that the water in Mill Fork Canyon disappearing into the small sinks connects and enters the fault controlling the Little Bear Spring groundwater system under the ridge top below where the ridge top survey was conducted.

The most prominent anomaly in Mill Fork Canyon in the field data is located at station 22. This area was thought to be the main connection at the time of the field survey, so survey lines were added on either side of Mill Fork Creek in this area. It was not until all corrections were made to the data that it was realized that the fault structure supplying water to Little Bear Spring crossed under Mill Fork Canyon further to the west. The crossing of Mill Fork Canyon is indicated by the anomaly at station 44. The location of station 44 is concurrent with the continuation of the fault structure supplying water to Little Bear Spring. This would indicate that water is also entering the Little Bear Spring system south of Mill Fork Canyon, and is flowing to Little Bear Spring via this fault system.

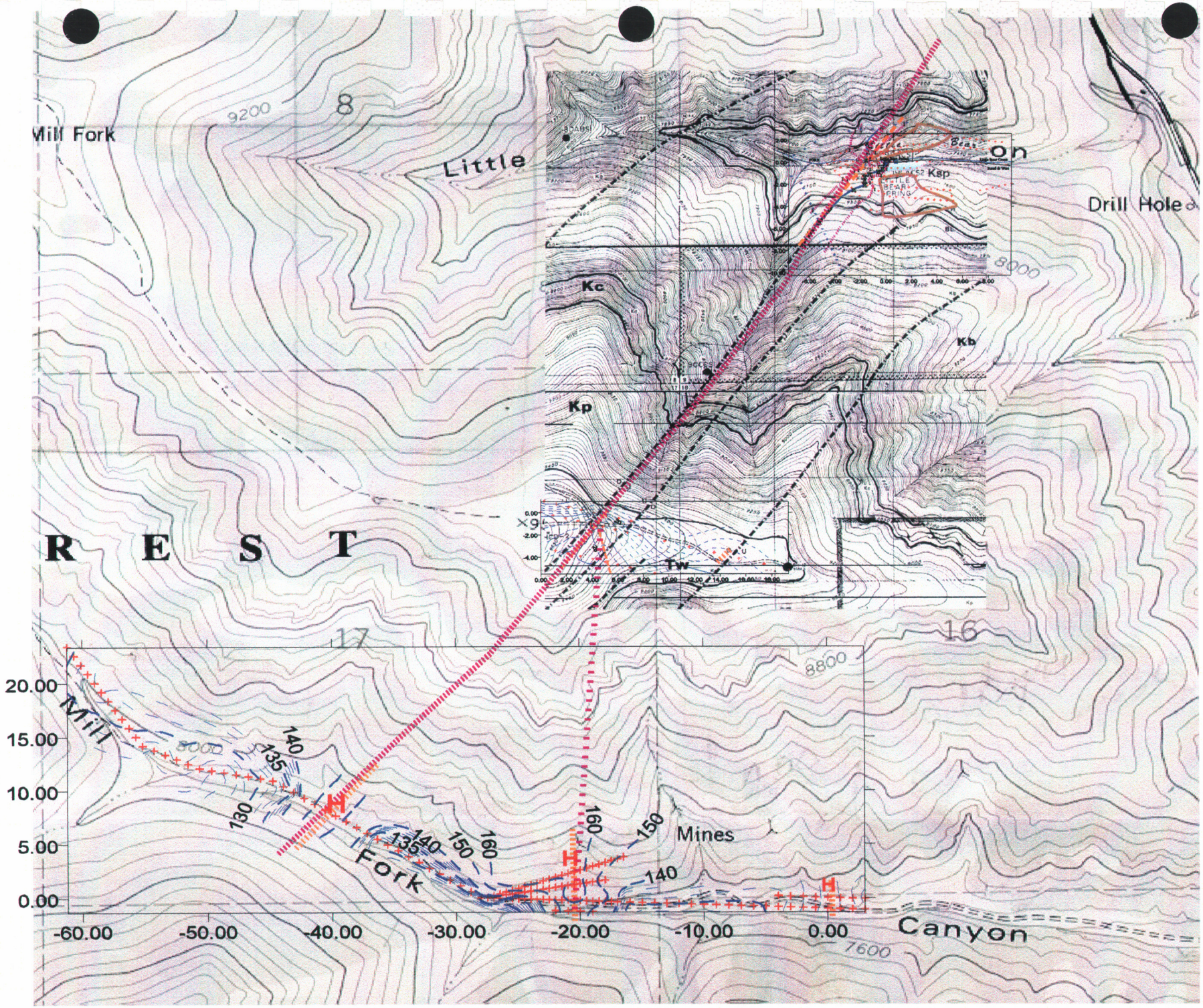
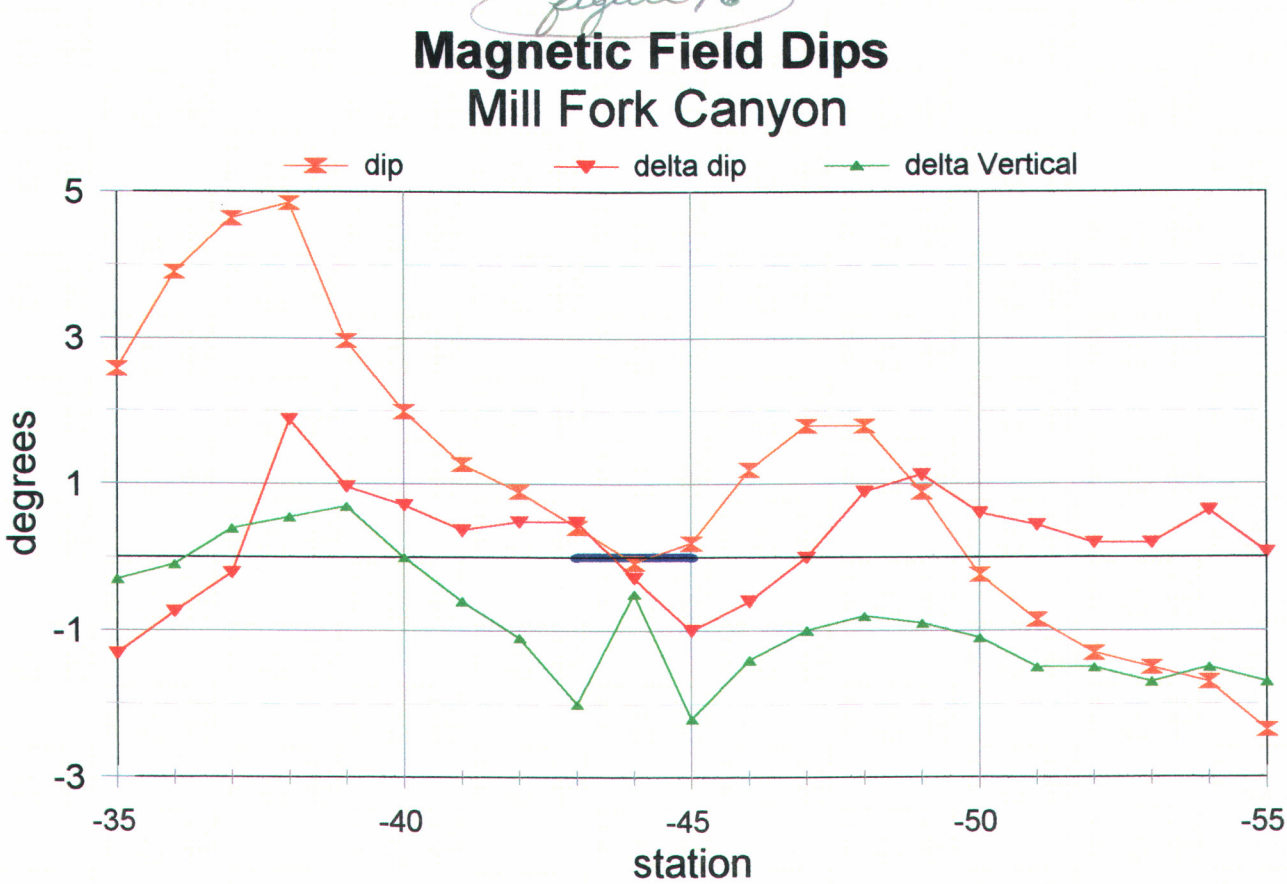


Figure 15 Combined surface interpretation map of the AquaTrack data.

The data in Mill Fork Canyon in the vicinity of station 44 was examined in detail in an attempt to determine the depth to water. The vector model indicated that the station spacing was too large to use this modeling technique. The limits for this type of model are the station spacing plus or minus a half of station spacing. The station spacing was 100 feet, thus the deepest the subsurface water could be at this location is about 150 feet. The model provides no information on how shallow the water might be.

Figure 16 is a plot of the magnetic field dip (dip, orange), rate of change of the dip in the horizontal direction (delta dip, red), and the rate of change of the vertical field along the profile (delta Vertical, green). Each of these indicates a different effect on the magnetic field due to the subsurface conductor. Between stations 38 and 43 the dip is positive indicating that a conductor is ahead, the dip from station 45 to 48 is negative indicating a conductor behind, and the dip at station 45 is zero indicating a conductor below. However, the dip does not show convergence on station 44 from stations 43 and 45. This indicates that the spacing was too large for the depth of the conductor. The delta dip does cross over from positive to negative values as they should if a conductor has been crossed. The delta vertical also starts into a low with a peak in the center of the low as seen at station 44. This is also indicative of a shallow conductor and that station spacing too large to determine the precise depth of the shallow target. The blue line along zero indicates the area within which the fault could cross Mill Fork Canyon, and the highest probability is very close to station 44.

figure 16



Mining in Mill Fork Canyon

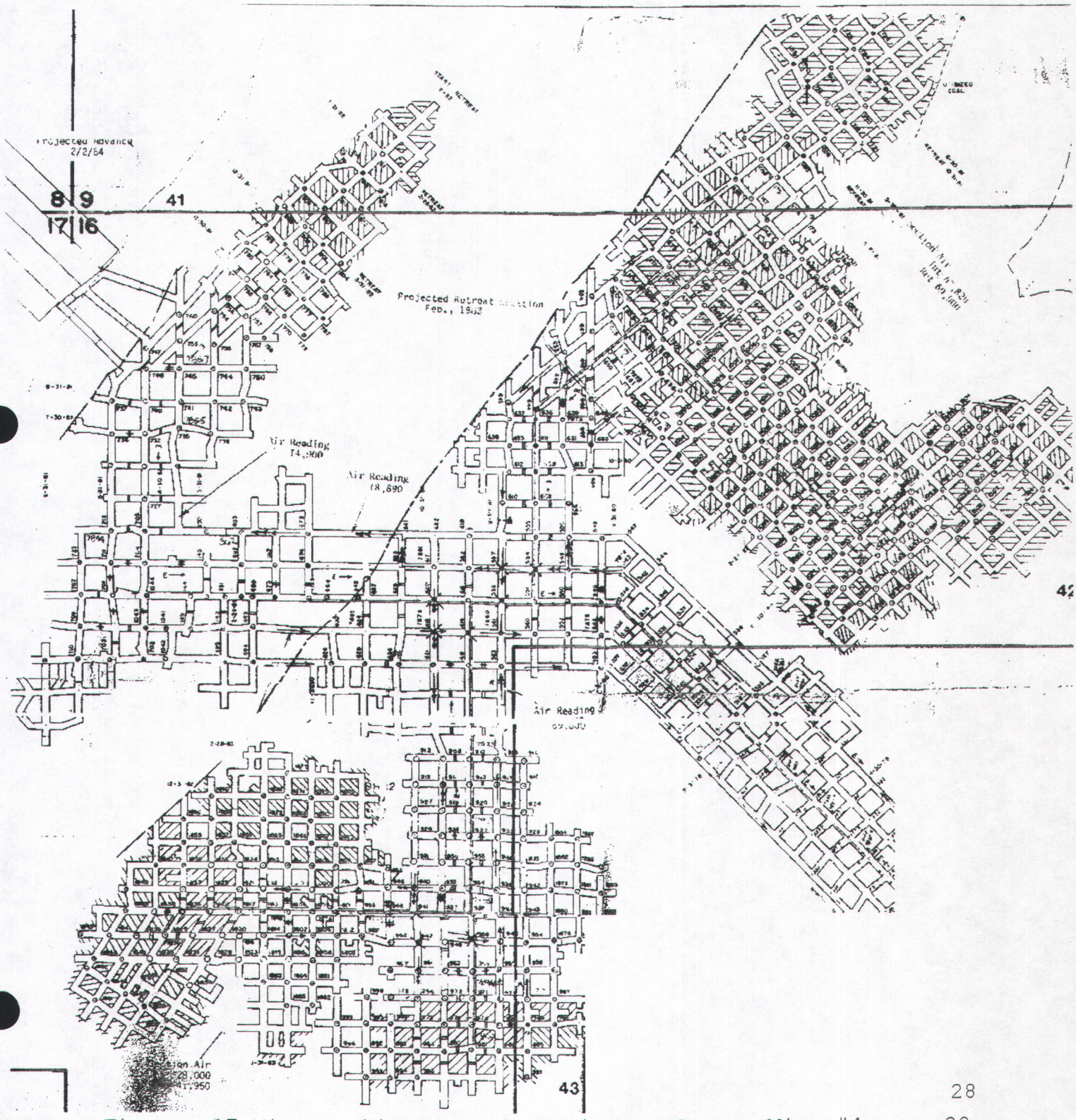
The representative of Pacific Corp. made the observation that this report did not include data from a coal mine that had operated in Mill Fork Canyon. His comments are included in the following box.

> As point in the fall of 1998 (Emery County Public Lands meeting), the preliminary interpretation was hampered by not including historic coal mine data from the Huntington Canyon #4 Mine. The 1999 interpretation again fails to include mining history from the #4 Mine involving the Mill Fork Fault crossing. A review of the mine maps reveal coal horizon (Blind Canyon Seam) at approximately 7840 feet in the area of the Mill Fork fault crossing. As stated by ARCO mine geologist, "only minor occurrences (damp areas) of groundwater were encountered within the Mill Fork Fault system." Mining occurred within approximately 2500 feet of Little Bear Spring without any documented alternations in flow.

As a consequence the data relating to Mine #4 was provided by the Department of Oil, Gas and Mining. Maps of the old workings were provided as well as comments by the Mine Engineer. The box insert below contains comments made by Dan Guy, the Mine Engineer at Huntington Mine #4, to Ken Wyatt the first of February 1999.

> Summary of Notes form February 1, 1999. Discussion of Ken Wyatt with Dan Guy, Mining Engineer, Previously with Beaver Creek Coal Company.
>
> RE: In-mine water at Huntington #4 Mine
>
> **In Mine Water**
>
> I talked with Dan Guy on Feb. 1, 1999 about in mine water interception at the Huntington #4 Mine. He indicated that the mine intercepted very little water as they crossed the first fracture associated with the Mill Fork Graben system. The fractures shown on the maps were derived from exploration drill holes and outcrop data. There were no igneous dikes. Fluvial sand channels were encountered.
>
> As they approached the second fracture in the mine, they did not receive much water but did notice the area was oxidized. Water that was entering the mine came from the floor and not the roof or fluvial sand channels. It was wet enough to make operations messy and they did decide to re-work the sediment pond to receive the extra mine water.
>
> **Mill Fork Creek**
>
> Discussions about Mill Fork Creek. He indicated that there is a losing section of stream. Above the mine the stream "flowed like hell" but 100 yards below the switch back the stream would be dry.

Figure 17 is a portion of the mine working map in the area of interest for this survey. It shows spot elevations and fault locations. These values have been transferred to Figure 18.



Figurer 17 Mine working map of Huntington Canyon Mine #4

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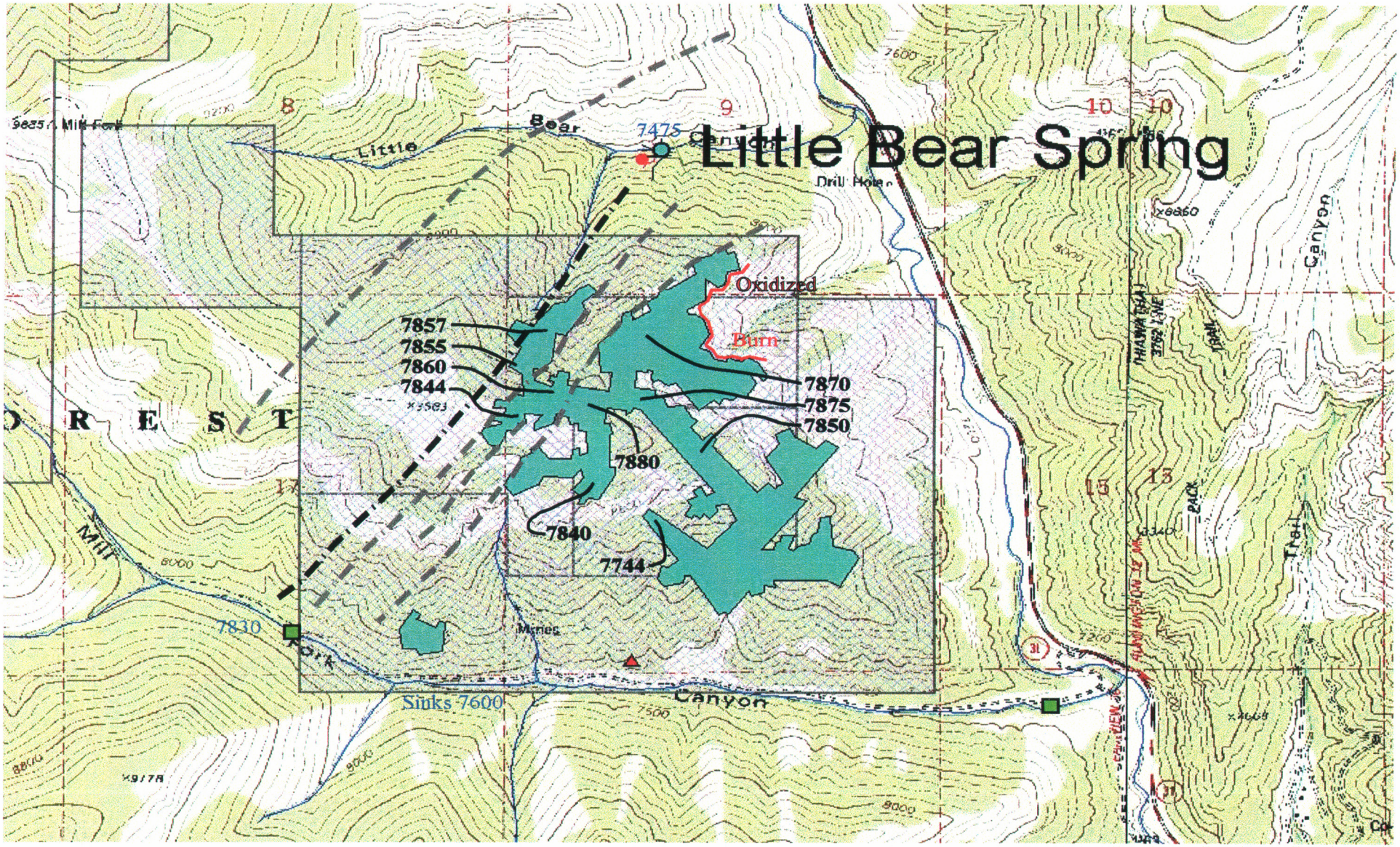

Figure 18 Topographic map showing the mine working for Huntington Canyon #4 Mine with elevations of the old workings.

Figure 18 is a portion of a topographic map between Little Bear Canyon and Mill Fork Canyon. Superimposed on this topographic map is an overlay of the Huntington #4 mine workings (dark green). Also, included are the fault locations. The Faults are shown in gray except for the fault controlling water feeding Little Bear Spring, and that fault is shown in black on Figure 18.

The elevation of Little Bear Spring, the elevations where the fault controlling water feeding Little Bear Spring crosses Mill Fork Canyon, and the elevation of the small sinks into which Mill Fork Creek disappears are shown in dark blue on Figure 18.

The information shown in the previous figures was used to generate a cross sectional view of the system along the fault that controls the water feeding Little Bear Springs. This cross section is Figure 19. The surface is shown as a green line, The location of the mine workings is shown in gray and black. The gray is behind the fault and the black represents that part of the old mine workings that cross the fault.

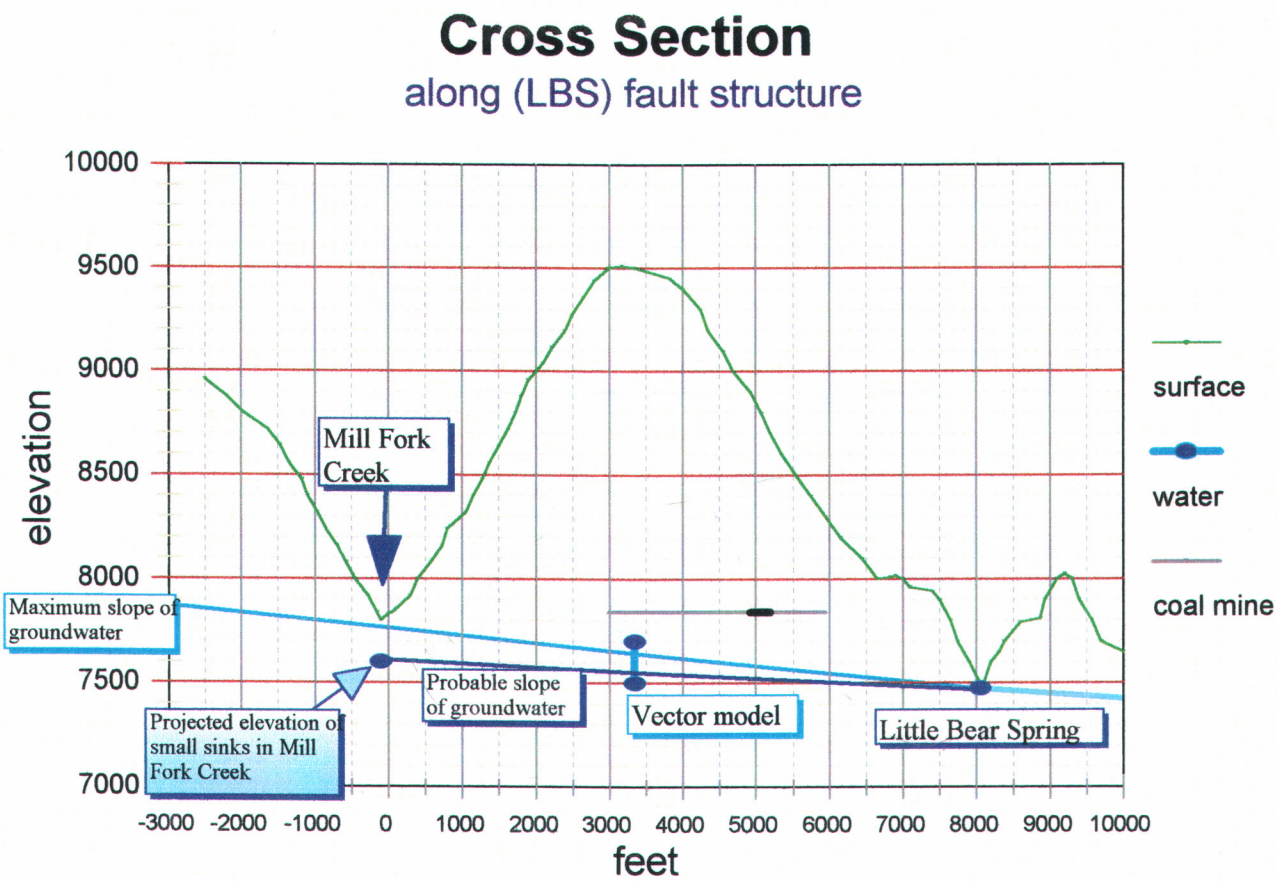

Figure 19 Cross section along the fault that controls the water feeding Little Bear Spring.

Two hydro levels are shown in the cross section. The darker blue is based on the water entering the small sinks, and reemerging at Little Bear Spring. The lighter blue line represents the maximum slope of the hydrostatic head feeding Little Bear Spring. Both of these levels agree with the data from Huntington Mine #4 and the vector model for the top of the ridge. The mine engineer indicated that only a limited amount of water entered the mine when they cross the fault of interest and then what water did enter the mine came from the floor. All these facts indicate that the hydraulic surface is relatively flat dropping a maximum of 150 to 200 feet in 8000 feet horizontally. The rate of flow with this flat of a hydraulic surface would indicate that the entire system is very open with good inter-connectivity. It will be reiterated here that the openings could be called "cave" like but this does not mean large openings. The voids are more on the order of a couple of feet at the most and any void would look very much like the pock marks created by wind and water on the exposed cliffs. The difference would be that the sand would stay in place rather than be removed. Additionally the fault could have elongated places where the walls do not touch. These spacings could range from an inch to a foot or two. But the elongated inter-connected nature of these small openings create a type of cave structure, even though the cavern or open spaces would generally be too small for a human to enter.

If the hydrological surface was sloping greater than the light blue line the water would create a spring in Mill Fork Canyon at about the location of station 44, and possible springs rather than sinks further down Mill Fork Canyon at about station 19 or 20. The dark blue line is the more likely hydrological level, and this would place the water level about 150 feet below Mill Fork Creek at station 44. This provides good agreement with the mine data, the models created by the magnetic data, and what is required hydrologically by where water is entering and exiting the system. The sinks are at about 7600 to 7625 feet and Little Bear Spring is at about 7475 feet for a difference of about 125 to 150 feet. The floor of Mill Fork Canyon where the fault crosses the canyon is about 7830 feet. This is 200 to 225 feet higher than the elevation of the sinks. The ground water at this location could not be deeper that about 150 to 200 feet based on the magnetic data. The water could not be closer to the surface than about 100 to 150 feet or there would be enough head to force water out of the small sinks in Mill Fork Creek. The most logical depth to water in the fault where it crosses under Mill Fork Canyon is about 150 feet plus or minus 50 feet. This yields a slope for the hydrological surface that is an average of the two shown in Figure 19.

RESUME'

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EDUCATION

University of Phoenix, Salt Lake City, UT MBA course 1985 & 1986
Leeds University, Leeds, England. Geostatistics. March 1974
University of Utah, Salt Lake City, UT. Ph.D.; Major Geophysics, minor Geology. June 1973.
Weber State College, Ogden, UT. B.S.; Major Physics, minor Math. Cum Laude. June 1965.

WORK EXPERIENCE

Private Consultant Jan 1999 - Present
Hydrology - groundwater mapping.
Developing new technologies related to subsurface waters.

Water Technologies and Research April 1999 - Present
Chief Scientist
Responsible for all research and development

Weber State University Sept 1997 - Sept 1999
Adjunct Research Professor of Physics

Hydro Geoscience Inc. Sept 1997 - Dec 1998
President and Chief Scientist
Developed and Patented (5,825,188) technology to track groundwater.
Managed Research.
Oversaw Fieldwork.
Directed Interpretive work.

Weber State University Oct 1996 - Sept 1997
Research Professor of Physics
Directed student research and served as PI for research projects.

U.S. Bureau of Reclamation Feb 1996 - Sept 1996
Staff Scientist/Researcher
Developed and built a truck-mounted mechanized device/machine that removed lead from soils.

U.S. Bureau of Mines, Salt Lake City Research Center (SLRC) Dec 1990 - Present
Staff Scientist/Researcher, May 1993 - Feb 1996
Principle Investigator and supervisor of following projects:
Uranium removal from waste water using bacteria in beads.
Bio removal of acetate from spent leach solutions.
Electromagnetic tracking of underground pollution plumes.
Electromagnetic monitoring of subsurface biological processes.
Electromagnetic monitoring of In situ mining.
Technology Transfer Officer, Dec 1990 - May 1993
Coordinated and facilitated the Technology Transfer program.
Created and supervised graphics department for SLRC.
Instituted and supervised the video production department for SLRC.
Supervised computer facilities for SLRC.
Supervised technical library at SLRC.

Weber State College, 1989 - 1993
Adjunct Research Professor of Physics
Directed student research and served as PI for research.

U.S. ARMY, Dugway Proving Grounds, Sept 1986 - Dec 1990

Operations Research Analyst

Contracting Officers Representative for diverse contracts.
Devised unique technique for analyzing time dependent data.
Formulated cold temperature model for agent parameters.
Evaluated composite materials for impact strength and water sorption.

ASARCO Incorporated, Aug 1968 - March 1986

Chief Geophysicist/Manager, Dec 1984 - March 1986

Coordinated geophysical surveys with geologic projects.
Reviewed all papers and reports before publication.
Establish procedures for field and laboratory work.

Computer Manager/Regional Geophysicist, Dec 1979 - Dec 1984

Managed computer department, and supervised staff.
Supervised field projects and crews.
Organized, directed and interpreted geophysical surveys.
Conducted engineering and ground stability studies.
Developed programs to study groundwater pollution (environmental).
Expanded theories to implement improved computer models.

Exploration Geophysicist/Computer Analyst, Jan 1975 - Dec 1979

Directed and interpreted geophysical surveys.
Supervised computer program development for exploration.
Coordinated use of satellite imagery.
Developed interactive graphics modeling programs.
(gravity, magnetics, resistivity and induced polarization)

Theoretical Geophysicist, Aug 1968 - Jan 1975

Developed analysis and computer programs for;
Regionalized statistics, and numerical integration,
Convolution, deconvolution, linear and non-linear filters,
Analyzing and displaying random data, and modeling for theoretical analysis.
Developed and tested new instrumentation.

Weber State College, 1963 - 1965

Physics Lab Instructor for university and engineering physics

OTHER ACTIVITIES

Co-directed construction of Stansbury Park Astronomical Observatory with a 16 inch Newtonian telescope.
Served as Director on the Board of Director for:

Salt Lake Astronomical Society	- four years.
Alta Mining Company	- five years.
Wasatch Martial Arts	- twenty years.
Hydro Geosciences Inc	- two years.

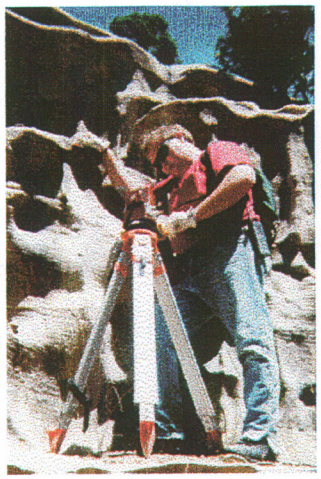
Black Belt 3rd Dan Tae Kwon Do, under a multinational organization *Kyuki-Do*.
Started own school *Wasatch Martial Arts*, Spun off two subsidiary schools.

PUBLICATIONS:

University of Utah . . . . . Dissertation, ... plus	10. spin off publications
Utah Geologic and Mineral Survey	1. publication
ASARCO Inc.	182. publications
U.S. ARMY, Dugway Proving Grounds	8. publications
U.S. Bureau of Mines	22. publications
U.S. Bureau of Reclamation	1. publication

AQUATRACK APPENDIXES

These appendixes are included to provide the reader with an overview of the technology behind **AquaTrack**. They will assist the reader in understanding the methodology of interpretation. They are not intended to be all inclusive. They are simply intended as an overview to afford appreciation.



Differences between AquaTrack and conventional groundwater tracking technologies.

Current groundwater mapping technologies fall into one of the following categories:

- conventional geophysics
- tomography
- monitoring wells using logging technologies or tracers

Older Conventional Technologies

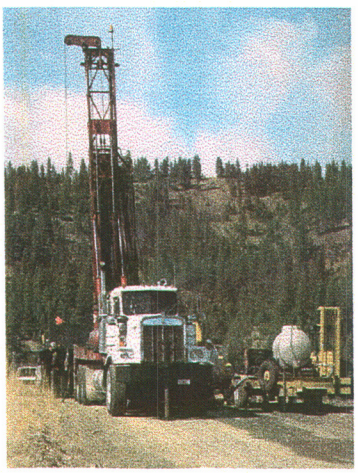
Conventional geophysics generally involves indirect energizing and measurements which includes: galvanic resistivity, electromagnetic conductivity, conventional electromagnetic surveys, ground penetrating radar, and magnetic surveys. Conventional geophysical technologies do not have the capability of resolving separate subsurface anomalies and confirming that they result from a particular plume or groundwater channel. Thus a particular feature of interest is not isolated and definitively measured. Adjacent features can appear as contiguous features even though they may or may not be connected. There is no assurance as to the various anomalies are related. Detecting groundwater plumes or even resolving plumes at depths greater than about 100 feet is very difficult, using conventional geophysics.

Tomographic type technologies include: electrical resistance tomography, seismic tomography, and radio imaging method. Tomographic technology is a very powerful and sophisticated tool that involves very complicated algorithms to develop models. The draw backs to tomographic technologies are that they are very time consuming and expensive.

Monitor wells: The drawback to drilling is that you only identify what is at the location of the drill hole. To establish linkage between holes it is necessary to use tracer solutions or a geophysical continuity test. These techniques establish connectivity but, do not provide a trace of the subsurface path between the drill holes. Using monitor wells it is difficult and requires many wells to map a subsurface water system and be certain that all branches have been identified. It is possible to miss narrow channels of groundwater. Wells provide inconclusive and at times even misleading results.

Well logging technologies include: thermal logging, gamma logging, neutron logging, acoustic logging, electrical resistivity logging, and electromagnetic induction logging. Well logging technologies have limited range of detection. Generally the detection limits on well logging tool range from a fraction of a meter too just a few meters from the well.

Tracer technologies: Tracers are any substance that can be easily and uniquely identified. Tracers are introduced into the medium being investigated and then wells or seeps are monitored for the appearance of the tracer. Tracers are a powerful technology, however, it takes time for the tracer to move through an aquifer. The aquifer must be continually monitored and sampled to pick up and generally require sophisticated lab analysis to detect the tracer. In some situations it may be objectionable to introduce any additional chemicals into a sensitive system.



New Technology

AquaTrack mimics tracer technologies in that it uses electrons as its tracer and magnetic sensors to monitor the movement of the tracer. Thus, not only is continuity established but maps can be made of the subsurface water channels. Data reduction is

done on a p.c. computer, and interpretation involves analyzing profiles, creating models and interpreting contour maps of the field data.

Technology analogous to AquaTrack

AquaTrack uses the concepts similar to several existing technologies but differs in the execution of the application to tracking water.

The technology is similar to the idea of directly connecting or nearly directly connecting to an ore body as utilized in the Mise-a-la-masse method. Mise-a-la-masse is used to detect mineralization just missed by drilling and in the immediate vicinity of the drill hole.

Another similar technology is used by the phone company to detect wires in walls. They attach a signal generator to the wire and energize it. Then a small loop antenna is used to locate the trace of the wire in the wall.

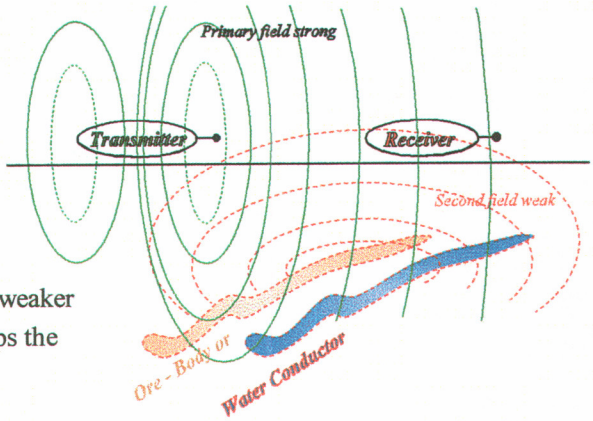
The location of underground pipes and utilities, using Metro Tech tools is also very similar to the technology behind AquaTrack. A Metro Tech transmitter connected to a pipe and to a grounded electrode. A receiver is used to map the electromagnetic field generated by the current following the pipe. The buried portion of the pipe is located by listening for the loudest signal from the receiver. When using AquaTrack to track groundwater, underground pipes and wires create noise that must be identified and corrected for when mapping groundwater.

How AquaTrack Works

Electromagnetics have long been employed by geophysicists to find minerals and ore deposits. A fluctuating electrical current in a coil will generate a fluctuating magnetic field. A conductor placed in a fluctuating magnetic field will have electric currents circulating in the conductors which in turn will produce their own weaker magnetic field.

In conventional electromagnetic techniques a transmitter coil is near the surface is energized to create an alternating magnetic field. This alternating magnetic field induces electric current in all the conductors in the area. A secondary magnetic field is generated by the current flowing in the conductors. The secondary magnetic field interferes with the primary magnetic field and this interference is measured (See illustration above). There are two draw backs. (1) All conductors in the subsurface are energized and will respond in similar ways. (2) Second the secondary magnetic field is much weaker and is hard to resolve.

AquaTrack combines a non conventional electromagnetic geophysical and tracer technologies. By directly energizing the ground water with electricity the ions in the groundwater become tracers. As current flows in the groundwater it generates a magnetic field. This magnetic field can be measured some distance away from the electrical current thus measurement can be made on the surface, above the groundwater. AquaTrack creates the primary magnetic field using the groundwater of interest. Other conductors not of interest generate only a weaker secondary magnetic field. The path followed by the electrical current maps the groundwater and related structures.

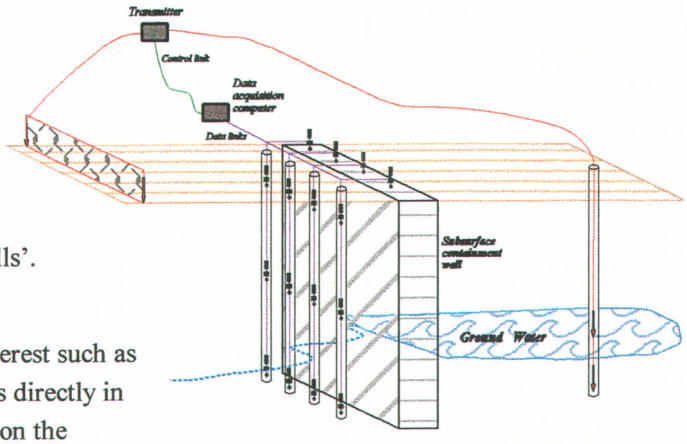


Conventual E.M. surveys

Some of the capabilities of AquaTrack:

The principle of ions acting as tracers is utilized so that AquaTrack can actively:

- Map subsurface pollution plumes.
- Find the source of seeps.
- Delineate leaks in earthen dams and drain fields.
- Monitor changing subsurface ion concentrations or reaction-fronts.
- Monitor surface retainer and subsurface containment walls'.
- Monitor leaching solutions.



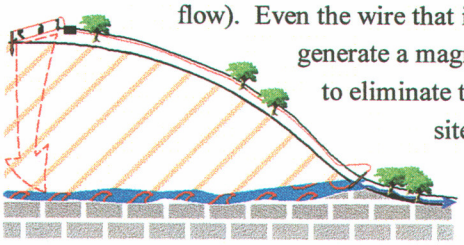
Subsurface Containment Wall

When there is a surface expression of the groundwater of interest such as a seep or spring the best technique is to place one of the electrodes directly in the seep or spring. The return electrode can be in a well or fence on the surface (see illustrations to left).

When only a drill hole is used, the preferred electrode configuration is to place the return electrode below the energizing electrode. When the return electrode is the upper electrode the current flowing back is closer to the receivers on the surface and thus masks the signal from the groundwater. When the energizing electrode is higher than the return electrode the current in the ground water is closer to the receiver and thus the current following the groundwater creates the stronger signal (see illustrations below).

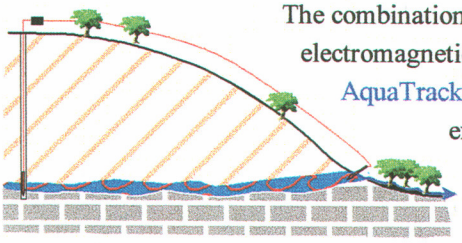
While AquaTrack is based on sound scientific theory, in practice it can be quite difficult. The water being tracked maybe only one of several conductors being energized or partially energized. A clay layer in soils often acts as a weak conductor producing a broad superimposed field.

Power lines or buried cable will produce their own magnetic fields. The depth of the water from the surface may also vary and will cause variations in the field measurements. Other potential influences include changes in water conductivity due to changing ion concentration or a broadening of the water stream (sheet flow verses channel flow). Even the wire that is used to energize the water stream and connects the return electrode will generate a magnetic field. The data obtained by AquaTrack allows someone with experience to eliminate the extraneous effects, it is always prudent to consider all prior knowledge of a site to confirm observations and as a double check for data interpretation. AquaTrack data frequently enhances the value of other types of data that has been colleted for the site.



Review of Physical principles involved

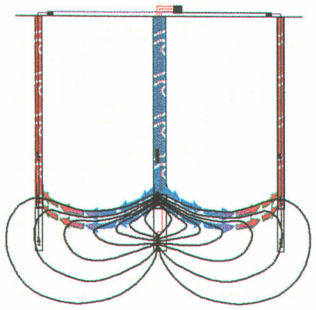
The combination and interplay of several electrical phenomena and adaption of several electromagnetic principles, in combinations not previously used provides the foundation for AquaTrack. The following is an overview of these principals and in some cases' examples of how they are used to interpret AquaTrack data.



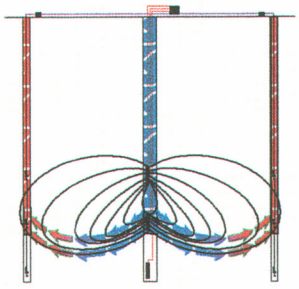
1. Current flowing in a wire generates a magnetic field that wraps around that wire perpendicular to the flow of current.

- In AquaTrack the wire is replaced by groundwater in a subsurface channel, current following that groundwater creates a magnetic field. By mapping the magnetic field the water channel can be located.

2. Two coils in close proximity are coupled magnetically. A transformer is a special case of two



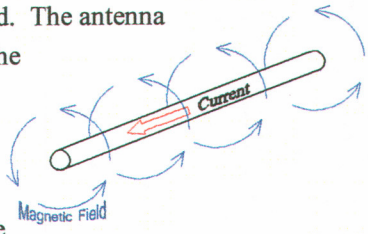
Current Flow bottom & middle electrode



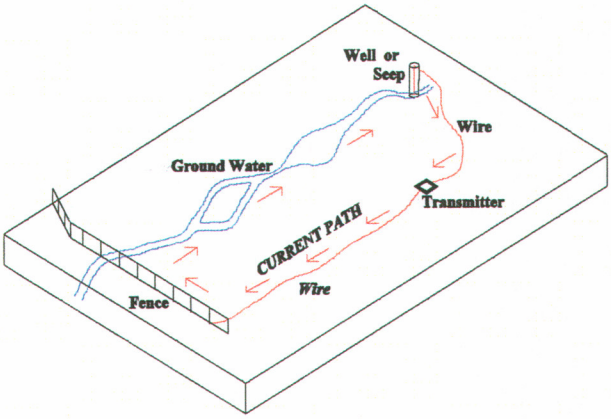
Current Flow top & middle electrode

coupled coils. The primary coil is the loop carrying the initial current. The secondary coil has current induced in it by current flowing in the primary coil.

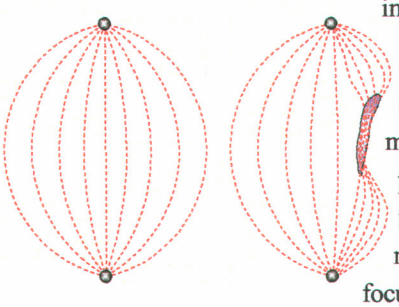
- The primary coil in AquaTrack is created by a large primary loop on and in the ground. The antenna wire forms one part of the loop and the subsurface water path forms the other part of the primary coil. The wire portion behaves like a single turn coil, but the groundwater portion can behave as a single turn or like a multiple turn coil. A virtual primary transformer coil is created by the antenna wire and groundwater path.



- The secondary coil of this hypothetical transformer is the receiver. The physical shape of the groundwater portion of the loop will determine whether it exhibits properties of a single wire or simulates multiple windings. A broad groundwater flow path approach the characteristics of a large number of small wires. A narrow groundwater channel will exhibit properties similar to a single loop. The way that the primary and secondary coils couple, and the current generated in the secondary coil is controlled by how many virtual turns are emulated by the groundwater. Thus transformers and large loop theory can be used to analyze the resultant magnetic field and infer the shape, location, and path of the groundwater channel being energized.



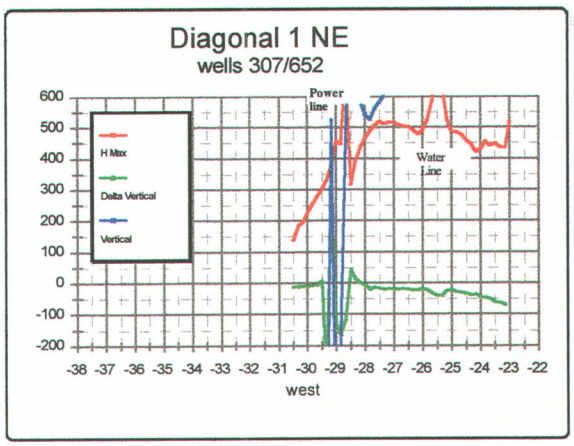
3. A good conductor, such as a metallic object, placed in a moderate conductor will gather current from the moderate conductor into the good conductor.



This is demonstrated by the classical physics experiment where two electrodes are placed at opposite ends of a tray of water. The electric field in the tray is first mapped containing only water. Then different types of conductors or insulators are placed in the tray. Objects with greater conductivity than the water warp the electric field in a way that diverts current through the conductor. This is because the entire metal surface is at the same electrical potential. This changes the gradient which focuses the flow of current through the metal. *Conductors gather current.* Insulators whose resistivity is greater than the water divert the current around the object. *Insulators do not gather current.*

Good conductors in the ground will gather electrical current flowing in the ground. This is referred to in the geophysical literature as *current gathering*. There are three general classes of good conductors in the ground.

■ First are groundwater channels. When current is directly injected into the conductor of interest it is important to remember that the signature of that conductor will be the strongest because the current will preferentially remain in that conductor. Current will disperse from the conductor at a rate that is a function of the resistivity contrast of groundwater channel and surrounding medium.



■ Second types of conductors are man made (refer to Diagonal 1NE diagram to the right), these include:

- communication lines
- over-head power wires. The effect seen on the profile to the right at station -29 is due to overhead power lines. Communication line and pipe have similar signatures but not as strong.

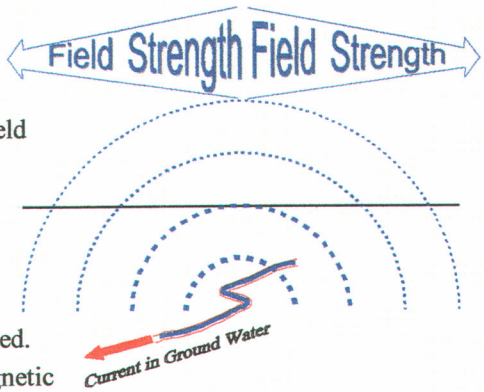
- under-ground metal pipes (at station -25.5 on Diagonal 1 NE).
- chain link or steel stake fences

The locations of fences, wires, pipes and conductors are usually known thus they can be accounted during interpreted.

■ Third are mineral deposits such as ore bodies. These are rare and are generally easy to distinguish from other types of conductors.

Application of these principles to AquaTrack

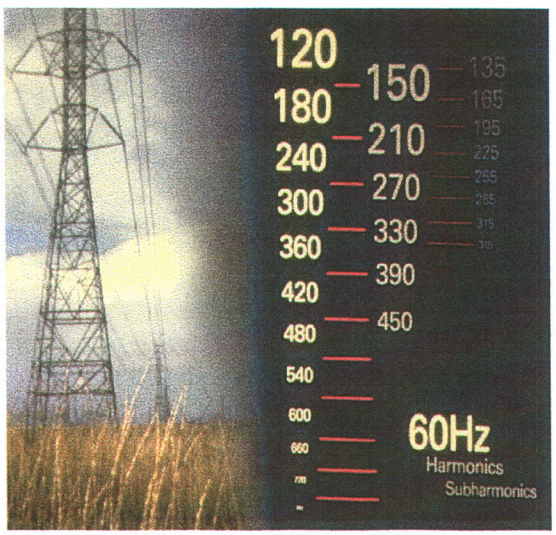
Following are observations of how the magnetic field behaves when using AquaTrack and how this technology is used to map groundwater channels. A loop is formed by the wire and current in the ground. A magnetic field is generated by electrical current following subsurface water.



Consider what happens when electric current flows in a wire. A magnetic field is produced that circles the wire. Replace the wire with groundwater and a magnetic field is generated around the groundwater's channel. On the surface this field will be horizontal and perpendicular to the groundwater. A curved conductor will essentially behave the same way. The strongest horizontal magnetic field will be measured directly over the conductor. The magnetic field traces a path on the surface that follows the path of water, in the ground.

An important part of this technology is that the groundwater is directly energized. This can be done in several ways but ultimately all achieve the same effect. The magnetic signal that is measured at any point in the survey is a compilation of the current flowing in the earth and the field created by the wires leading to the electrodes energizing the groundwater.

The magnitude of the magnetic field is related to the size of the loop and the current flowing in the loop. The vertical magnetic field inside a loop will be its maximum and is constant when completely inside the loop. The vertical field decreases when crossing any flow paths that short circuit part of the loop flowing in the ground. The vertical magnetic field will have a relative zero (maximum slope) directly over a water channel. If the water channel is confined, the vertical field will change rapidly over a very short distance. When crossing a wide water channel, the vertical field will start to change, decreasing in strength, before the first edge is crossed. It then stabilizes over the channel and decreases abruptly as the second edge is crossed. Outside the loop, the vertical field will decrease away from the loop. The horizontal magnetic field inside the loop will be a minimum. The horizontal field is maximum crossing over any conducting strand of the loop.



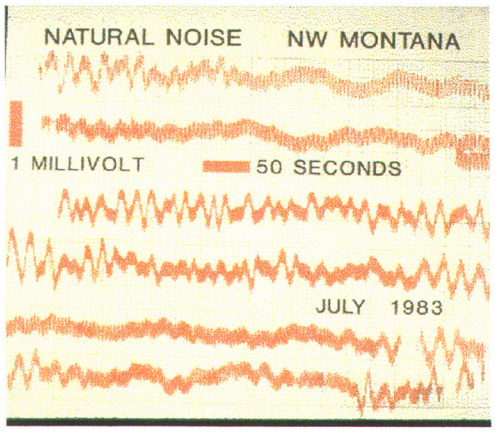
Noise

There are three large sources of electrical noise in the ground that must be accounted for when analyzing AquaTrack field measurements.

- The first results from power companies which use the earth for their return circuit for all their power distribution. Thus as usage changes during the day the electrical and magnetic field produced by the returned electrical power will shift and change. These effects are screened by frequency locks between the transmitter and receiver. Corrections are made from multiple base station readings used to monitor drifts in the local magnetic field.

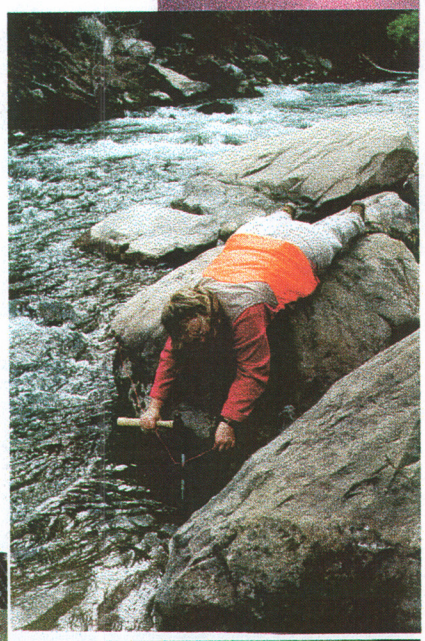
Filters are provided to lock the frequency at a precise 400 cycles. The frequency, 400 cycles, is selected to eliminate interference from stray 60 cycle current or any harmonics of 60 cycles.

- The second strongest noise source is telluric currents created by the electrical currents that the sun generates in the ionosphere. Multiple readings at a base station help identify and correct for these influences.
- The third electrical noise source is distant thunder storms. The electrical static generated by lightning strikes becomes trapped in a wave guide between the ground and the ionosphere. With distance, the frequencies generated begin to blanket the electromagnetic spectrum usable in this technology. Noise from this source is corrected using a combination of frequency locks and bases station corrections.



Field procedures

The first step is to provide a path for the current to flow in a large primary loop. As stated the water path to be mapped is included as part of this primary loop circuit. This is done by directly connecting an electrode to the water to be mapped. To provide a return path and continuity between the electrodes wire is strung from the primary electrode to the grounded point or points.



The second electrode can be in contact with the water to establish the flow path between two points. However if the subsurface path is an unknown then it is better if the return electrode does not bias the flow of electricity in the ground. This is best done by using as the second electrode a broad ground plain such as a chain link fence or surface water such as a pond or stream.

A controlled AC transmitter is included in the wire portion of the loop. The frequency is controlled to provide a locked frequency between the transmitter and receiver. Outputs are controlled, monitored, and recorded during the survey, and corrections are made for any transmitter drift.

Data is collected at each station using a special receiver. The receiver consists of a coil and a filtered amplifier. The magnetic signal picked up in the coil is correlated with the transmitter signal and filtered for noise. Magnetic field measurements consist of magnitude and direction of the magnetic field components. The minimum field is detected first because it is more definitive. The field direction is obtained using a compass mounted on the receiver coil. The maximum is measured by rotating the coil 90 degrees and recording the voltage induced in the receiving coil. The coil is again rotated

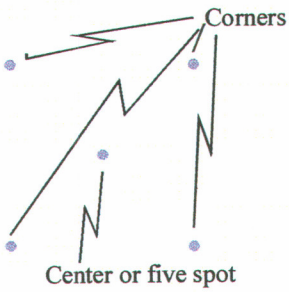
90 degrees in the vertical to measure the vertical component of the field.All readings are locked to a base station and corrected for diurnal drift.

The values measured at each station were:

1. Location in northings and eastings,
2. Minimum magnetic value and bearing,
3. Maximum magnetic value and bearing,
4. vertical magnetic value,
5. time, and
6. any adjacent cultural feature

Grided Data and Detailed Profiles

The preliminary or regional data is generally gathered on a north-south/ east-west oriented grid with 100 foot spacings. The primary survey is made by taking measurements at the grid points and at the center of each grid square, or the five-spot. The reduced maximum horizontal magnetic field values are contoured to determine general location and orientation of the ground-water channel feeding the energized water source. Readings taken over a grid area provide general information related to water flow and preferential direction of channels. Grid data may not provide detailed information defining channels or the edges of channels.



In some surveys rather than use a grid, profiles are used that are oriented perpendicular with respect to the feature being studied. The profile can be straight or curved. The decision to use straight or curved profiles are generally a decision based on the topography of the area being studied. Flat terrain lends its self to square grids or straight profiles very well. When the topography is steep or rugged the profiles are usually run were there is access.

Detailed profiles can be taken perpendicular to the groundwater channel as determined by the original survey data. Detailed data improved accuracy in determining the center of the water channel and the location and type of channel edges. Subsequently detailed readings may be taken along selected profiles in locations where the initial data indicated the existence of groundwater channels. The station spacing for detailed profiles is dictated by the needs of the user.

Whenever possible stations in the field are repeated. Thus if a new line crosses an older line, the point or station where they cross is re-occupied and a new reading is taken. This assure quality in the data and allows all parts of the survey to be calibrated the same.

Data Reduction

Analysis of the data includes correction for drift of both the transmitter and receiver. These corrections are the same as standard correction made to all geophysical data.

The data interpretation includes standard mathematical formulas that are applied equally to all data to remove regional and other effects. For example:

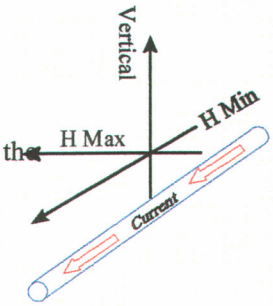
First current bleeding from the conductor, i.e., groundwater channel, will cause a gradually reduced signal due to lower current flow. This effect can be adjusted by adding a factor based on the stations distance from the current source.

Second, the electrodes, or contact points, can act as electric poles and will create a very predictable field. This field can be calculated and removed mathematically from the data.

The data is presented in various forms such as profiles, contour maps along with various models.

Data Interpretation

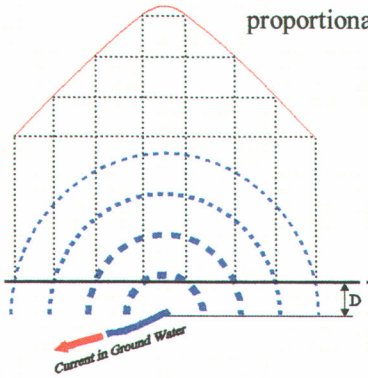
General guide lines

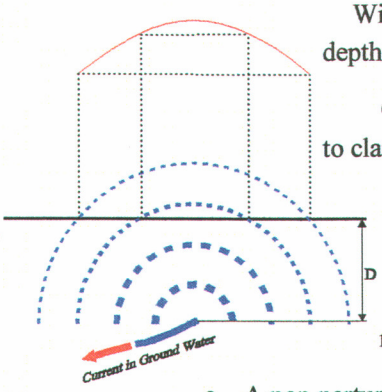


In the simplest case, such as a wire-like conductor, field strength will be greatest at a point directly over the conductor. Horizontal magnetic field strength measured on a line perpendicular to the conductor will increase until it is directly over the conductor then decrease.

The direction of electrical current flowing in the ground, represents the groundwater channel. Electric current flows in the same direction as the minimum horizontal magnetic field which is the direction of the subsurface water channels.

The rate of change of the vertical magnetic field intensity with distance across the anomaly is proportional to the width of the current path which indicates the width of the groundwater channel.





Width of the horizontal magnetic field is proportional to depth and width of the channel.

Correlation of vertical and horizontal data can be used to clarify ambiguities of width and depth.

Specific case examples.

The following are examples of how possible features will show up when site data is plotted in a manner similar to that of a contour map:

a. A non perturbed field, where no conductor is energized, would form a contour map composed of concentric circles around the point where the water is energized.

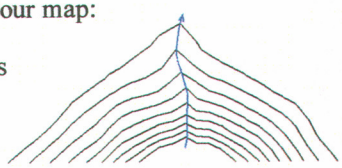
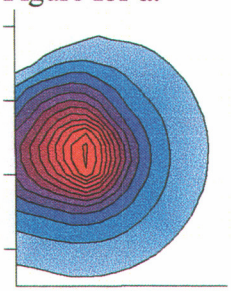


Figure for b.

Figure for a.



b. Water in a narrow channel will form a V shape in the contours. The shape of the "V" will be sharper the closer to the surface the channel is.

c. A vertical structure such as water flowing toward, then flowing down a vertical fault, will also form the "V" contour but with a somewhat lower gradient as fields generated at the deeper portions past the fault structure will add to the fields generated closer to the surface.

d. A flat conductor or sheet flow of water will produce a flatter signal than a deep narrow conductor. The gradient will increase toward the edge of the water, then level off, only to reduce sharply on the other side, making the edge of the sheet flow more pronounced than a deep narrow conductor.

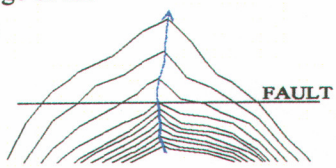


Figure for c.

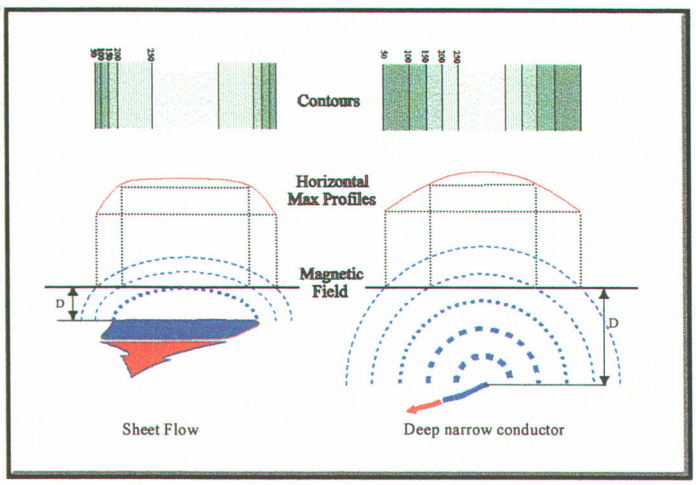


Figure for d.

e. Up welling along a conductor will start with lower values due to the depth of the initial flow then increase and narrow in the area of the up welling.

f. Branching in a conductor will show very misleading results in the area of the branch as two or more fields will be measured at one time.

g. If the water becomes less conductive or if the thickness of the water layer thins, this area will change to a lower field strength as less current will be carried. An example would be where relatively fresh water passes through a reaction zone and picks up additional minerals. Measured from the high conductivity side to the low conductivity side, there will appear to be a rapid decrease in conductivity, far more pronounced than could be accounted for by increased distance from the current source. This will look very similar to water flowing along a vertical structure. (see Figure for c)

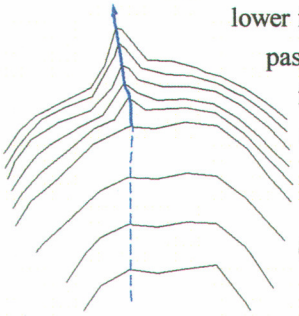


Figure for e.

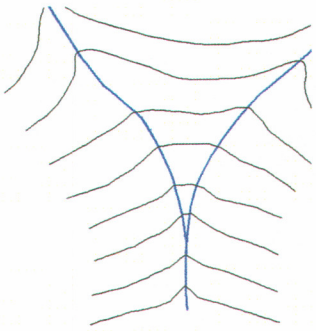


Figure for f.

h. Conductors in the surrounding rock or soils, even weakly conductive soils, will cause distortions in the fields measured and may even form secondary fields. These conductors may be a wide variety of things, the most common of which may be power lines, water pipes, or phone lines. These generally produce wide and wild variations in the field and are thus easy to identify.

i. An attached clay lens, such as a repository lining, will tend to mask the field of the conductor being tracked and could produce localized high readings in wet areas as they will act as good conductors and concentrate current. What generally happens over a clay liner is that there is a broad low intensity anomaly that outlines the clay liner and thus this anomaly can be modeled and removed.

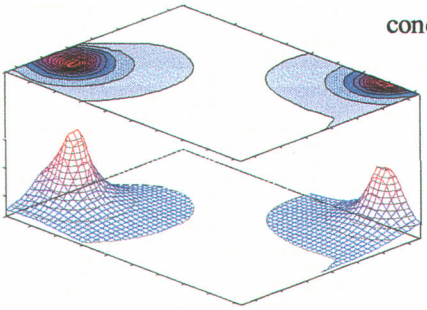


Figure for j.

j. Fields in the area of a return electrode show higher values as the current will be collected and concentrated at the electrodes no matter which path it has taken. As shown in the Figure for j, this anomaly is very localized and predictable thus it can generally be accounted for in the data.

k. The rate of change in the horizontal direction of the vertical magnetic field intensity across the anomaly is proportional to the width of the current path and thus can be used to calculate the width of the groundwater channel. The amplitude is related to the resistivity contrast between the channel and the soil. The (λ) width is related to how well the channel edge is defined. The (Δ) width is related to overall width and sometimes can provide clues as to depth. These are all theoretical calculations and unfortunately more often than not, cannot be used with field data. The most common reason that this valuable tool cannot be used is that the data spacing is too wide. Generally it is not practical to use close station spacing in an area where preliminary data is being used to outlining the water channels for the first time.

l. Width of the horizontal magnetic field is proportional to depth and width of the channel

m. Correlation of vertical and horizontal magnetic field data is used to clarify ambiguities of width and depth.

n. Locale intensity increases in either the magnetic fields can indicate chemical or biological activity. Chemical and biological activity translate into the ability to produce ions.

o. A study conducted over time, weeks or months, will show changes in field values and are plotted by take the difference or ratio of the readings.

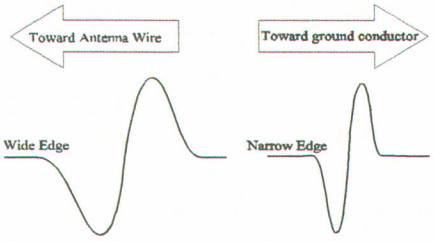


Figure for k.

p. A study conducted over time, weeks or months, will show changes in field values at the same location due to changes in the flow of water, chemical changes over time (such as oxidation or acid production), or biological activity. Variations from one season to the next would be expected due to variations in seasonal water flows.

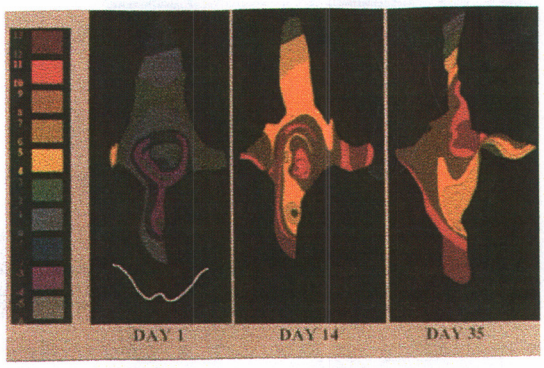


Figure for n, o, p, q. **Comparing all three surveys shows the increase in conductivity and movement of draw down cone as the result of well pump down test.**

q. Comparing changes in the various components of magnetic field over time provide information relating to fluid movement, change in chemical activity, changes of fluid in an aquifer, changes in subsurface biological activity, movement of chemical or bio reaction fronts, leaching progress and activity relating to in situ mining, progress of subsurface chemical or biological remediation, increases or decrease in subsurface flow, changes in salinity, or any change in the groundwater that affects any of its electrical properties.

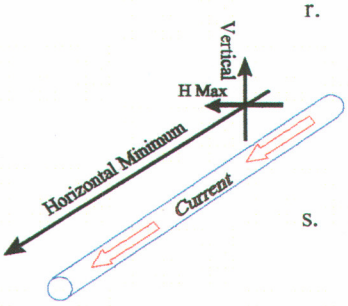


Figure for r.

r. The direction as the minimum horizontal magnetic field or a direction perpendicular to the maximum horizontal magnetic field indicates the direction of the current or subsurface solution path. This is visible in vector plots of the minimum field direction.

s. As current flows down the groundwater channel, some electrical current leaks into the surrounding medium. The electrical contrast between the channel and host rock can be evaluated by the rate at which the magnetic and electric fields degrade.

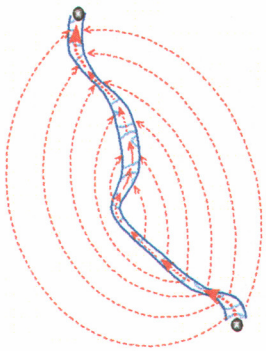


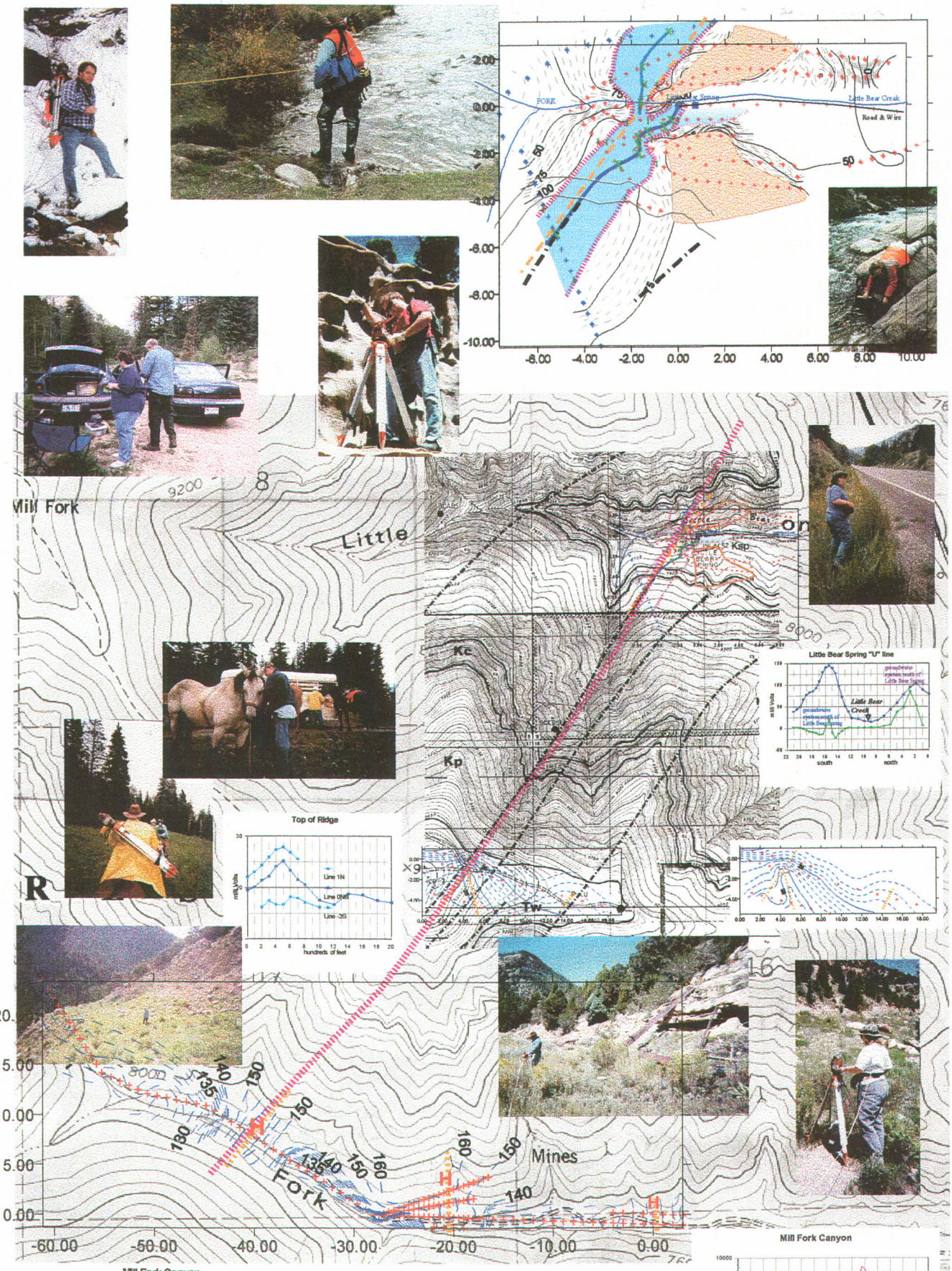
Figure for s.

t. The dip of the magnetic field is related to depth and dispersion of the ground current that is following the groundwater.

<u>The simple case will rarely exist</u>. Interpretation of the field measurements must therefor, include as much information of the site as possible. It is obvious that some field measurements could be interpreted to represent widely different outcomes. Historic data can often be used to eliminate possible explanations. Any known influence on the field must be accounted for and normalized out of the measurements as best as possible. Attempts to overcome this are made by performing a precursory analyzing data as it is being gathered on the site and confirming the interpretations with further observations, extra diagonal profiles, and by using any historic data about the site.

All possible explanations for the data obtained need to be considered. For example water will flow along the course of least resistance and most likely will not be straight. Its depth from the surface may also change. The channel the water follows may expand and contract. The path of the water may split following several channels. Other conductors may also exist in the area and may be energized. All these contingencies must be taken into consideration during the interpretive phase, with no prejudgment.

It is possible to prejudice the interpretation if care is not taken and data is not thoroughly analyzed for all possible solutions. Dr. Montgomery has over 30 years of experience interpreting geophysical data with proven success.


Little Bear Creek
Road & Wire
Mill Fork
Little
Kc
Kp
Ksp
Mines
Fork
Little Bear Spring "U" line
Little Bear Creek
south
north
Top of Ridge
Line 1N
Line 0N
Line -3S
hundreds of feet
Mill Fork Canyon
Electrods in the
Sinks
Springs
Little Bear Spring zone
Electrods in the
hundreds of feet
Mill Fork Canyon
station