APPENDIX 7-59

LITTLE BEAR SPRING STUDY (INITIAL STUDY, 1998)

AQUA TRACK

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SEP 16 2003

AquaTrack Survey

Little Bear Springs Study

Huntington Canyon, Utah

Jerry R Montgomery, Ph.D.
Sarah Montgomery
Rich Montgomery

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APR 15 2005

DIV OF OIL GAS & MINING

PO Box 701290
Salt Lake City, UT 84170-1290
(801) 951-1551 fax (801) 951-2561

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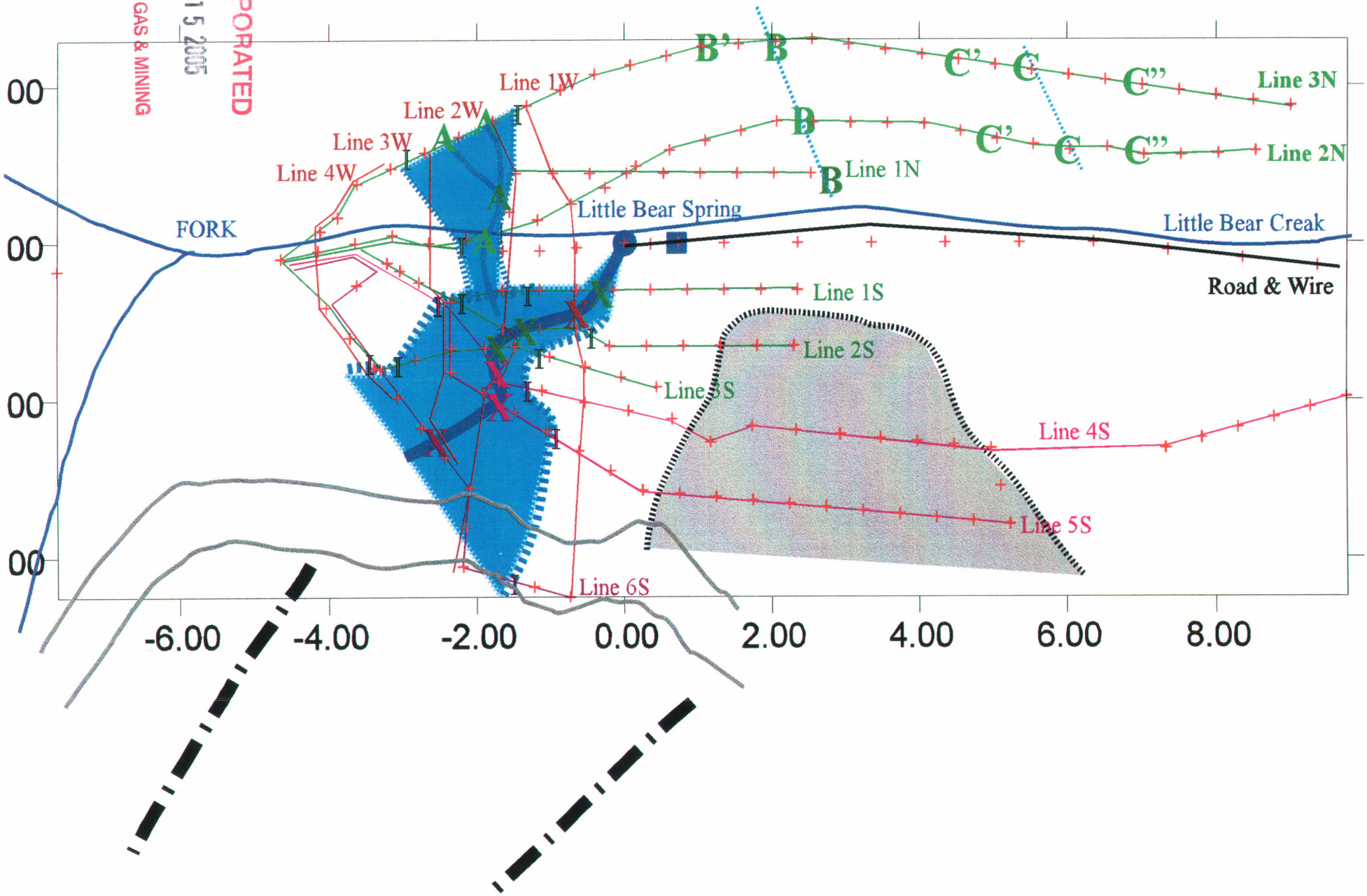
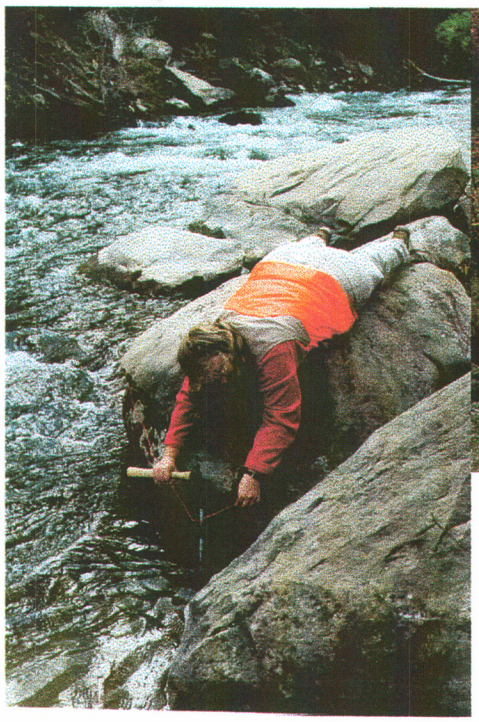
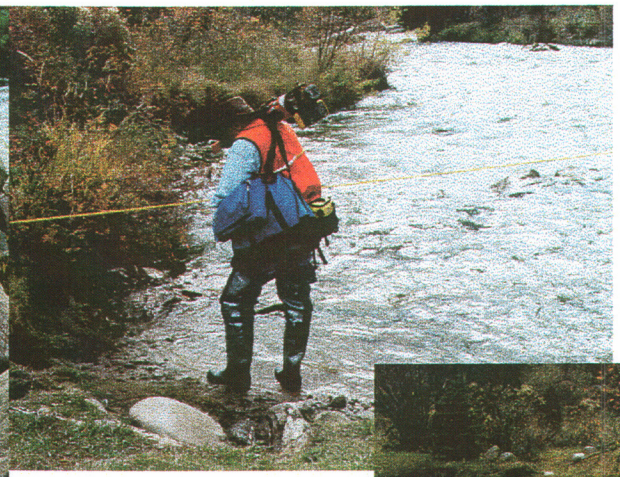


AQUATRACK

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 can cause interference problems.





PO Box 701290
Salt Lake City, UT 84170-1290
(801) 951-2551 fax (801) 951 2561

AQUATRACK

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SURVEY OBJECTIVES

An AquaTrack survey was conducted at Little Bear Spring to map the subsurface-water feeding the spring located in Little Bear Canyon, a side canyon to Huntington Canyon. The goal of the survey was to identify if possible paths, structures, and sources of groundwater responsible for Little Bear Spring. In this regard, we were asked to provide information on the following:

1. Map the subsurface flow paths in the vicinity of Little Bear Spring.
2. Identify the subsurface path or paths of the groundwater feeding Little Bear Spring.
3. Identify the structure channeling groundwater to Little Bear Spring.
4. Identify the controlling structures for Little Bear Spring.
5. If possible determine the source that is feeding Little Bear Spring.
6. If possible find the source that replenishes Little Bear Spring every year.

CONCLUSIONS:

Results obtained from data procured during this investigation are summarized below.

1. Subsurface flow paths of ground water feeding Little Bear Spring are shown behind the front cover and on page 27. Partial results are shown on pages 16 and 23. For an overlay of this interpretive map on topographic contours see page 29.
2. Groundwater feeding Little Bear Spring come from both sides of Little Bear Canyon.
   a. The groundwater coming from the north is supplying between 30 and 40 percent of the total for Little Bear Spring, see pages 21 and 27. For interpretation of the north side of the canyon see pages 13 thru 16.
   b. The groundwater coming from the south is supplying between 60 and 70 percent of the total for Little Bear Spring, see pages 21 and 27. For interpretation of the south side of the canyon see pages 17 thru 23.
   c. The interpretation as to where and how the two systems connect, see pages 24 thru 26.
   d. There is no groundwater coming down Little Bear Canyon, from the west, that feeds Little Bear Spring, see pages 24 thru 26.
3. The structure that is channeling groundwater to Little Bear Spring is a confluence of two fracture systems. Both of these fractures have been modified by the water flowing through them. They now appear to be sinuous and cave like in nature, see pages 21 thru 23. The cavern like structures provides for three favorable characteristics.
   a. First both systems are probably able to hold a great deal of reserve water.
   b. Second both systems are able to release this water over an extended period of time.

c. Third both systems have probably developed channels that come near the surface that can be replenished every year.

4. There are several structures that combined control the location of Little Bear Spring.

   a. Little Bear Canyon is located in the bottom of a syncline, see pages 30 and 31.

   b. The fracture system in Little Bear Canyon is probably controlled by the syncline. On the south side of the canyon the fractures trend from southwest to northeast, see pages 23, 29, and 30. On the north side of the canyon the fracture trend from northwest to southeast, see pages 16, 30, and 31.

   c. Fractures from each side of the canyon meet just above the spring, see pages 16, 19 and 20.

   d. Just east and down gradient of Little Bear Spring is a very low conductivity zone that indicates very low porosity and/or low permeability. This would force groundwater flowing down gradient toward this area to surface. This zone is down gradient on the syncline, and the fractures. This low conductivity zone would explain the system of seeps and springs that exist along a 500-foot stretch, below Little Bear Spring, see pages 20 thru 22, and 27.

   e. The rock formations in this location can form voids because of weaker cementing of some of the sand in the sandstones. These voids and possibly ruble along fractures, have formed cave like structure(s) along the subsurface channels feeding Little Bear Spring, see pages 21, 22, and 28.

5. Based on the directions of fracture systems when considered in conjunction with structural and topographic bottoms and their relationship to the position of Little Bear Spring, there are three possible sources feeding Little Bear Spring; the south-fork of Little Bear Canyon, Mill Fork Creek, and Crandall Canyon.

6. The same three sources probably makeup in part the replenishment system for Little Bear Spring. The south-fork of Little Bear Canyon, Mill Fork Creek, and Crandall Canyon. This survey was unable to determine the source replenishment of Little Bear Springs.

   a. The south or left fork of Little Bear Canyon is considered one of the three because the fault that projects into the cave system feeding the spring is centered on the south fork, see pages 27 thru 30.

   b. Mill Fork Canyon was surveyed using a more powerful transmitter. One line was run down Mill Fork Canyon , but there was insufficient signal reaching that far with the antenna setup used, see pages 29 and 30. To determine if the water from Mill Fork is feeding into the Little Bear Spring system an antenna system will have to include both, Little Bear Spring and the water in Mill Fork Canyon.

   c. With no signal reaching Mill Fork Canyon no attempt was made to survey Crandall Canyon.

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 50 feet, thus the accuracy of any point located by the data taken during this survey is ± 25 feet. This implies that the error in locating the channel center is ± 25 feet with a maximum error in the width of the channel of ± 50 feet.

Survey lines (SL), are lines where field data is collection in the survey area. Profiles or lines are the survey lines data after mathematical corrections have been made for objects that influence the data such as drift, noise, power lines, and known utilities. A profile or line can be created by combining stations from different survey lines and data from individual stations. Station refers to a point on a survey line where data were collected. Channel(s) are paths of current flow that can result from electricity following groundwater, utility lines, ore bodies, 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 of point zero as positive numbers on the grid, south and west are negative numbers. For the diagonal lines the negative numbers represent the most southern or western portion of the profile.

The numbers along the bottom of the profiles, charts, and along the edges of plan maps 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, north, or northwest. In the case of the east/west profiles, profiles north and south of Little Bear Spring, 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. Coal mining in the area might threaten 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 data used in this survey and report were collected in October and November of 1998.

TECHNOLOGY USED- AQUATRACK, How it Works:

AquaTrack uses electricity to follow the groundwater and map it 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 Spring and using Huntington creek for the return 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 included the groundwater to be mapped. In this case that was Little Bear Spring. At least one direct contact with the water is desirable to establish the circuit. (*It is possible to conduct a survey without a direct contact with water but the results will not be as reliable as the current could potentially follow another conductor in the ground.*) The current takes the best path (*the path of least resistance and generally the shortest*) to the return electrodes, completing the circuit. Most surveys, including this one, utilize only one direct contact point with the water being surveyed. Groundwater is always a significantly better conductor than the surrounding soil or rock, due to waters ability to take ions into solution. These ions and other dissolved solids that are in all ground waters turn the water into an electrolyte.

Survey Area

The survey area covered the area surrounding Little Bear Spring. The primary lines were run parallel to the canyon. There were a sufficient number of station also taken west of Little Bear Spring to determine if the source of the groundwater was coming down Little Bear Canyon. On the hillside directly north of the spring three lines were surveyed. The survey on this side was limited by a continuous set of cliffs. However, there was sufficient room below these cliffs for three survey lines of data. This provided information relating to the groundwater movement north of Little Bear Spring. To the south the hill was steep and moss covered. There was sufficient time before the snow to obtain about six survey lines. Several of these line had to be collected over a period of days because of terrain limitations. There are more lines on the south slope for two reasons, first it appeared in the field data that the majority of the water seemed to be coming from the south side of the spring, and second because cliffs limited our access on the north slope more than the south slope. We would have liked to take a few more survey lines to the south and west of Little Bear Spring but conditions, such as a foot of snow, did not permit. Data stations

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 several ways. 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 chanal 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 clearer in profile.

The following discussion will first look at the contour data and subsequently the profiles. The two 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

Figure 2 is copy of a topographic contour map in the vicinity of Little Bear Spring. The spring is shown in the center on this map.

Sedimentary Rocks above and below Little Bear Spring

The geology around the spring is important in attempting to understand how the spring may have formed and what structural influences may have contributed to it creation and location. Little Bear Canyon is located approximately along the bottom of what appears to be a low angle or weak syncline. The cliff forming formations are pock marked with small cave like structures. These are either places where the formation was not well cemented or where the cement was calcite and was at some later time leached away leaving these voids or holes in the cliff forming rock. In the formations stratigraphically directly above Little Bear Spring this phenomena void spaces and holes is particularly prominent. Figure 3 is a generalized geology map of the area. The formations that could possibly directly or indirectly affect Little Bear Springs are briefly described in the following section.

Kpr - Price River Formation (upper cretaceous)-Grayish mixture of conglomerate, sandstone; with minor shale layers. The formation is locally massive and well cemented. The conglomerates contain quartzite, quartz, chert, and a little limestone. The sandstones are fine to coarse grained. The Price River Formation forms steep slopes and low cliffs.

Kc - Castlegate Sandstone (upper cretaceous)-Sandstone and some conglomerate. The formation is irregularly bedded and is massive. The sand grains can be fine or coarse. The Castlegate Sandstone contains some thin, shaly siltstones and some carbonaceous material.

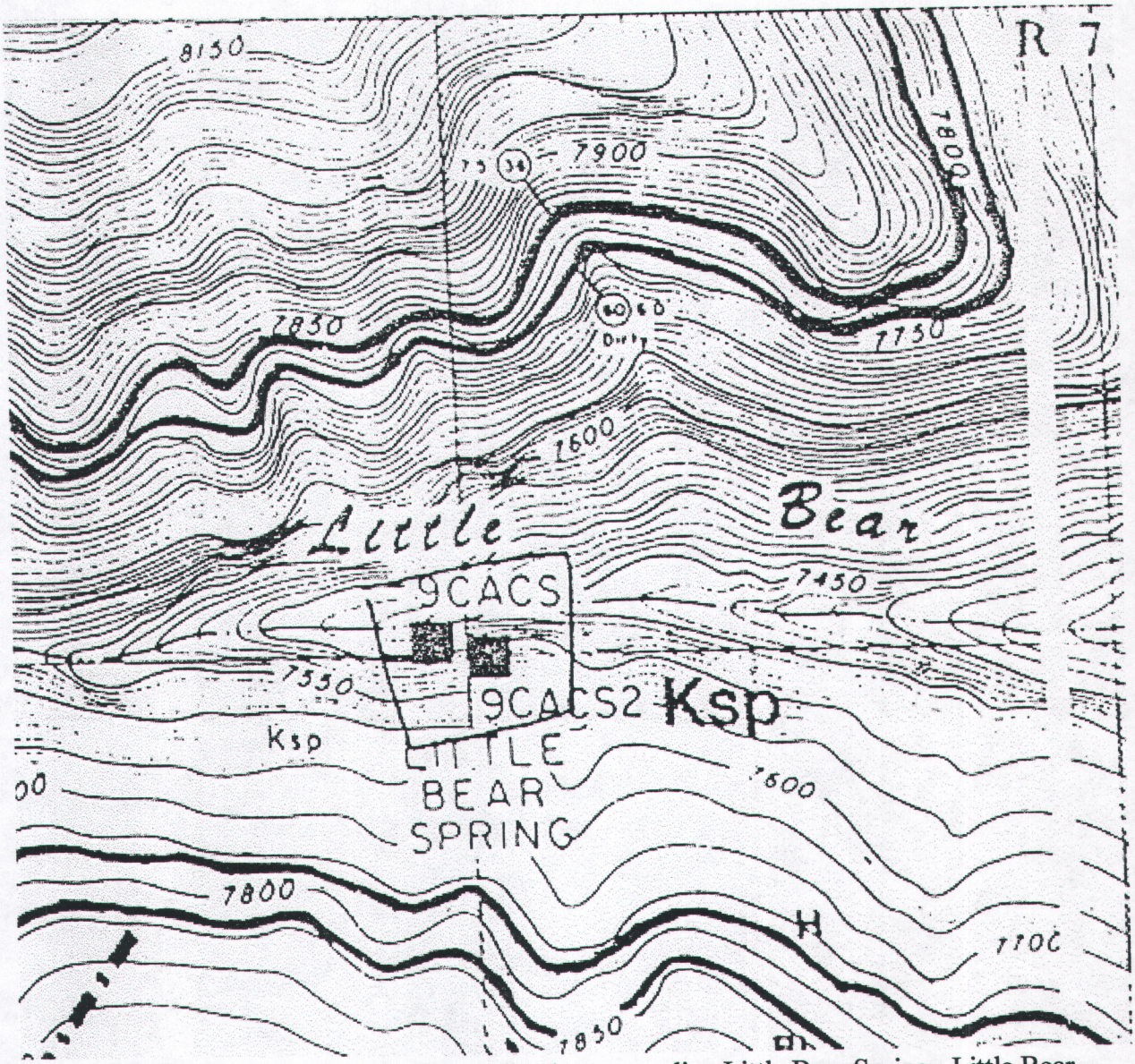


Figure 2 Contour map of the area immediately surrounding Little Bear Spring. Little Bear Spring is in the center of this map and is indicated by a black square. Some of the geology of the area is also shown on this map.

Kbh - Blackhawk Formation (upper cretaceous)-Sandstone, shaly siltstone, shale, carbonaceous shale, and coal. The sandstones are gray to brown, and are thin to medium bedded with some cross bedding. The sand is fine to medium grained. The Blackhawk contains many coal zones with a major thick coal zone at base directly overlies Star Point Sandstone. The Blackhawk Formation is a major coal producer.

Ksp - Star Point Sandstone (upper cretaceous)- This is the formation from which Little Bear Spring flows. Light-brown sandstone, shale, and shaly siltstone. It is thin to medium bedded; and fine to medium grained. The formation consists of three sandstone units. The formation forms

that were collected during this survey are shown in Figure 1. They are all located is relation to the Little Bear Spring. Little Bear Spring was the 0,0 point for this survey, and that point is also visible on Figure 1 as a blue dot.

Electrode Placement

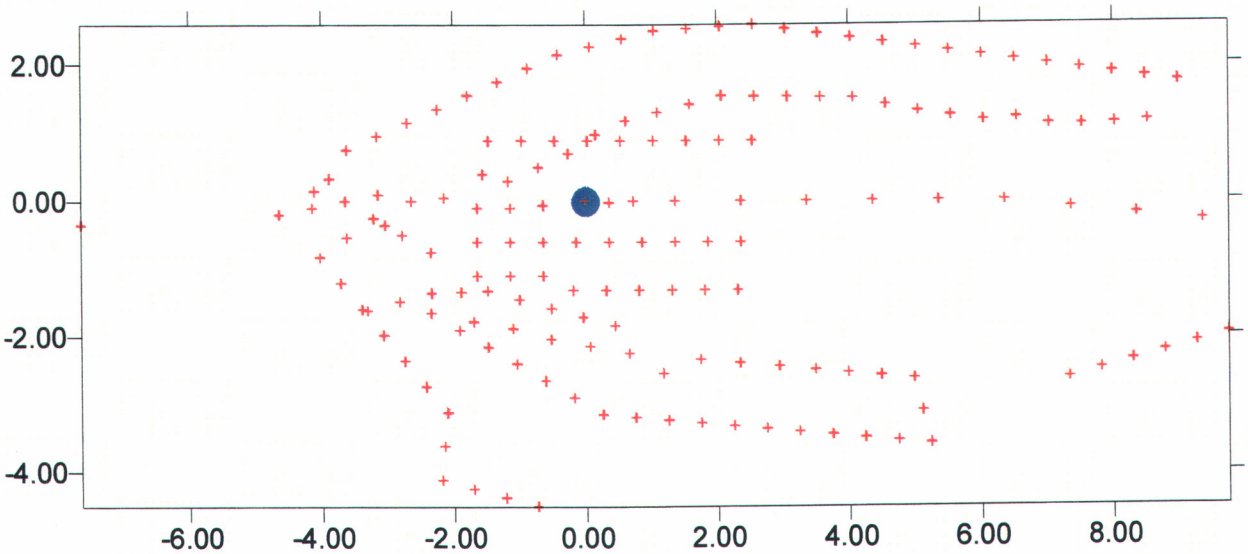


Figure 1 Station locations for the Little Bear Spring AquaTrack survey.

Four injection electrodes where placed into the water to be mapped, Little Bear Spring. A return set of four electrodes where placed in a Huntington Creek to completes the circuit. The connecting wire was run down Little Bear canyon. This was the route that posed the least likelihood of interfering with the survey by masking the subsurface water channel. Huntington Creek was used because it was thought that this would least bias the subsurface current flow path. The electric current followed the groundwater coming to Little Bear Spring as far back into the hill side as it could, slowly bleeding off to find an electrical return path to Huntington Creek.

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 lines. The base station was located at the 90 degree turn in the road leading to the spring at the mouth of Little Bear Canyon.

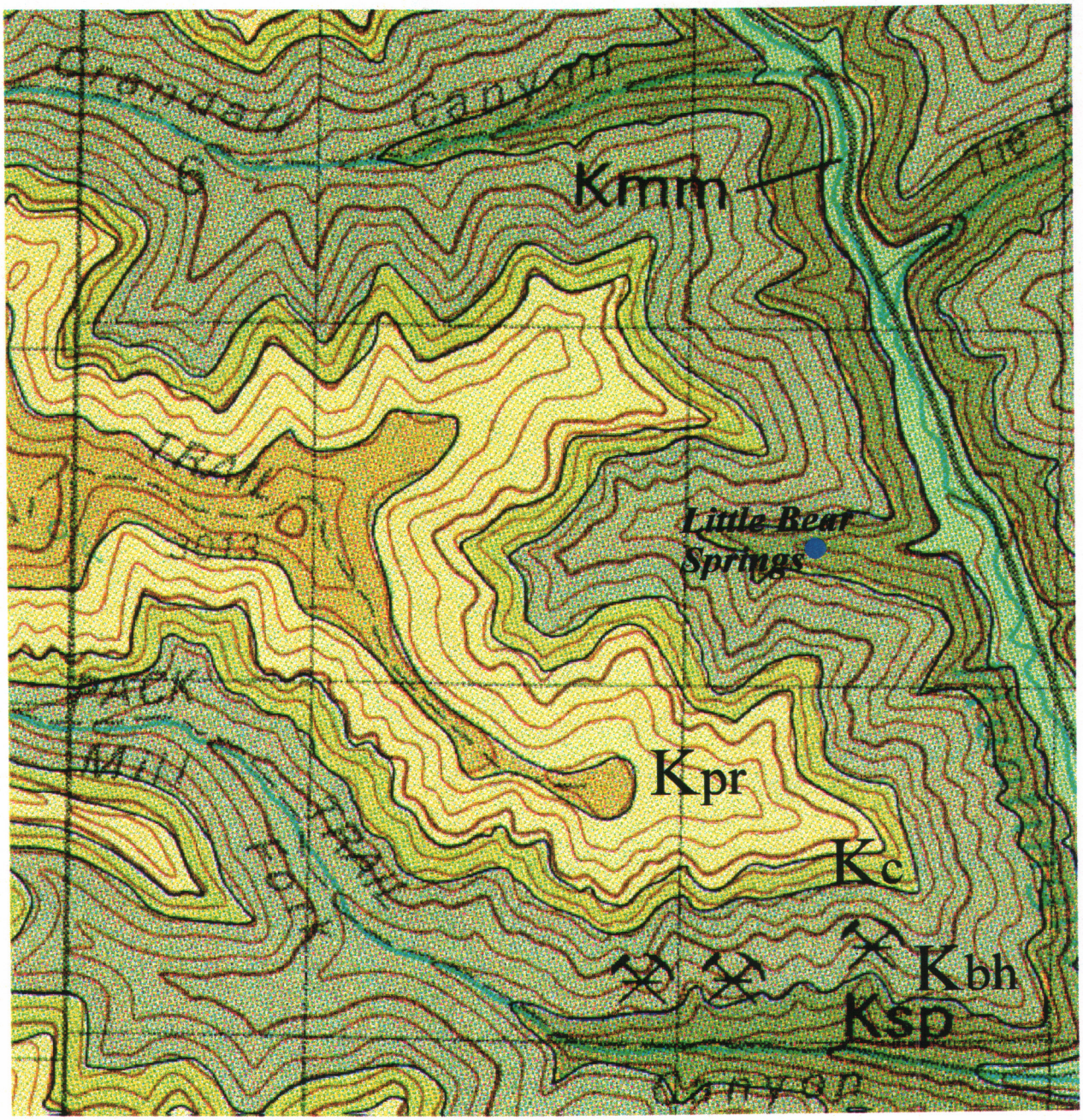


Figure 3 Generalized geology map of the area surrounding Little Bear Spring.

ledges and cliffs. From top to bottom they are the Spring Canyon, Storrs, and Panther Tongues. The sandstone layers are separated by beds of shale and shaly siltstone. The Star Point Sandstone is a fluvial deposit, and in this area is about 110 m (360 ft) thick.

Kmm - Mancos Shale (upper cretaceous)-Consists of five members, however, the only one of import in this area is the Masuk which is composed primarily of shale and silt stone. It is light gray, and in most places just looks like part of the soil. Masuk is located in the bottom of Huntington canyon.

Figure 4 is a plot of 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. This is obvious for this map near the center along 0 NS from 3 to 10 east. The wire was in that area and thus no meaningful data could be collected. Often it is best to ignore the contours in such areas. On the rest of the maps used in this report these contours have been removed.

The stations east of Little Bear Spring along the road were so over whelmed by the signal emitted from the wire that they had no significance and thus were not used in the analysis.

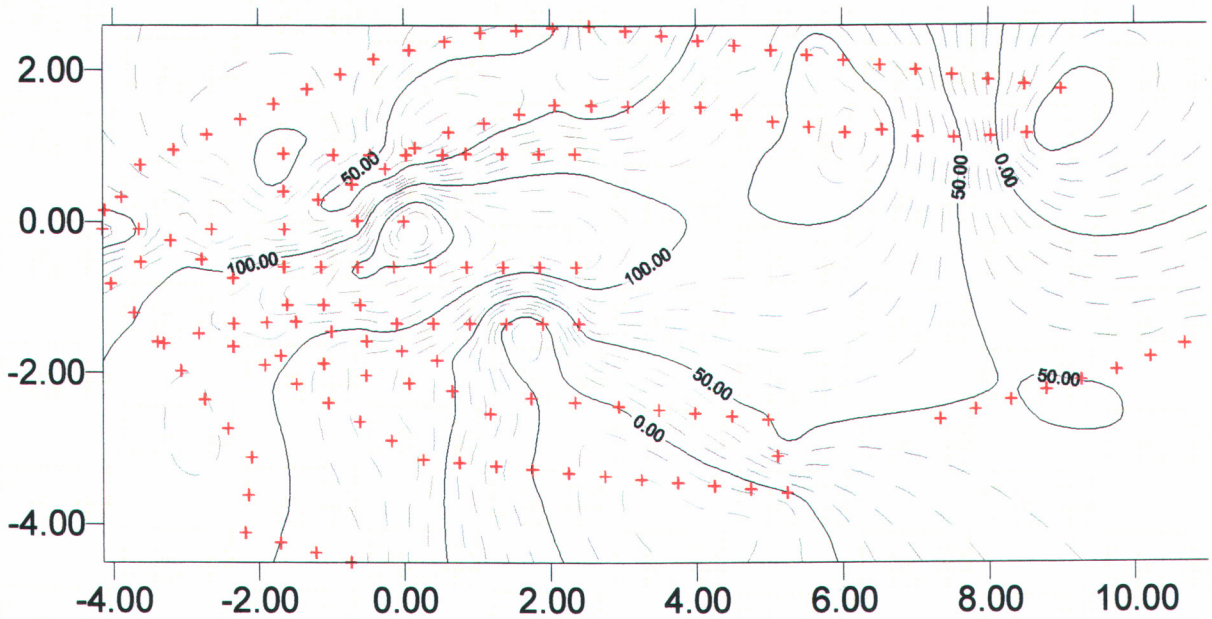


Figure 4 Contour map of the magnetic field created by energizing Little Bear Spring.

The profiles shown in Figure 5 were created from the data set and do not indicate what order or how the data was gathered. The profile are arbitrary and were chosen to provide the details for the structures that needed to be studied. In the following sections the profiles north of the spring will be interpreted first, and the profiles that are south of the springs second.

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 always in red, and blue is reserved for water and related groundwater structures.

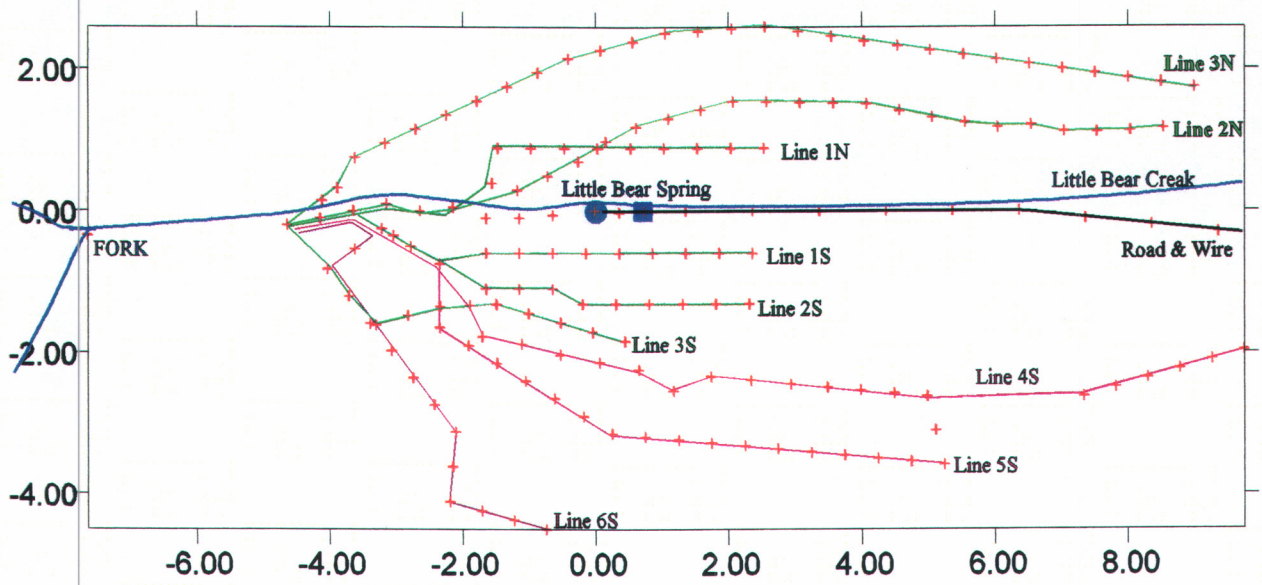


Figure 5 Stations used to create the lines or profile north and south of Little Bear Spring.

The potential profiles west of Little Bear Spring are shown in Figure 6. The profiles created to the west were used to tie the two sides together and show that no groundwater is coming from the west down Little Bear Canyon that contributes to the flow of Little Bear Spring.

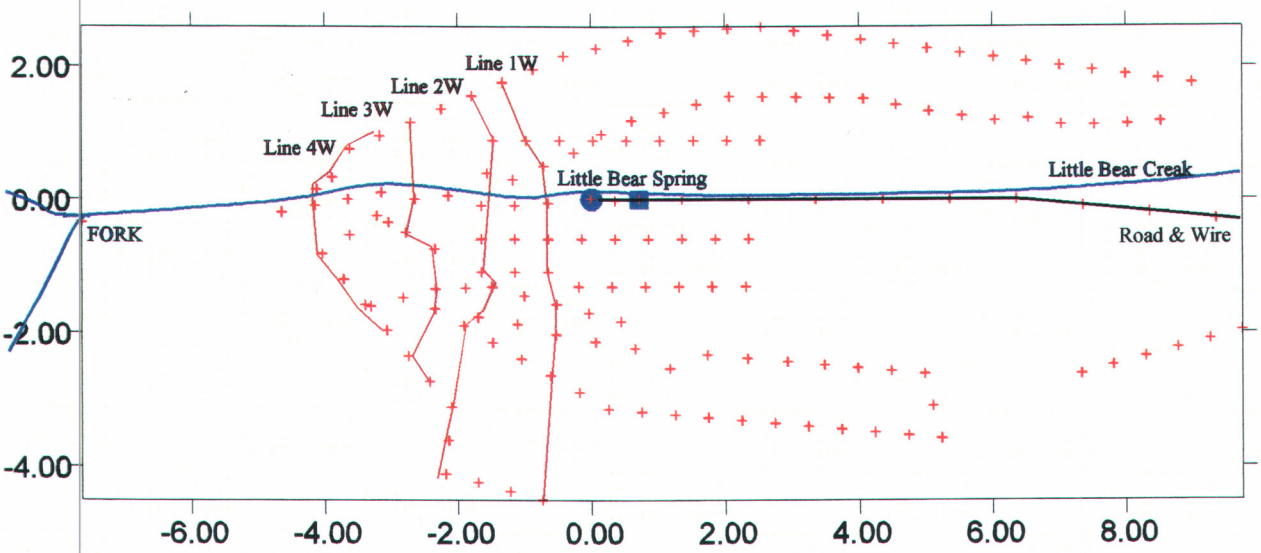


Figure 6 Potential profiles west of Little Bear Spring that can be created from the data.

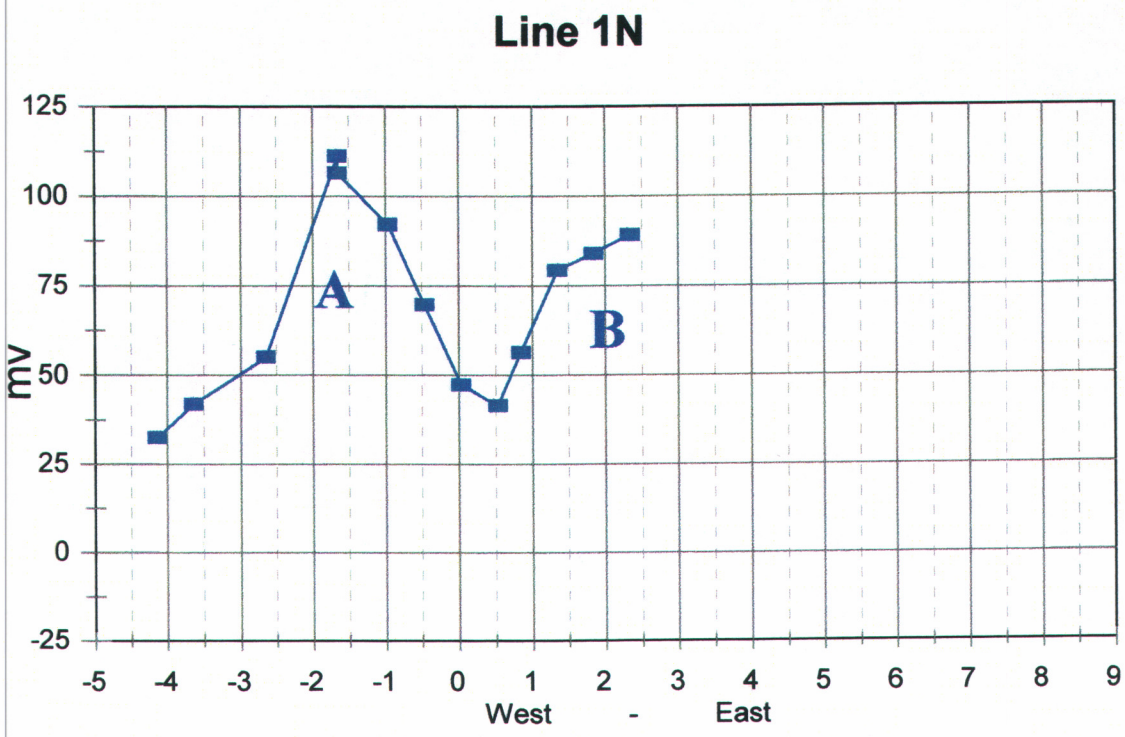


Figure 7 Line 1 N showing the channel center for "**A**" and "**B**".

Line 1 N is a short line that is just about is approximately even with the spring until station -1.5 west. At this point the line jogs north. The two stations at about 1.5 north are 40 and 90 feet north of the spring respectively. The rest of the line runs east, west about 90 feet north of the spring. Two anomalies are visible in this data. The first is labeled "**A**"and the second is labeled "**B**".

Anomaly "**A**" is caused by a narrow structure at this point. This is evident from the pointed Christmas tree shape of the anomaly. When comparing this with the next two profiles, what appears to be happening is that there is some type of funneling occurring at this location. This funneling is above Little Bear Spring and appears to probably cross the canyon feeding into the main water supply that feeds Little Bear Spring. This cross over is west the spring, and indicates that Little Bear Spring is being fed by two sources. As will be shown later, "**B**" is the smaller source but still a significant portion of the water. This double source or conjunction of sources is probably why Little Bear Spring is the biggest spring in the area.

Anomaly "**B**" is caused by a smaller source than Anomaly "**A**" , and Anomaly "**B**"and Anomaly "**C**" is possibly responsible for a lot of the seeps downstream (east) from Little Bear Spring. The rest are seepage from the Little Bear Spring system.

If the reader keeps in mind that Little Bear Canyon is located at the bottom of a syncline and seems to be the conjunction of several other bedrock features it will provide an understanding of the complex nature of this spring system, and how they **all** play a roll in creating Little Bear Spring.

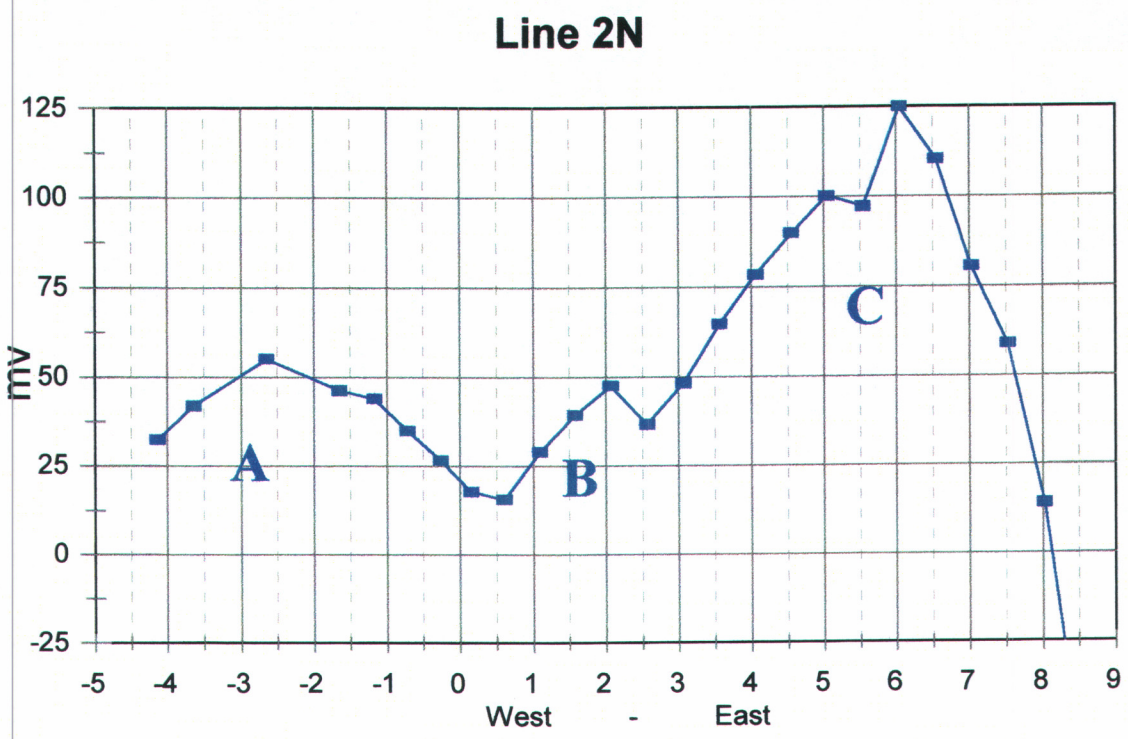


Figure 8 Line 2 N showing the channel center for "**A**", "**B**", and "**C**".

2 N is a long line that runs just above the cliffs located north of the road leading to Little Bear Spring. It uses the same first few stations as line 1 N but deviates cutting at an angle up through the broken cliffs until the profile was above the primary lower cliff structure. The rest of the line averages about 140 feet north of the spring and creek. Three anomalies are visible in this data. The first is labeled "**A**", the second is labeled "**B**", and the third is labeled "**C**".

Anomaly "**A**" is broader on this profile. This is the result of two phenomena. The first is the angle that the second survey line cut through the anomaly and the second is that the subsurface structure broadens over a very short distance. It should also be noted that anomaly "**A**" has a lower amplitude on this profile. However the area under the curve, height vs. width, is about the same which indicates that about the same amount of water is involved in creating anomaly a on both lines.

Anomaly "**B**" is caused by a smaller source than Anomaly "**A**". Anomaly "**B**" is now a side feature to Anomaly "**C**", and anomaly "**C**" is the strongest feature on this and on Line 3 N. However the shape of anomaly "**C**" indicates that it is very narrow and extends to a great depth. Again see the pointed Christmas tree shape of the anomaly, with a very long side that is almost straight with little or no curvature at the top..

Anomaly "**B**"and Anomaly "**C**" are as stated before probably responsible for most of the seeps downstream, from Little Bear Spring.

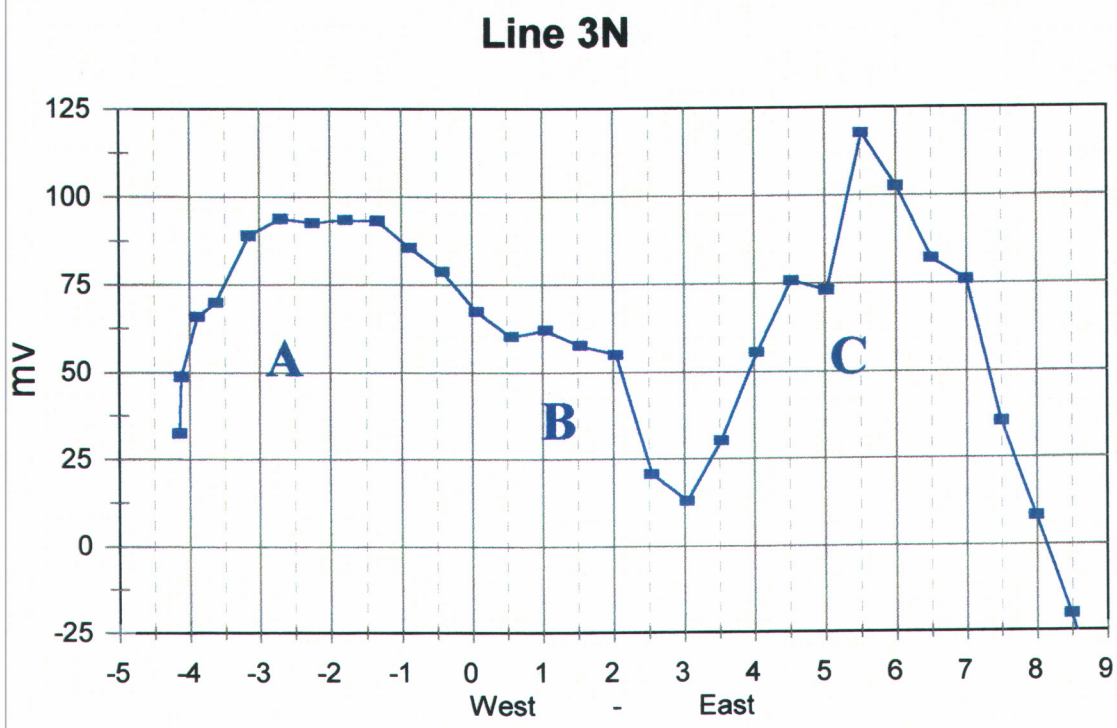


Figure 9 Line 3 N showing the channel center for "**A**", "**B**", and "**C**".

Line 3 N is a long line that runs just below the upper cliffs in Little Bear Canyon. These cliffs are unbroken and there was no way up through them. The only route would have been to follow the creek bottom to where the creek breached this layer. Line 3 N starts with the same first station as line 1 N and 2 N, but cuts up at an angle through the broken cliffs until the profile was at the base of the upper cliffs. After the base of the cliff is reached the rest of the line averages about 225 feet north of the spring and creek. As with Line 2 N three anomalies are visible in this data. The first is labeled "**A**", the second is labeled "**B**", and the third is labeled "**C**".

The ground is getting complicated by crossing of subsurface structure and changes in width and depth of these structures. Anomaly "**C**" is developing a shoulder on either side. These are probably the result of similar parallel structures that are not as wet. Anomaly "**B**" is changed from a shoulder on anomaly "**C**", to a shoulder on anomaly "**A**". Anomaly "**A**"has broadened giving the indication that there might be substantial subsurface storage or reservoir capacity behind anomaly "**A**". The short distance in which the edge of the western portion of this anomaly drops in value after holding the same value for 250 feet indicates not only a voluminous structure but a near the surface structure as well.

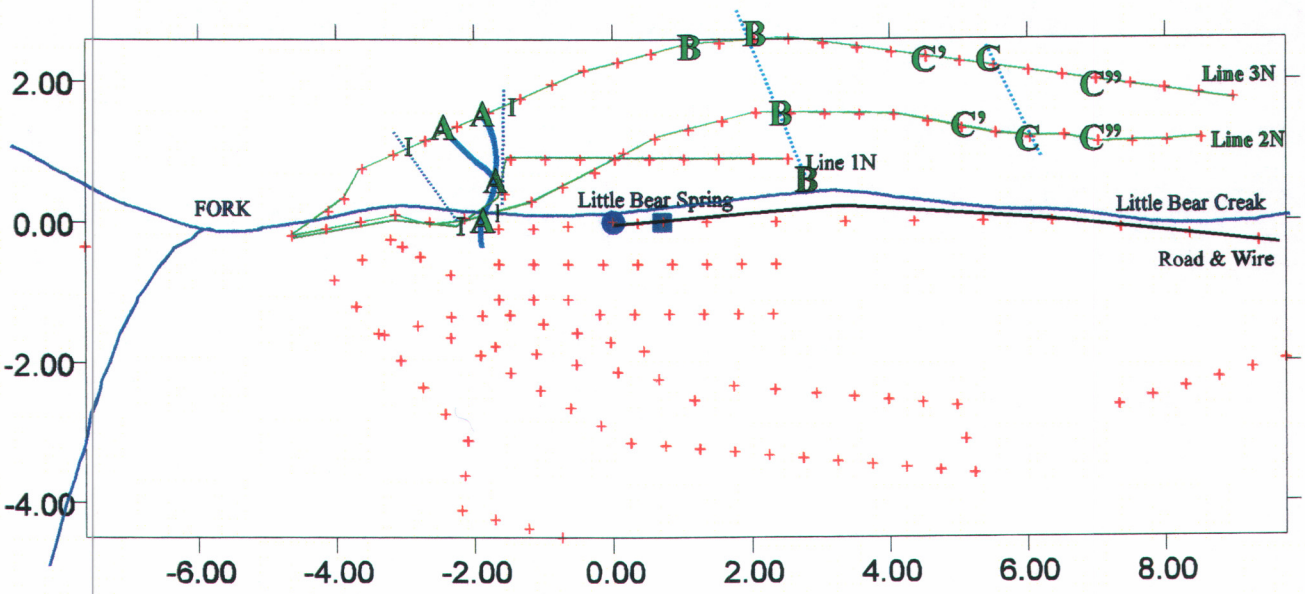


Figure 10 Interpretation of the three profile north of Little Bear Spring.

Anomaly "**A**" is narrow at the bottom of Little Bear Canyon but broadens to the north on Line 3 N. The data gives every indication that this groundwater source passes under Little Bear Creak and most likely enters the underground system that feeds Little Bear Spring. When the profiles to the west and south of the spring are looked at, and interpreted this will become more evident.

Anomalies "**B**" and "**C**" with their side fractures are generally so thin that they probably do not carry much water. They are most likely responsible for all of the small seeps that occur downstream from Little Bear Spring. They are also probably part of a set of fracture or subsurface structures that are also responsible for Anomaly "**A**". An interesting observation is that this set of fractures are located at about 135 degrees to the fracture system mapped on the south side of Little Bear Creak. This could be an artifact resulting from the slight synclinal structure in this valley or it could be related to larger overall past tectonic condition in the area.

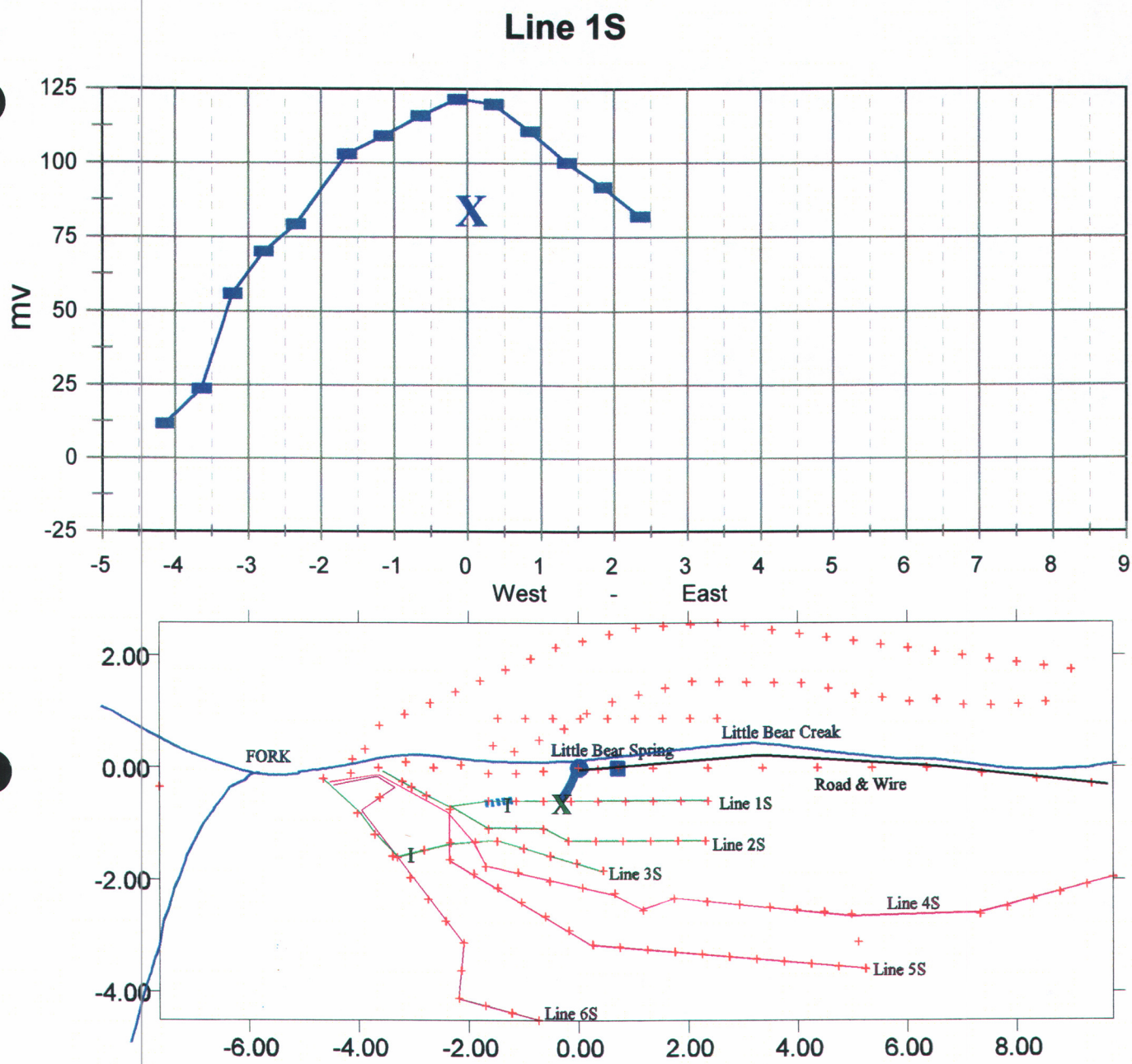
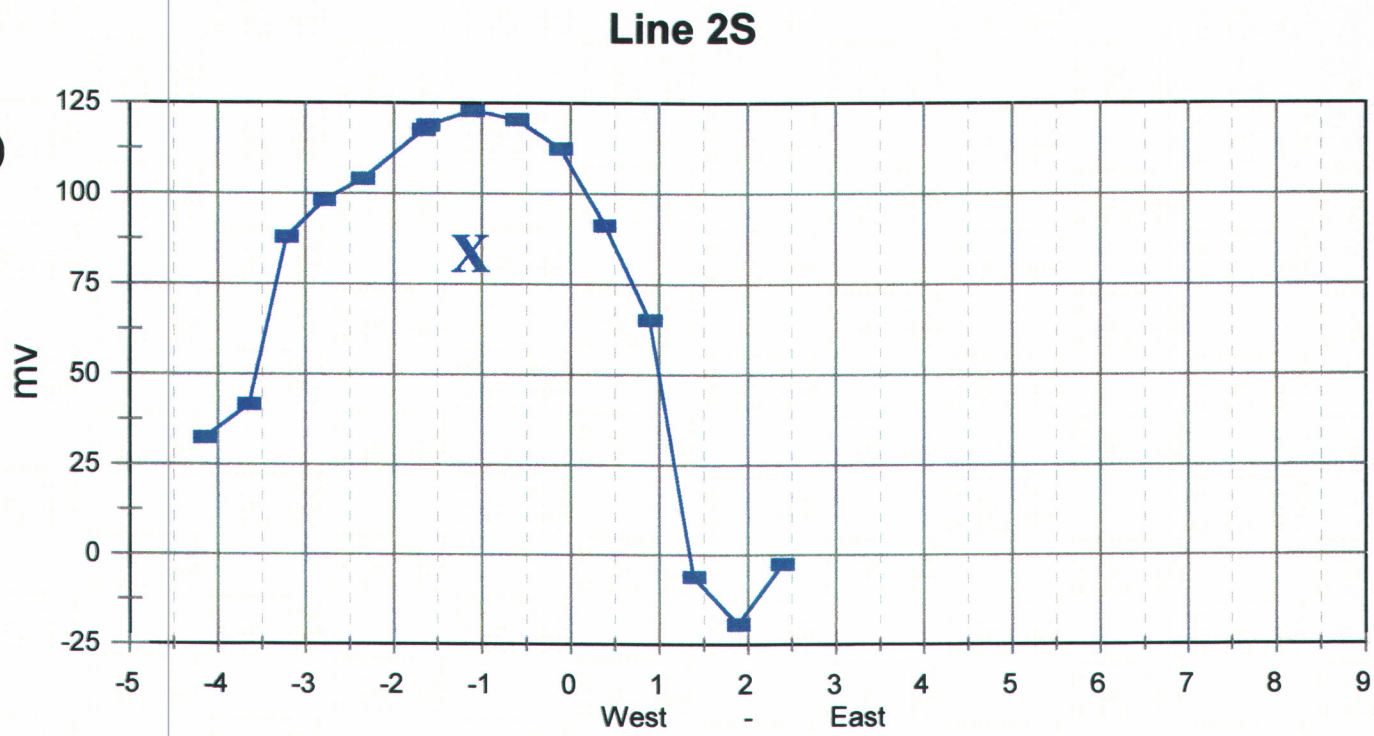


Figure 11 Line 1 S showing the channel center and its position on the plan map.

The magnitude of the anomaly labeled "X" on line 1 S dominates the entire profile. It has two interesting qualities, the first is that the top is not pointed and second the area under the curve is substantial. This anomaly is not to deep at this point and is carrying the majority of the current. In turn this would imply that this anomaly is the primary feed for Little Bear Spring. The "X" marked on the map indicates the center of the channel. The west edge of the channel could be determined but not the east edge. However, the east edge cannot be more than 50 feet east of the channel center. The proximity of the electrodes to this edge, masks the anomaly that it would generate.



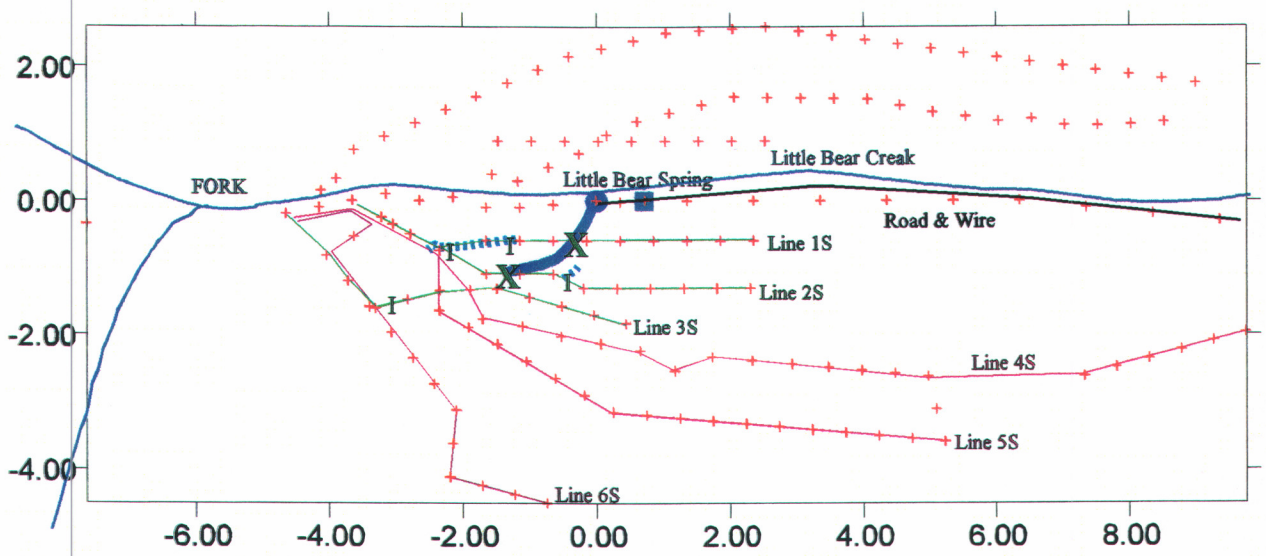


Figure 12 Line 2 S showing the channel center and its position on the plan map.

The anomaly labeled "X" on line 2 S still dominates the entire profile. As before the top is not pointed and the area under the curve is substantial. The sharpness of the edges of this anomaly indicates that it is still not very far from the surface. The edges are easy to identify because of the substantial drop in signal that occurs between coordinates -3.5 and -3 on the west side, and coordinates 1 and 1.5 on the east. The center is located at about -1.25 where on line 1 S the center was about -0.25. The channel center is about 100 feet further south on this profile. The anomaly is still not to deep underground and is carrying the majority of the current, implying that this anomaly is the primary feed for Little Bear Spring. The "X" with the solid blue line marked on the map indicates the center of the channel.

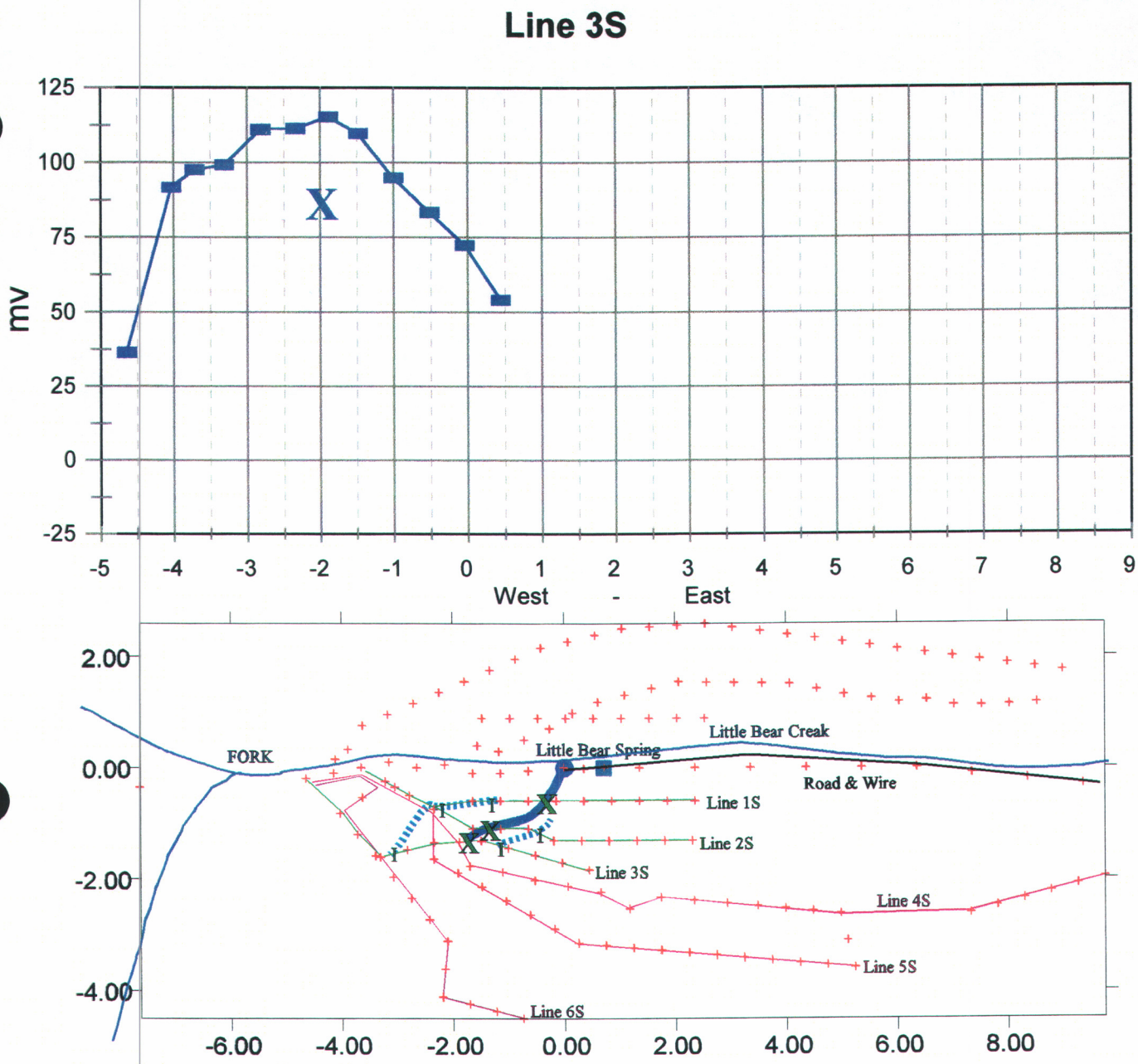


Figure 13 Line 3 S showing the channel center and its position on the plan map.

Line 3 S is short but still contains the center of the channel and a well defined western edge. The channel center is at about -2 and the west edge at about -4.25. It should be noted the a shoulder that was starting to develop on line 2 S is now very prominent on this line. This shoulder is were the water from "**A**" is entering the Little Bear Spring system. The anomaly labeled "**X**" on line 3 S still dominates the entire profile. The top of the anomaly is still rounded and as before the area under the curve is substantial. The edge west edge is easy to identify by of the drop in signal that occurs about coordinate -4.25. The center is located at about -2 so the center has moved another 75 feet to the west. The anomaly is still relatively close to the surface and is still carrying the majority of the current. The "**X**" with the solid blue line marked on the map indicates the center of the channel. The "I" with the dotted blue lines indicate the edges.

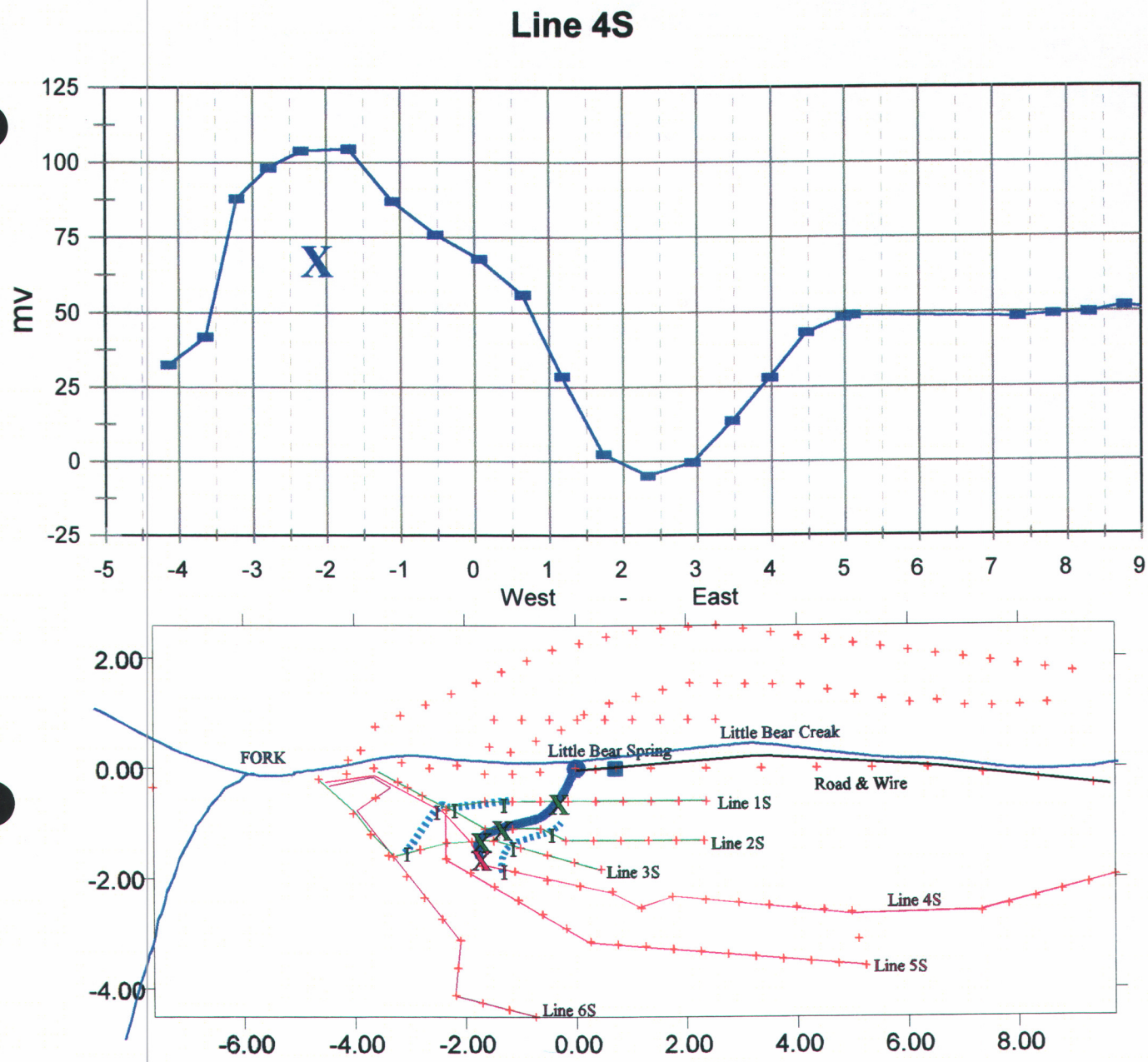


Figure 14 Line 4 S showing the channel center and its position on the plan map.

Line 4 S is a long profile and it provides additional insights into the feeder system for Little Bear Spring. The long tail of data on the east end of line 4 S provides insight into the general back ground value for this type of survey in this are. This constant value at the east end of the line establishes that about 50 mv is probably a good average corrected value for this area. It should be noted that on the west end of all the lines south of the spring the value that the readings approach is about 40 mv. This is for two reasons; first most of the lines ends are using the same stations and second those that don't close in proximity. When the reading on a line approaches 50 mv the readings are reaching background values. The background value is the data value that would be read in the ground if the groundwater was homogeneously distributed

throughout the subsurface. Values above this are more wet than normal and values below this are drier than normal for this area.

On line 4 S there is a dominant low centered at 2.5 east. The value of this low is basically zero or slightly negative. The low at 2.5 is indicative of a dry or low conductivity zone. This zone is probably impermeable and does not permit groundwater to move or even slowly percolate to the east. This impervious zone would force groundwater to the surface especially where groundwater in this area is entering the subsurface from both sides of the canyon. The groundwater is not only entering the canyon but it is in essence colliding with this impervious zone. The consequence is that all the groundwater entering this area is forced to surface. Even the small amounts of groundwater, coming from the north in the narrow "**B**" and "**C**" zones is forced to the surface. The spring system in Little Bear canyon ends where this low ends, about 500 feet east of Little Bear Spring. It is becoming clear that the confluence of geologic structures is not only responsible for Little Bear Spring but for the whole spring system in this area of Little Bear Canyon.

The groundwater feeding Little Bear Spring is flowing from both north and south of Little Bear Canyon. The ratio for the origins of groundwater for Little Bear Spring can be estimated by the area under the curves on the profiles. Based on these areas calculations it is estimated that about 60 to 70 percent of the groundwater is coming from the south side of the canyon and about 30 to40 percent from the north side.

On line 4 S the west edge of the channel feeding Little Bear Spring is located about -3.25. The channel center at about -2. On line 4 S the channel center is almost due south of the center on line 3 S. The east edge of the channel is located at between 1.75 and 1.25. There is a shoulder in the data between -1 and 1 with and average value of about 60 mv. This is probably the result of some water leakage from the Little Bear Spring system. This leakage moves east until it meets the impervious zone. This leakage probably contributes slightly to the seeps or spring system east of Little Bear Spring.

Line 5 S was also long enough that both the Little Bear Spring and the damming systems are visible in the data. The impervious zone starts about 0.5 east and the east edge of the Little Bear Spring channel is between -1 and -0.5 west.

The channel on line 5 S center is about -2 to -2.25, but still basically south of the last two centers or possibly slightly shifted to the east. The west edge is about -3.5, and as stated the eastern edge is about -.75.

The subsurface system feeding Little Bear Spring is widening, becoming broader, or encompassing more of the subsurface with each additional profile to the south. The system probably is involving void spaces or cave like structures in the subsurface rock. This also could be the result of several subsurface fractures forming some type of expanded reservoir like system. What ever the cause it appears that upstream, underground, the channel or fracture system

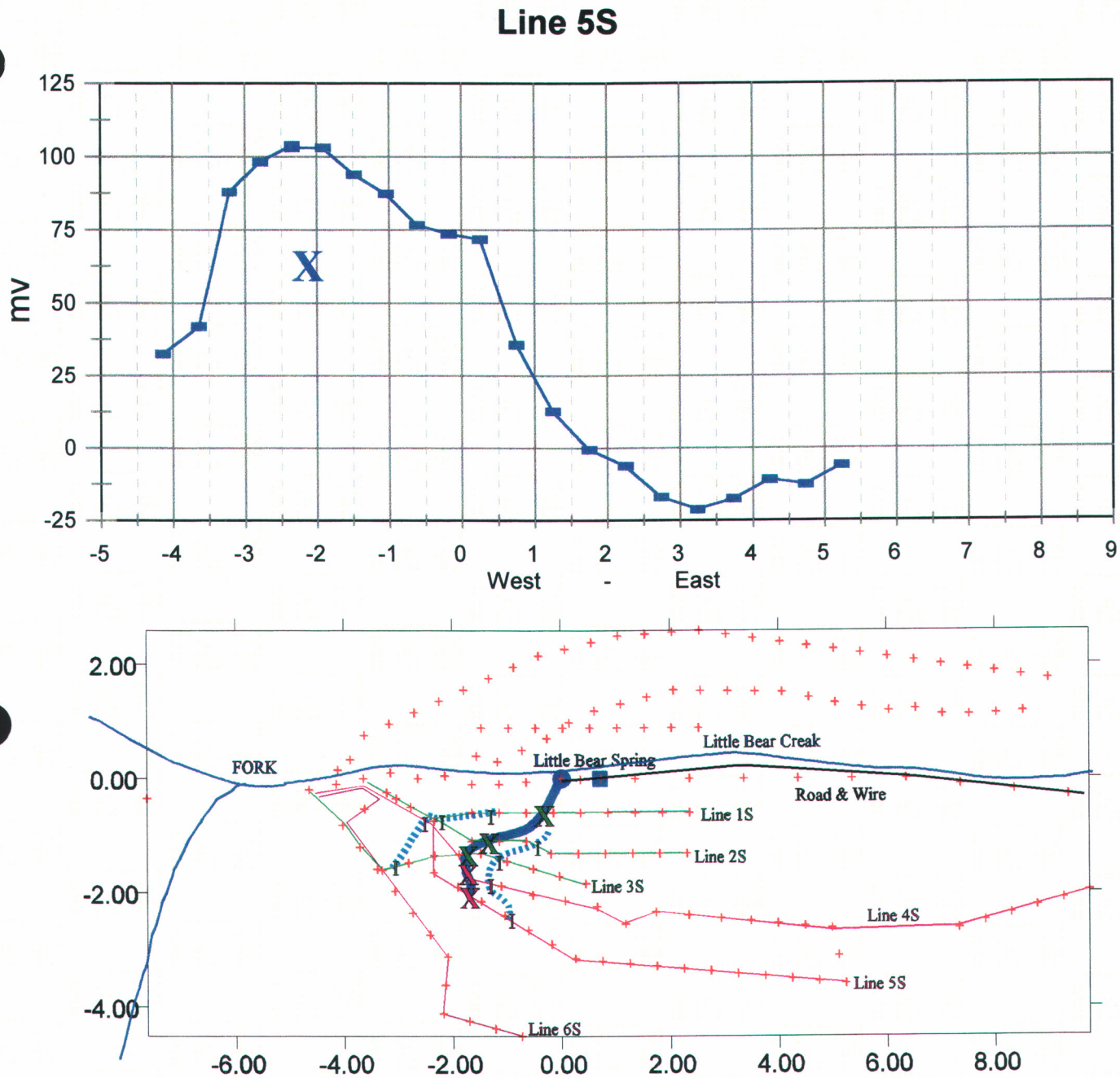


Figure 15 Line 5 S showing the channel center and its position on the plan map.

that is feeding Little Bear Spring is widening. The signature in the data gives every indication that some type of caves or cave like structures are involved. This is because neither the center of the channel nor the edges of the channel or system, whichever it is called, do not form straight lines, but rather have a curved or meandering course.

On line 6 S the sinuous patter becomes even more apparent. The center of the channel has shifted to about -3 which is 100 feet further west than on the previous lines. The western edge is located at about -3.5. The eastern edge

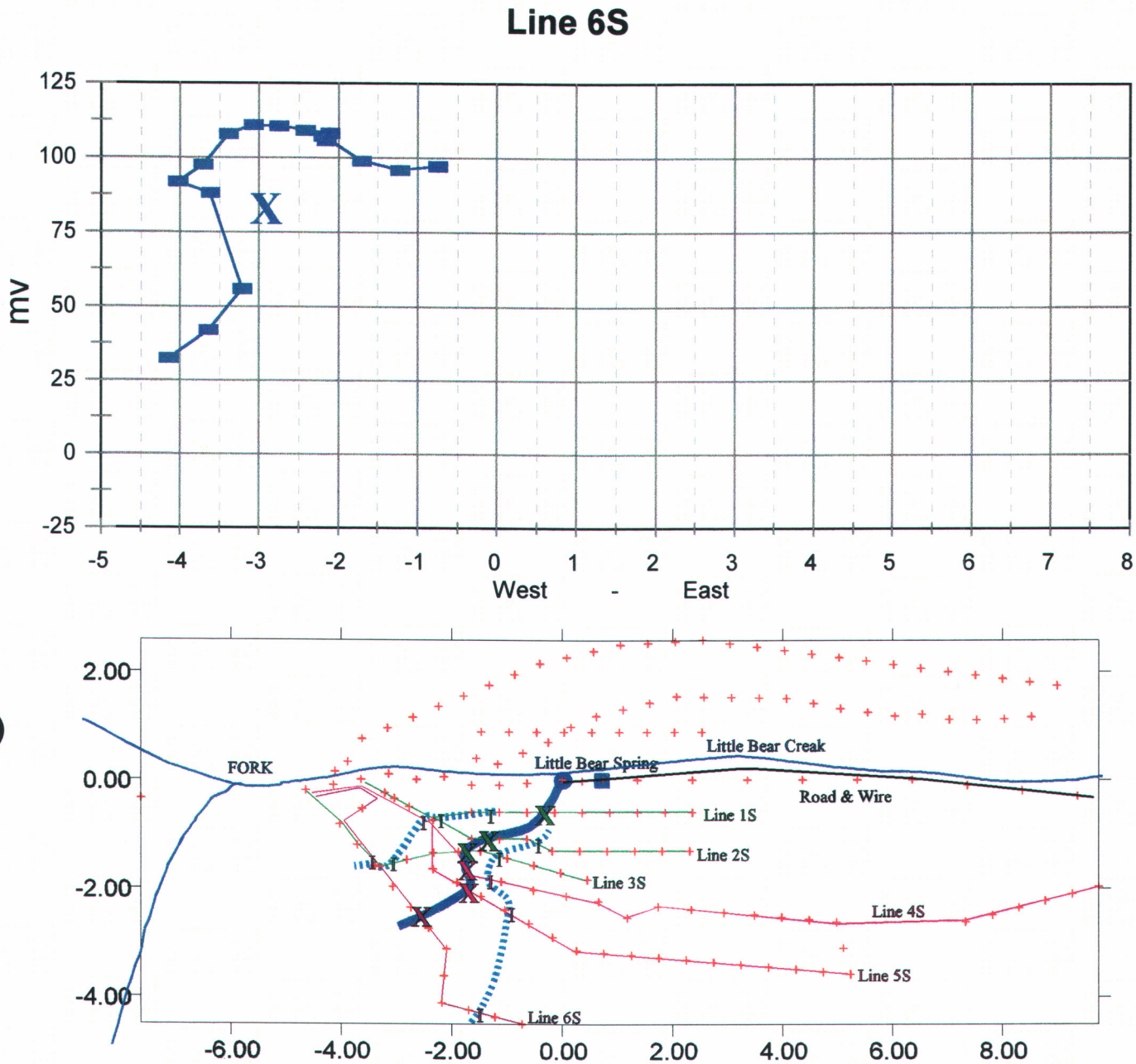


Figure 16 Line 6 S showing the channel center and its position on the plan map.

is controlled by the low conductivity zone, so the channel edge is somewhere between a -1 and zero. The total system is very wide at this location. If the whole system opens up as it penetrates deeper into the mountain it could represent a substantial reservoir that is slowly used during the summer and then replenished during the winter and spring. This would account for the seasonal fluctuations. As the reservoir gets low the pressure drops and the flow of the spring slows down. Then when the reservoir fills the pressure increases, which in turn makes the flow increase.

The general trend direction of the system feeding Little Bear Spring is toward a fault or fracture that follows the left fork of Little Bear Canyon.

Line 1 W, Figure 17, is about 70 feet west of Little Bear Spring. The point where the profile crosses the bottom of the canyon is a low in the values. The value at this point is very near background value. This indicates that the ground is wet above the spring but does not contain a channel that is helping to feeding the spring. The "**A**" and "**X**" channels can be seen in this profile, and at this point they are separate.

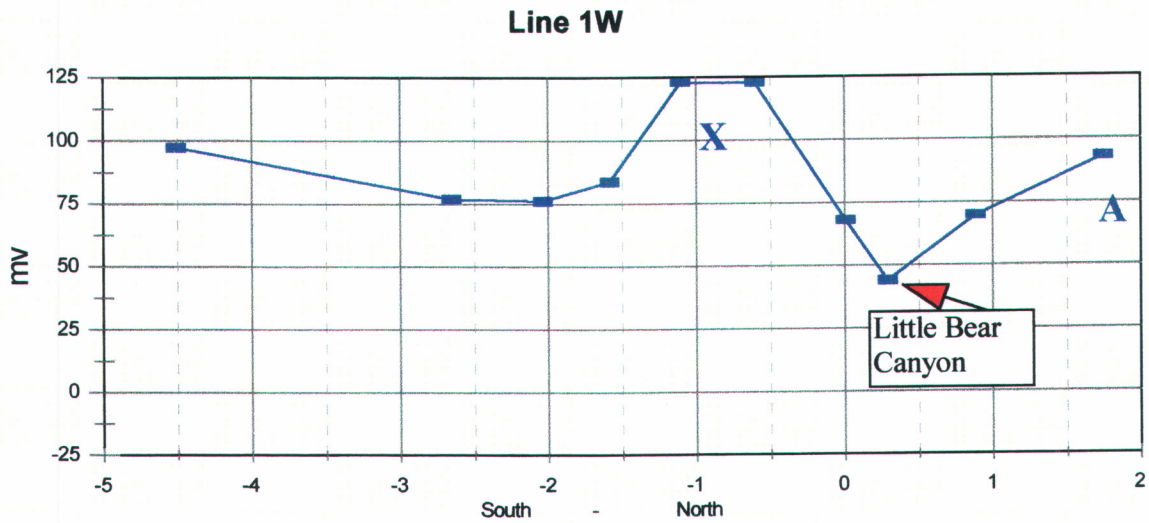


Figure 17 Line 1 W about 70 feet west of Little Bear Spring.

Line 2W, Figure 18, is another 100 feet up the canyon or about 170 feet west of Little Bear Spring. The two channels "**A**" and "**X**" are getting closer but they are still separated and no water coming down Little Bear Canyon stream is part of the Little Bear Spring system. The direction that channel "**X**" follows, places it primarily in the majority of the channel. Even so it is still possible to determine the center of the channel which is about -0.75

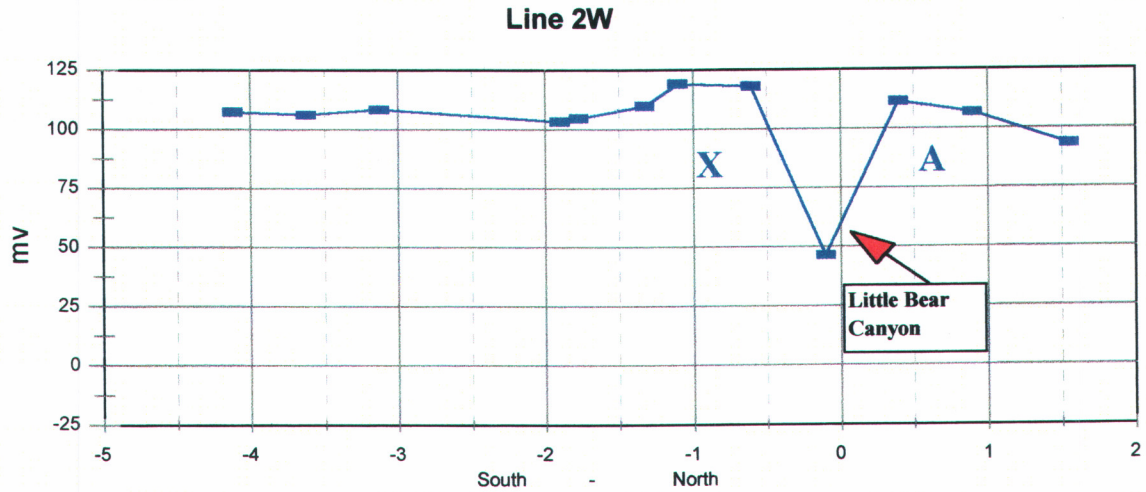


Figure 18 Line 2 W crosses Little Bear Canyon about 170 feet west of Little Bear Spring.

Line 3 W, Figure 19 is a very interesting profile. At first it appears to provide no information because it is so flat. The "**X**" side is a little higher than the "**A**" side, also the "**X**" channel is much broader. This was determined using the profiles north and south of the spring. The most interesting conclusion that can be drawn from this profile is that the survey line follows

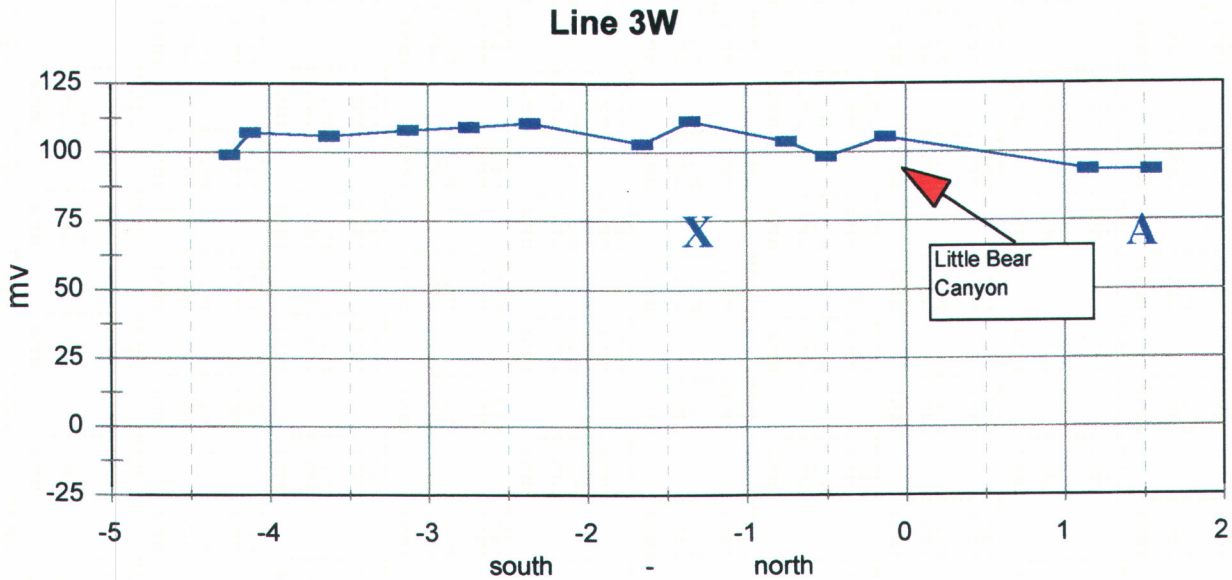


Figure 19 Line 3 W about 270 feet west of Little Bear Spring. There is evidence of a continuous channel along this profile

the channel that brings the "**A**" groundwater channel into the "**X**" groundwater channel. This interconnect is proof that Little Bear Spring is being fed from both north and south. Figure 20, Line 4 W again indicates that no water is feeding the springs from the west , and reestablishes the

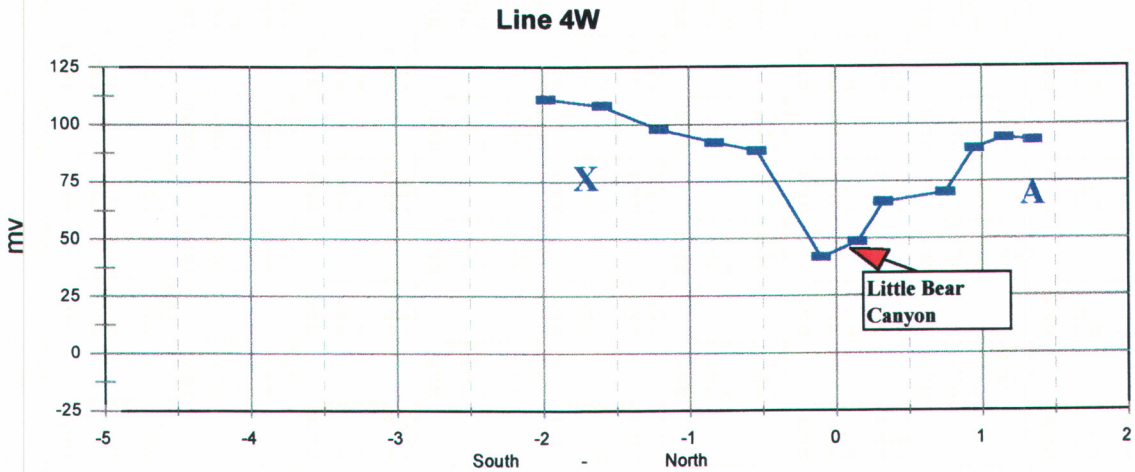


Figure 20 Line 4 W about 425 feet west of Little Bear Spring. The two channels are again evident in the data with a break in the bottom of Little Bear Canyon.

pattern seen in Figures 17 and 18. This shows that the channel under Little Bear Canyon connecting channels "**A**" and "**X**" is very narrow.

Figure 21 is an east, west profile constructed from stations in the bottom of Little Bear Canyon, along the creek west of Little Bear Spring. The interconnection point between channels "**A**" and "**X**" is visible on this profile, line 0 NS. The center of this interconnection or better said the extension of channel "**A**" to where it intersects channel "**X**" is about 250 feet west and up hill

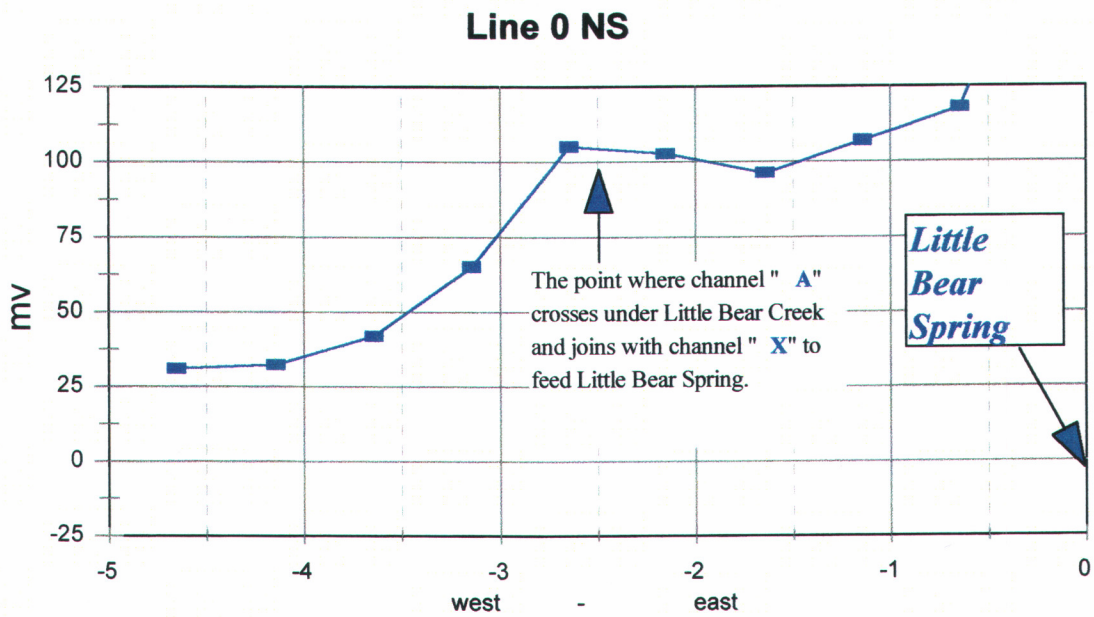


Figure 21 The point were channel "A" crosses under Little Bear Creek is about 250 feet west of Little Bear Spring.

from Little Bear Spring at -2.5 on the graph.

COMBINED RESULTS

When the results of all the data analysis are combined, the results are shown in Figure 22. The light gray area is the low conductivity zone that is most likely forcing the groundwater that is above it to the surface. That is most likely the reason that in addition to little Bear Spring there is a whole complex of springs and seeps in this general part of Little Bear Canyon. The blue indicates high conductivity zones which are usually associated with groundwater.

The ground water feeding Little Bear Springs is coming from two major sources. The one to the south is apparently supplying between 60 - 70 percent, and the one to the north apparently between 30 - 40 percent of the water. The data indicates that the underground system is quite open and extensive. This is indicative of some type of cave system. It could be one that has developed along a series of fractures or faults or it could be the result of deferential cementing that is visible in out crops which are very pock marked. In any case it appears that the system forms some type of reservoir that is constricted by the springs opening and thus supplies a flow all

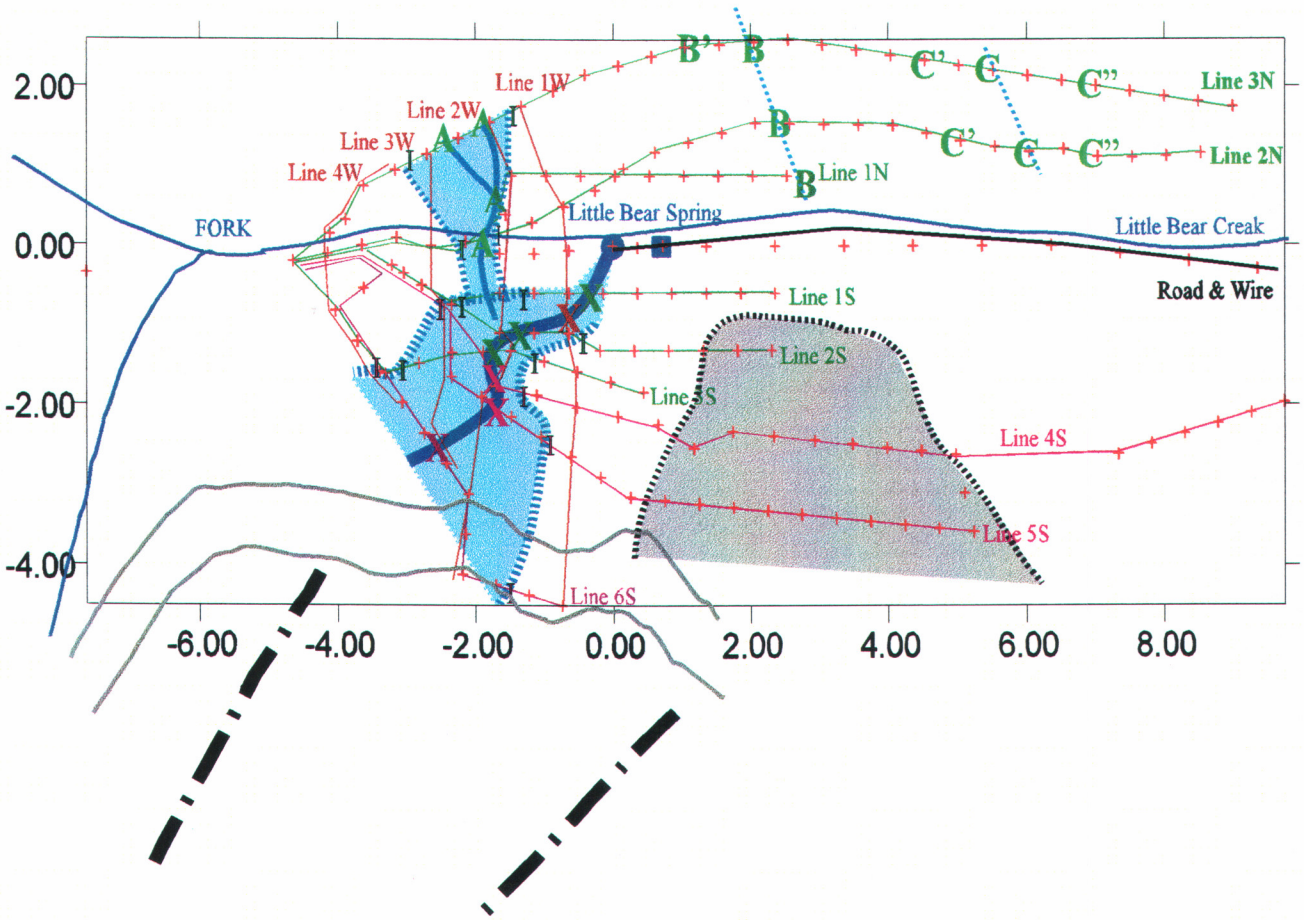


Figure 22 Final interpretation of AquaTrack survey for Little Bear Spring.

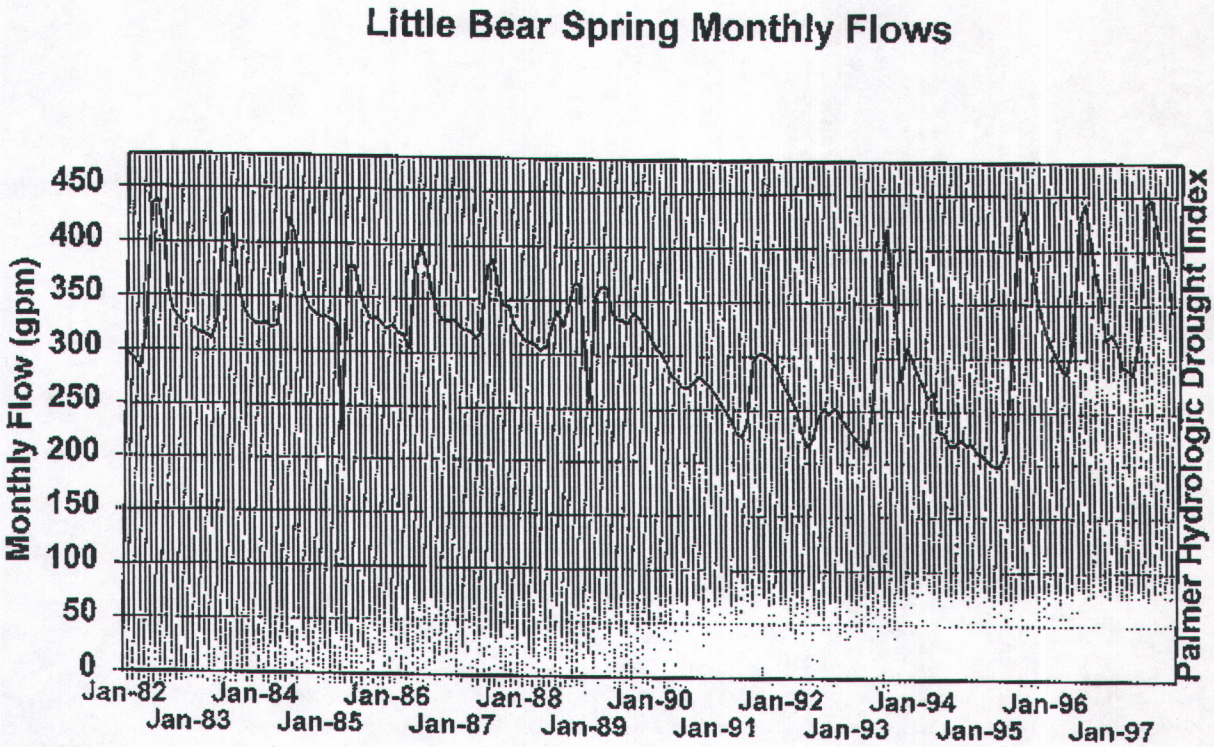


Figure 23 Annual cycles of flow from Little Bear Spring. On average for the last fifteen years the maximum flow occurs in late spring, and gradually tapers of to a minimum flow in the winter. year.

As can be seen in Figure 23 the flow is not constant but increases and decreases with the seasons. This would indicate that the recharge of the Little Bear Spring system is very dependant on seasonal recharge of the underground reservoir.

In Figure 24 the AquaTrack interpretation has been superimposed on a topographic map of the area. Note that some of the features from the Topographic map have been included in the interpretation map. These include Little Bear Creek, the boundary between the Blackhawk and Starpoint formations and the northern ends of two faults that have apparently been mapped in the Blackhawk but have not been mapped in the Starpoint formation. *An enlargement of the interpretation is also shown just behind the cover page.*

Figure 25 is an smaller scale copy of the topographic and geologic map used in Figure 24. This map is included to show the extent and trends of the faults that seem to terminate just above Little Bear Spring. It also shows two interesting aspects about the fault that is pointed at Little Bear Spring. First that is must be a soft or highly fractured fault because it seems to follow or even be responsible for forming the south fork of Little Bear Creek. The south fork could be just one of the recharge areas. Second, this fault reaches all the way to Mill Fork Canyon, see Figure 26.

Figure 26 is an even smaller scale map. The fault that seems to point right at Little Bear Spring is highlighted in green. On this map the fault extends to Mill Fork Canyon but was not mapped to the bottom of the canyon to Mill Fork Creek. To see if Mill Fork Creek might be contributing to Little Bear Spring a large transmitter was connected to the wire energizing the spring. A line of data was taken along the bottom of Mill Fork Canyon. The larger transmitter was able to supply three times the energy of the first transmitter. However, the canyon was not close enough for the current to reach Mill Fork Canyon and unfortunately bled off into the ground before it traveled that far. Thus, there was no signal measured in Mill Fork Canyon.

This should not be construed to mean no water from Mill Fork is part of the supply for Little Bear Spring it only means a different antenna arrangement is needed to test that hypophysis. The antenna setup was not optimal for testing Mill Fork Canyon. There was neither confirmation or non-confirmation that Mill Fork Canyon supplied water to Little Bear Spring.

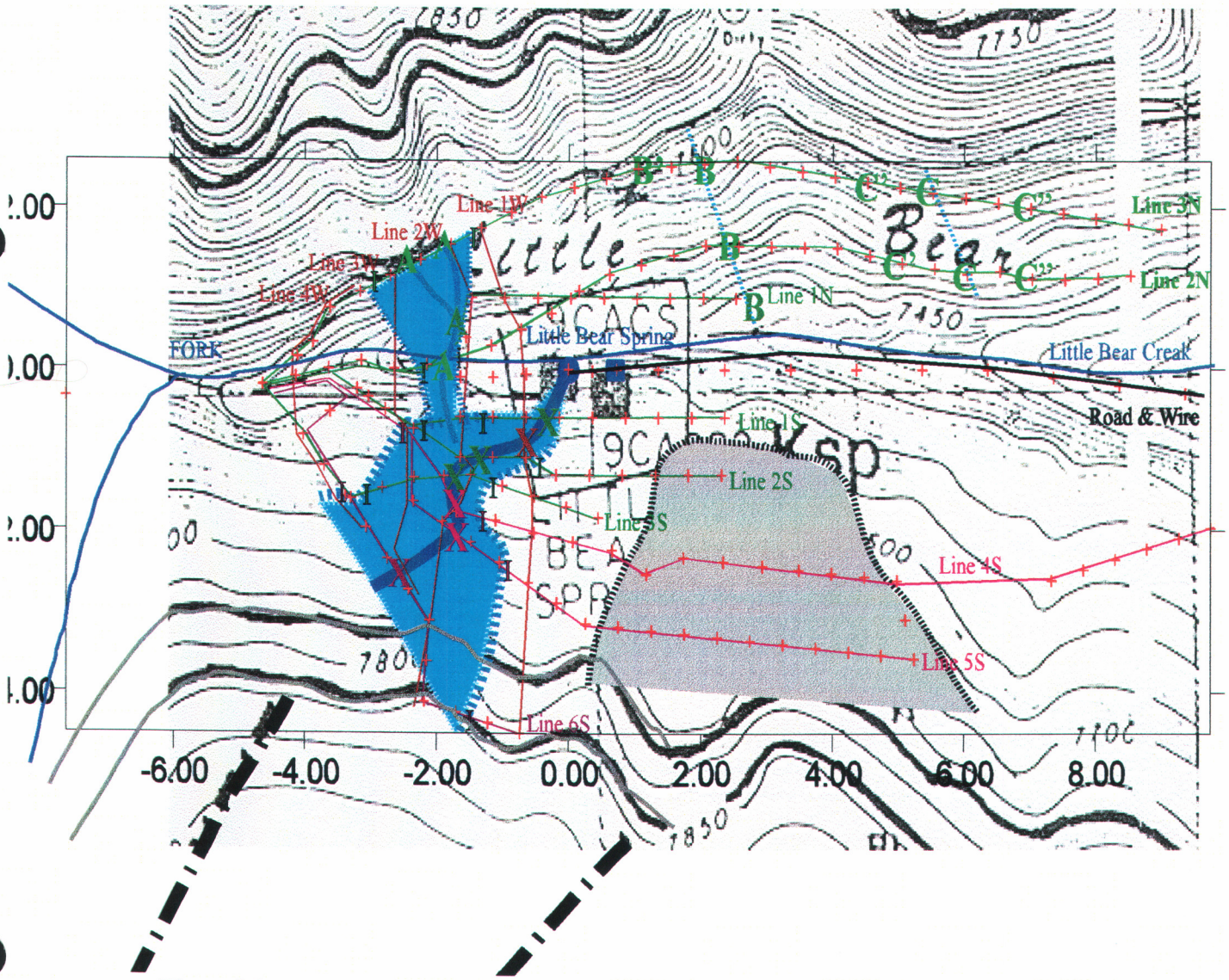


Figure24 Interpretation for Little Bear Spring overlain on a topographic map for the area.

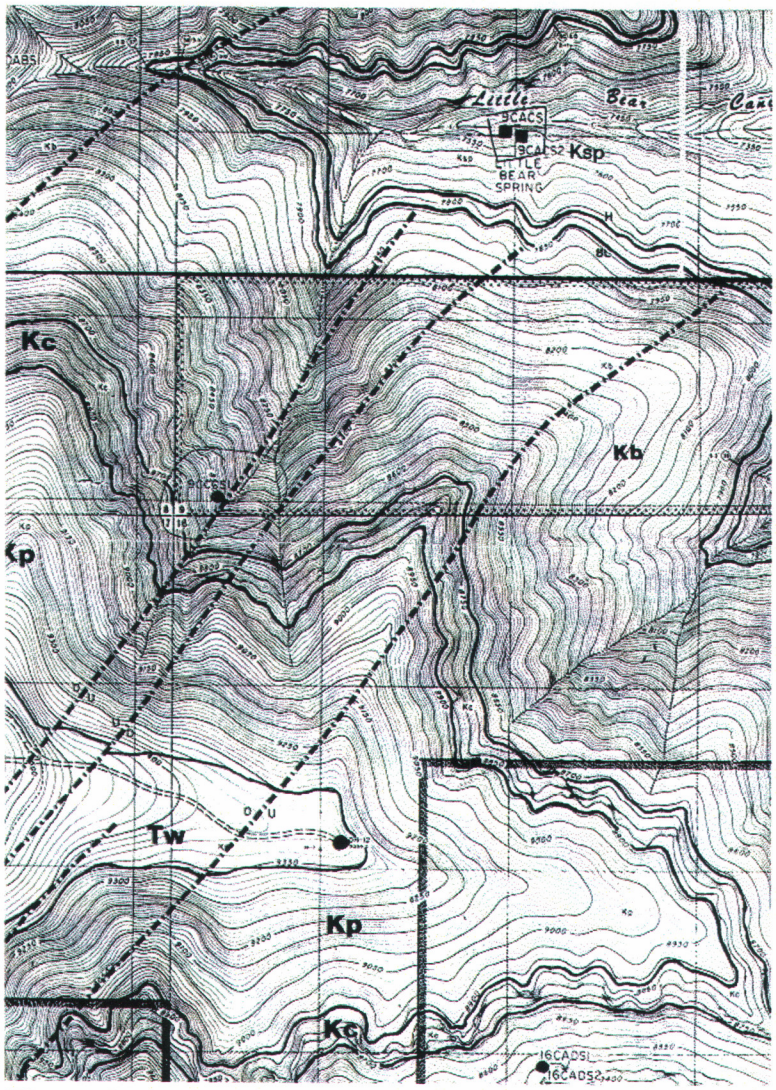


Figure 25 Expanded topographic and geologic coverage of the area around Little Bear Spring. The fault that extend to the southwest are also shown on Figure 22 and 23. On those figures only the very northern most part of the faults are visible.

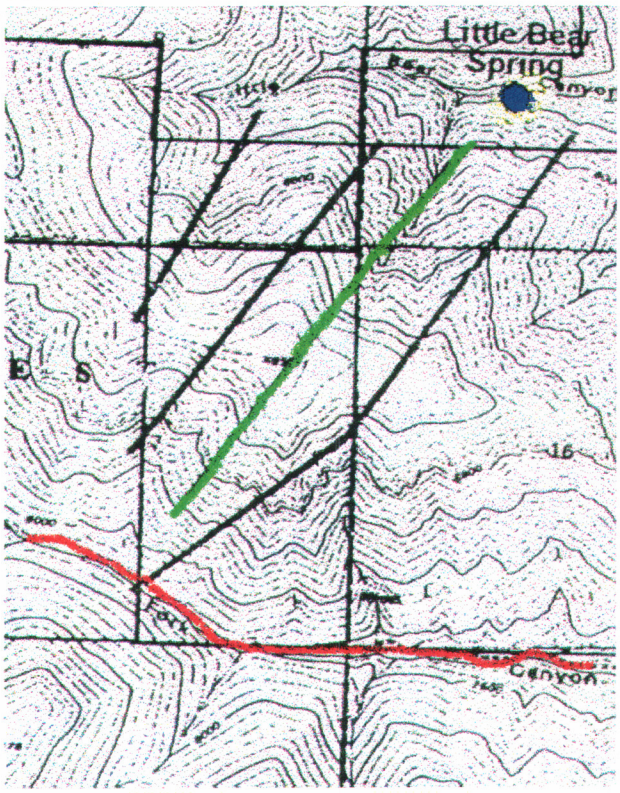


Figure 26 A larger scale map showing where faults extend into Mill Fork Canyon. The green line is the suspected fault. The red line indicates the location of a data line taken in Mill Fork Canyon.

Figure 27 is a combination of topography and geological structural features. It contains two interesting pieces of data. The first is that Little Bear Canyon is formed out of a syncline that is plunging to the west, this is shown in red. Thus, down gradient for all water is to the bottom of Little Bear Canyon. Second, this map indicates that on the northern limb of the syncline the faults are running at approximately 135 degrees to the faults that were shown in Figures 25 and 26, shown in green. The fault direction is the same direction indicated by the AquaTrack survey for structure the water is following on the north side of Little Bear Canyon.

We apologize for the quality of the last figure as we had to scan it from a poor reproduction.

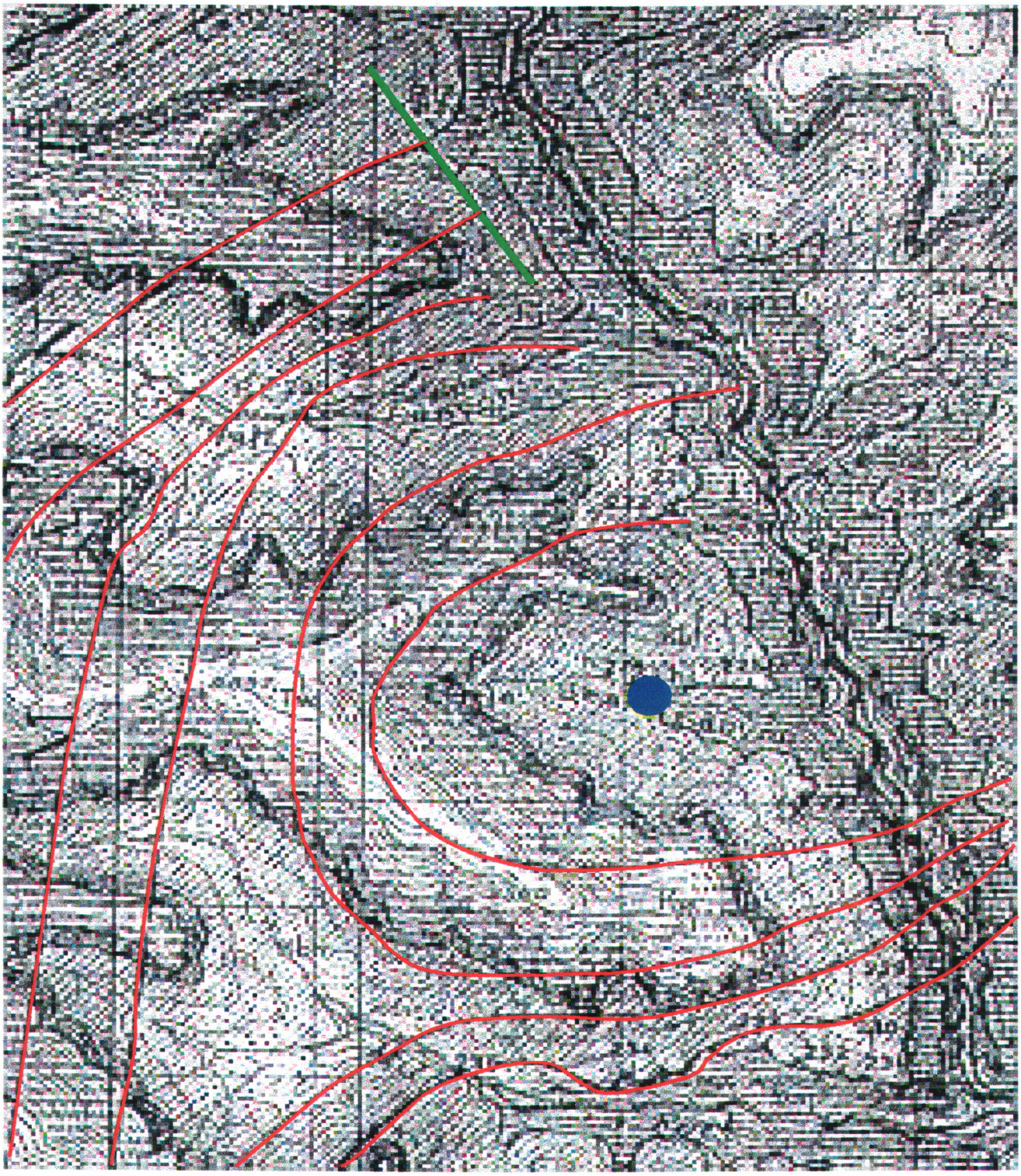


Figure 27 Structural contour near Little Bear Canyon. Little Bear Canyon is centered on a weak syncline, shown in red. Also notice to the north of Little Bear Canyon near the center of the map is a fault that is running northwest to south east, shown in green. This is the same trend as observed on the north side of Little Bear Canyon in the Aqua Track data.

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, but are simply intended as an overview to afford appreciation.

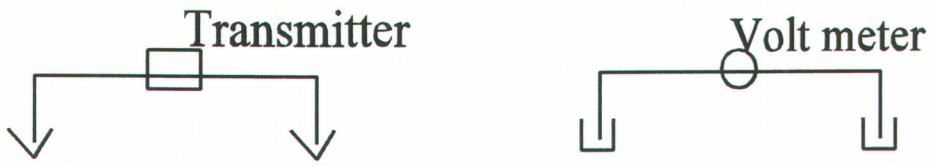
Differences between AquaTrack and conventional groundwater tracking technologies

Current groundwater mapping technologies fall into one of the following categories: conventional geophysics, tomography, or monitoring wells using logging technologies or tracers.

Conventional geophysics generally involves indirect energizing and measurements which includes: galvanic resistivity, electromagnetic conductivity, conventional electromagnetic surveys, ground penetrating radar, refraction or reflection seismic surveys, 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. Detecting groundwater plumes or even resolving plumes at depths greater than about 100 feet is very difficult using conventional geophysics.

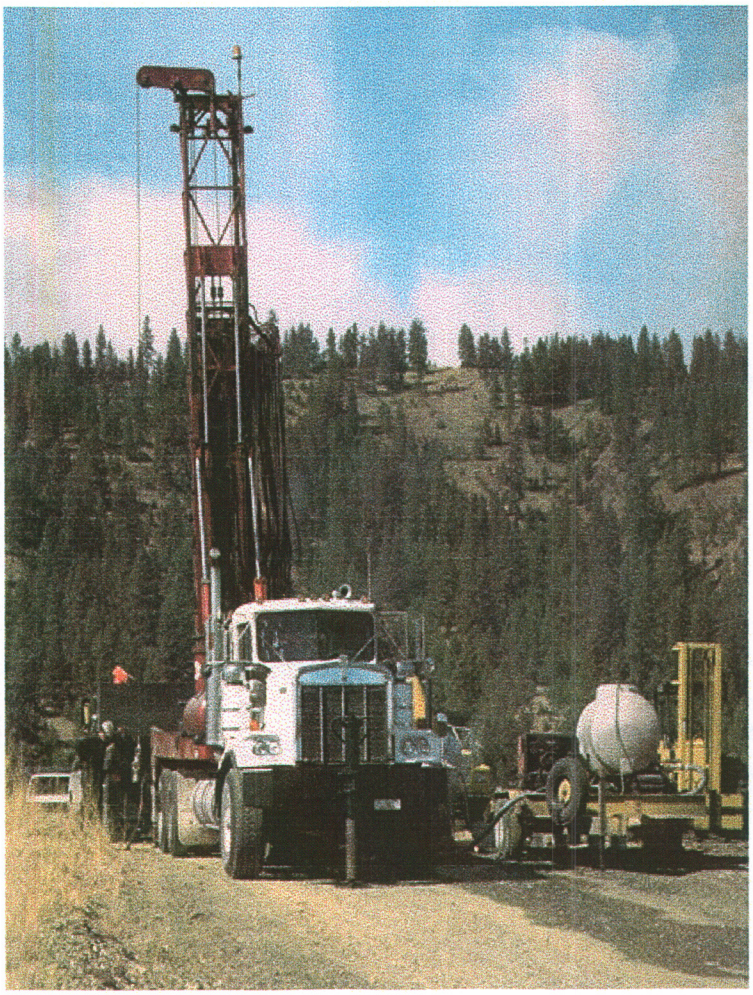
The disadvantages of resistivity and conductivity surveys are that they are indirect methods and map low resistivity zones. The zones may or may not be associated with the particular subsurface water in question. The various classical surface electrical resistivity and/or conductivity techniques map resistivity lows or conductivity highs. There is no assurance that the various anomalies are interconnected or just how they relate to the water of

interest. There can be two adjacent resistivity anomalies that may or may not be connected because of stratigraphic interference or other problems. Classical resistivity and conductivity technologies energize all subsurface features and average values over a broad area. 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.



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. Resolution is a function of the specific wavelength of the energy source used. The wavelength for seismic tomography is the frequency of the acoustic wave and for electrical resistance tomography, it is the spacing of the electrodes. The drawbacks to tomographic technologies are that they are very time consuming and expensive. In addition, resolution of individual features deteriorates as their depth from the surface increases, especially for small or narrow features.

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. One geophysical technology used to establish connectivity between holes is to place an electrode in one hole at the horizon of interest and then lower another electrode in the second hole to see if there is a response at the horizon of interest in the second hole. This technique establishes connectivity but does not provide a trace of the subsurface path between the drill holes. With monitor wells it is difficult to confidently map a subsurface water system and be certain that all branches or narrow off shoots 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 a limited range of detection. Generally the detection limits on well logging tool range from a fraction of a meter to just a few meters from the well.

Tracer technologies include: radioactive or non-radioactive tracer methods. Tracers are any substance that can be easily and uniquely identified. Tracers are introduced into the medium being investigated and then wells or leaks are monitored at outlying locations for the appearance of the tracer. This technology requires monitoring wells and relies on intercepting the tracer to detect leaks. Tracers are a powerful technology. However, it takes time for the tracer to move through an aquifer or subterranean system. The aquifer must be continually monitored and sampled to pick up an indication of the tracer which generally requires sophisticated lab analysis to detect the tracer in the minute quantities that make it through. In some situations it may be objectionable to introduce any additional chemicals into a sensitive system.

AquaTrack mimics tracer technologies in that it uses electrons as its tracer and magnetic sensors to monitor the movement of the tracer. Data reduction can be done on a computer spread sheet, and interpretation involves analyzing profiles and contour maps of the magnetic data.

Technology analogous to AquaTrack

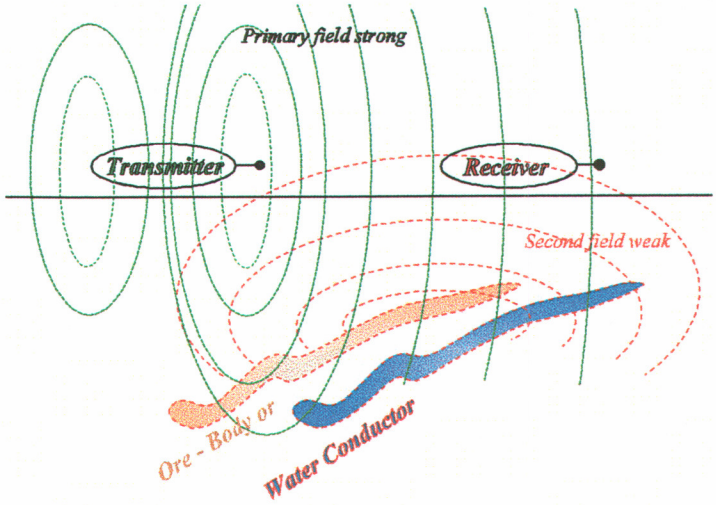
AquaTrack uses the concepts similar to several existing technologies but differs in its execution of the application to tracking water.

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 phone companies 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**. The closest analogy is 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 mapping the magnetic field. When using **AquaTrack** to track groundwater, underground pipes and wires create noise that must be identified and corrected.

Background

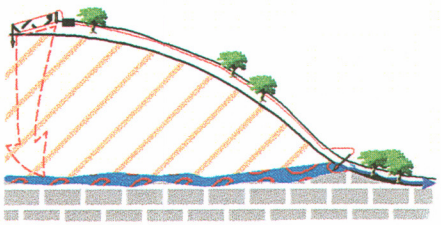


Conventual E.M. surveys

Electromagnetics have long been employed by geophysicists to find minerals and ore deposits. The concept of electromagnetics is straight forward. A fluctuating electrical current in a coil will generate a fluctuating magnetic field. The converse is also true. A fluctuating electric current will be generated in a coil placed in a fluctuating magnetic field. A sub corollary is also true, that any conductor placed in a fluctuating magnetic field will have electric currents circulating in the conductors which in turn will produce their own magnetic field which will oppose the first magnetic field. This secondary magnetic field will be much weaker than the primary magnetic field.

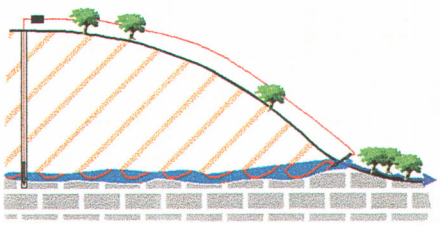
In conventional electromagnetic techniques a transmitter coil is placed on or near the surface. The transmitter coil is energized to create an alternating magnetic field. This alternating magnetic field induces electric current in all the conductors in the area. A second magnetic field is generated by the current flowing in the conductors. The secondary magnetic field interferes with the primary magnetic field and this interference is measured. There are two major problems with this method when mapping subsurface water channels. First, all conductors in the subsurface are energized the same amount and will respond in similar ways and second, the secondary magnetic field is usually much weaker and can be hard to resolve from the primary field.

The technology used to track groundwater uses electromagnetics, but **AquaTrack** combines geophysics and tracer technology. By injecting electricity into the solution being investigated the electrons become tracers. As ions in the groundwater move, they generate a magnetic field. This magnetic field can be measured some distance away from the moving ions thus direct contact with the groundwater is unnecessary. **AquaTrack** creates a primary magnetic field in the conductor of interest and other conductors not of interest generate only a weaker secondary magnetic field. The path followed by the electricity maps the groundwater and related structures. **AquaTrack** is an electromagnetic method developed to track and monitor ground waters.



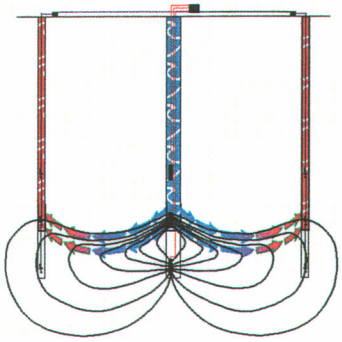
Some of the capabilities of AquaTrack are:

- Mapping subsurface pollution plumes.
- Finding the source of seeps.
- Delineating leaks in earthen dams and drain fields.
- Monitoring changing subsurface ion concentrations or reaction fronts.
- Monitoring leaching solutions.

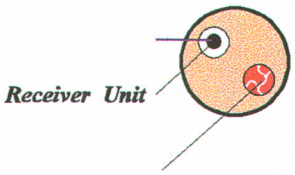


When there is a surface expression of the groundwater of interest such as a seep or spring the best techniques are to place one of the electrodes directly in the seep or spring.

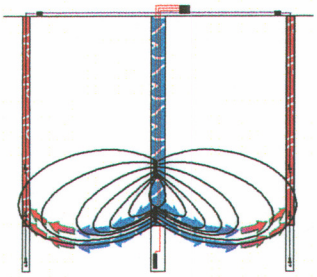
In a drill hole the preferred electrode configuration is to place the return electrode below the energizing electrode. When the return electrode is the upper electrode the current flowing back is closer to the receivers on the surface and thus masks the signal from the groundwater. When the energizing 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.



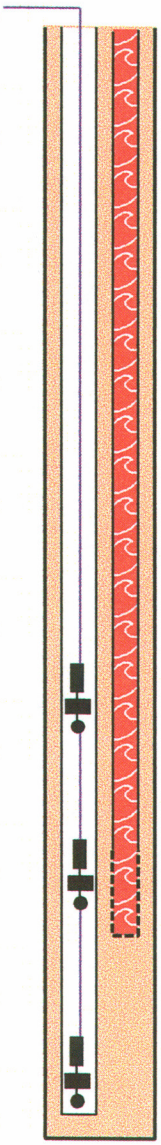
Current Flow bottom & middle electrode



The principle of electrons acting as tracers is utilized so that AquaTrack can actively monitor retainer walls and other subsurface barriers for leaks. This system not only detects leaks in the barrier but identifies the leak location. The leak can then be repaired with a minimal cost.

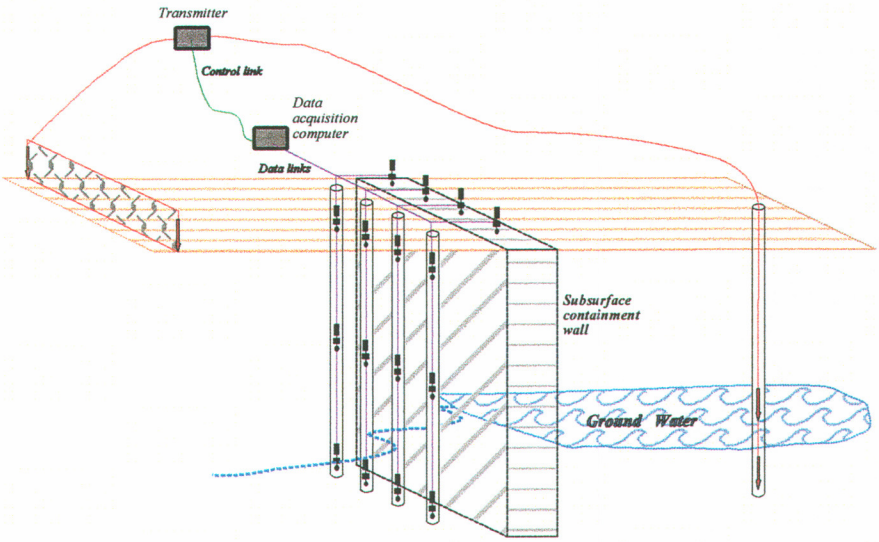


Current Flow top & middle electrode



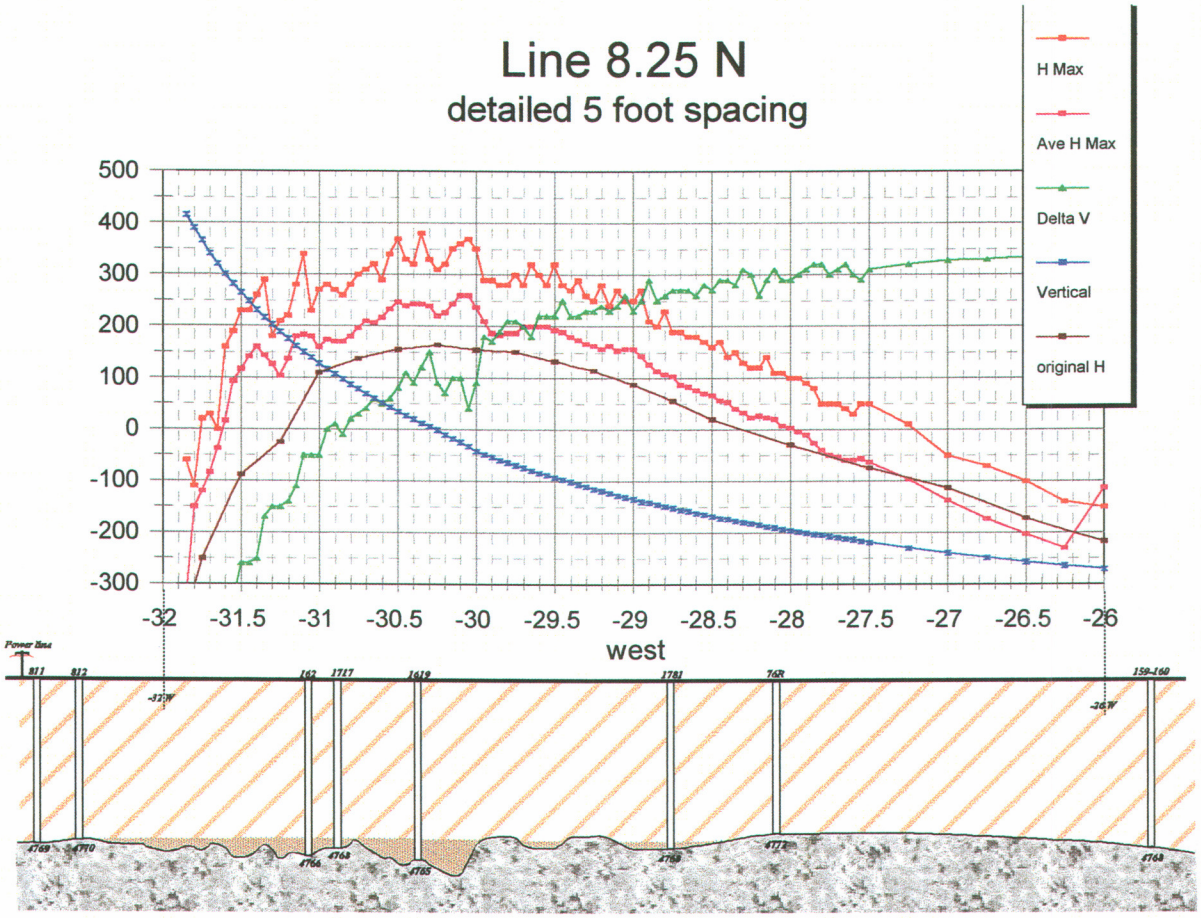
Pure water is not a good conductor, but groundwater is not pure, containing ions from many sources. The more minerals in the water the better a conductor the water will become whether the ions come from natural sources, pollution, or from leach solutions. Ground water is a better conductor than everything in the ground except metals. By directly energizing a stream of ground water, the water acts as a subsurface conductor. The magnetic field generated by the electric current flowing in that conductor can be measured on the surface. Since this is a primary field, it is stronger and much easier to track than the secondary fields used by other electromagnetic technologies. Directly energizing requires at least one point of contact with the water in question.

While AquaTrack is based on sound scientific theory, in practice it can be quite difficult. The water being tracked may be 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.



Subsurface Containment Wall

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. Although the data obtained by AquaTrack usually allows someone with experience to determine these things, it is always prudent to consider all prior knowledge of a site to confirm observations and as a double check for any data interpretation.

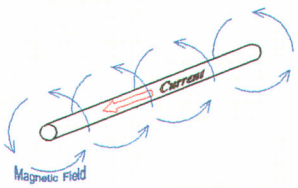


AquaTrack data frequently enhances the value of other types of data that has been collected for the site.

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 interpretive foundation. The following is an overview of these principals and, in some cases, examples of how they are used to interpret AquaTrack data.

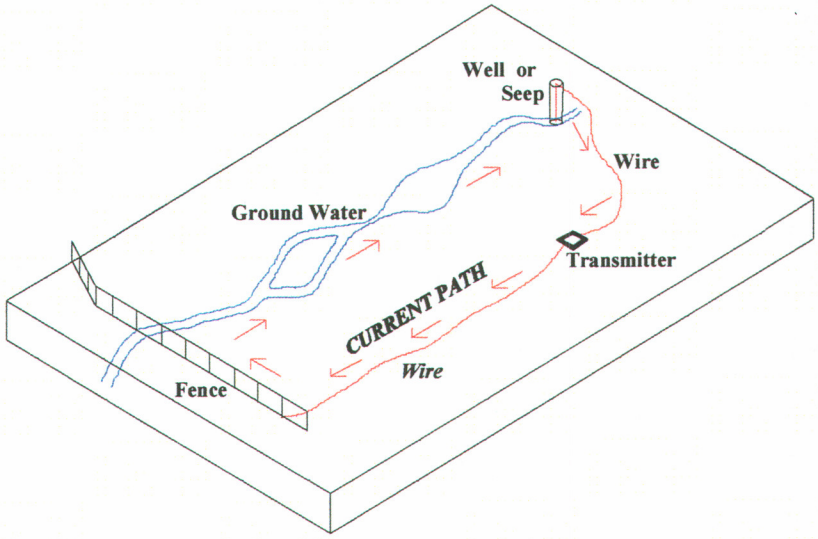
1. Current flowing in a wire generates a magnetic field that wraps around that wire perpendicular to the flow of current.



If the wire is replaced by another conductor, such as water in a subsurface channel, current following that water will create a magnetic field. By mapping the magnetic field generated by the electric current the water channel can be located.

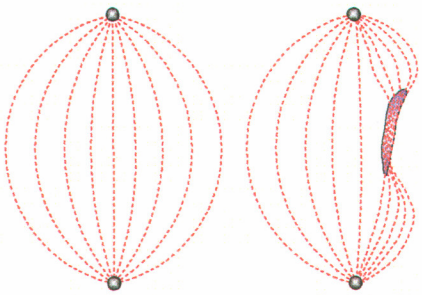
2. Two coils in close proximity are coupled magnetically. A transformer is a special case of two coupled coils. The primary coil is the loop carrying the initial current. The secondary coil has current induced in it by current flowing in the primary coil.

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



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

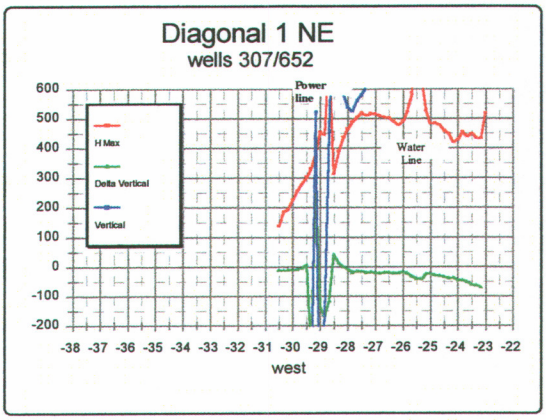
3. A good conductor, such as a metallic object, placed in a moderate conductor will gather current from the moderate conductor into the good conductor.



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.*

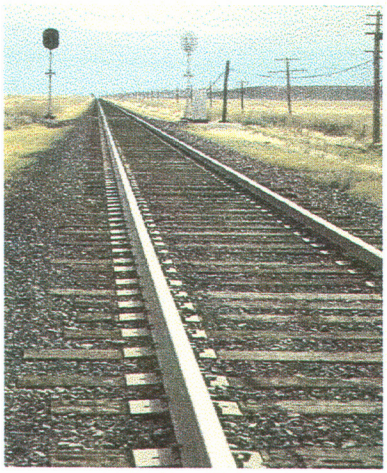
Good conductors in the ground will gather electrical current flowing in the ground. This is referred to in the geophysical literature as *current gathering*. Current flowing in the ground will preferentially follow good conductors in the subsurface. There are three general classes of good conductors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

■ First are groundwater channels. When current is directly injected into the conductor of interest, 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. These include:

- communication lines,
- overhead power lines, (The effect seen on the profile to the right at station -29 is due to overhead power lines. Pipes and communication lines have similar signatures but not as strong.
- underground metal pipes,
- chain-link or steel stake fences,
- rails or other elongated conductors.

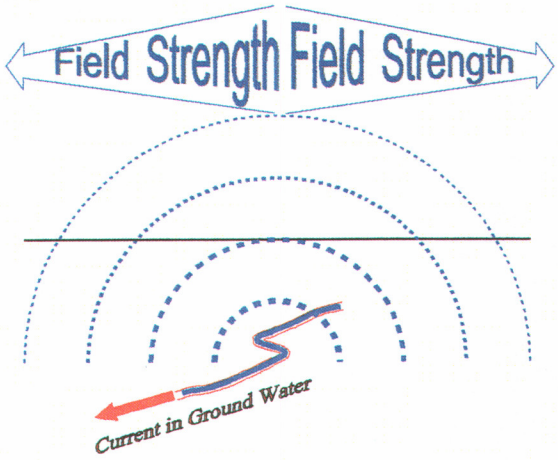


The locations of fences, wires, pipes and conductors are usually known thus they can be accounted when the data is interpreted.

■ 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

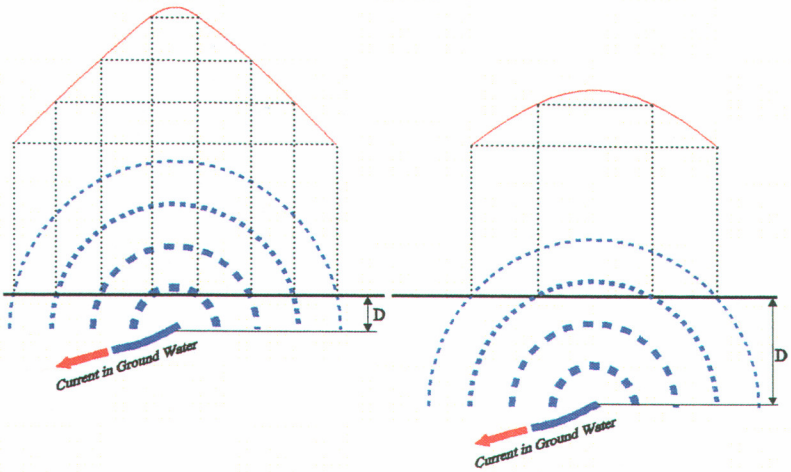
Following are observations of how the magnetic field behaves when using AquaTrack and how this technology is used to map groundwater channels. A loop is formed by the wire and current in the ground. A magnetic field is generated by electrical current following subsurface water. Mapping the components of the magnetic field provides information which can be used to map the electrical ground current, which maps the groundwater.



To examine what is happening we will return to our most elementary model which demonstrates the principle of how this technology works. Consider what happens when electric current flows in a wire. A magnetic field is produced that circles the wire. If a conductive stream of water or solution replaces the wire, a magnetic field will form directly above the water's channel. This field will be horizontal and perpendicular to the conducting zone just as it would be for a wire. A curved conductor will behave the same way. The strongest field strength will be measured directly over the conductor. If measured, the magnetic field traces a path on the surface that follows the path of water, in the ground. To create this current flowing in the groundwater, an electrode is placed in the solution to be studied. In the least complicated situation, a single electrode in the groundwater or site of interest would produce the strongest signal from the underground conductor. However, in the real world there are no mono poles and a second electrode is required.

An important part of this technology is that the groundwater or medium of interest is directly energized. This can be done in several ways but ultimately all achieve the same effect. The electromagnetic 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 field intensity can vary according to channel depth.



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 moving 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. When moving from inside to outside the loop the horizontal field will decrease and continue to decrease outside the loop when moving away from the virtual loop.

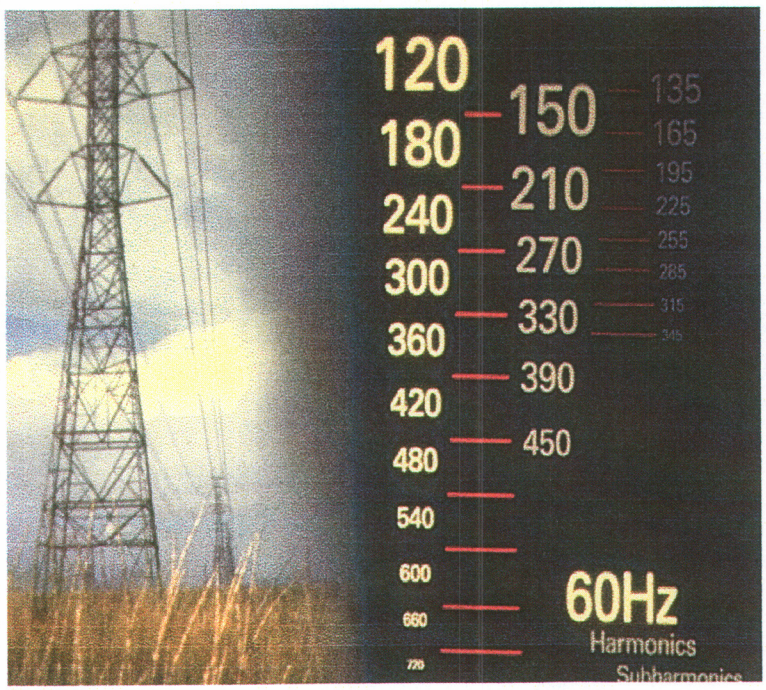
The magnetic field's rate of curvature is proportional to the distance from the water channel carrying the electric current.

The rate that the magnetic field falls off along the water channel is proportional to the resistivity contrast between the water channel and the surrounding media

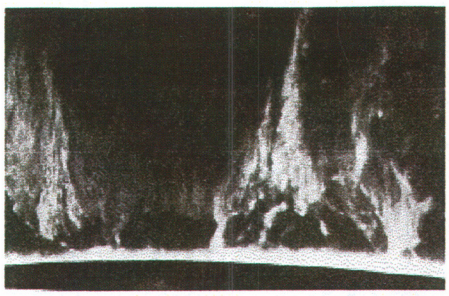
Noise

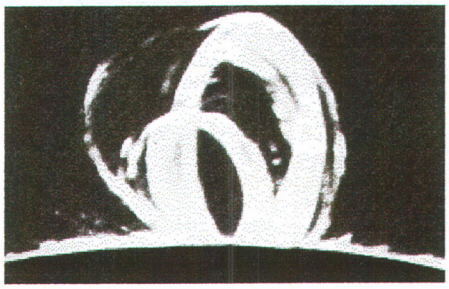
There are three large sources of electrical noise in the ground that must be accounted for when analyzing AquaTrack field measurements.

- 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 obtained from multiple base station readings used to monitor drifts in the local electromagnetic fields.

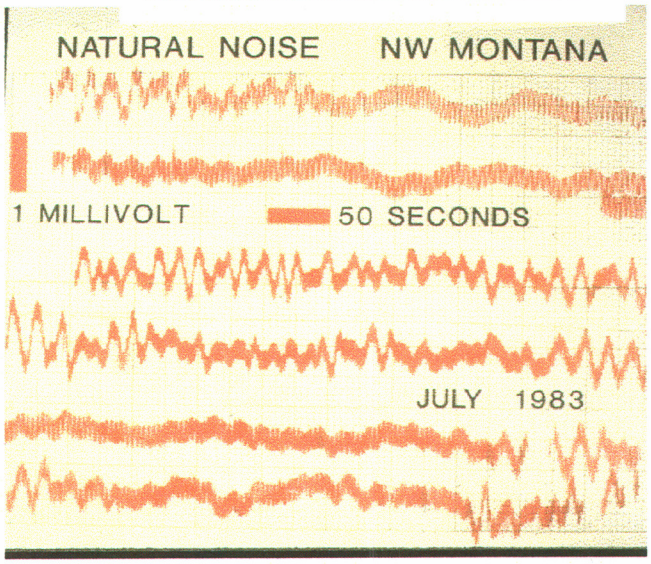




Filters are provided to lock the frequency of the AC current at a precise 400 cycles. Four hundred cycles was selected to eliminate interference from stray 60 cycle current or any harmonics of 60 cycles. Output voltage is controlled to produce the desired current Both the output voltage and output current are measured and recorded during the survey.

- 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.

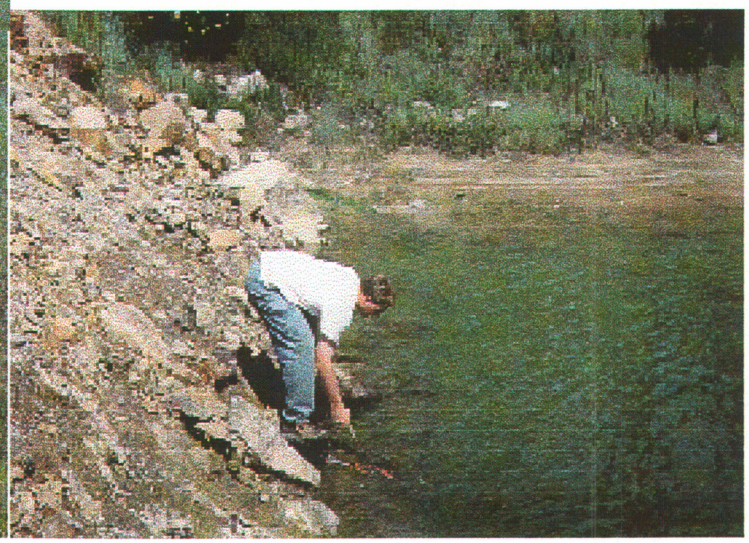
The third electrical noise source is distant thunder storms. The electrical static generated by lightning strikes becomes trapped in a wave guide between the ground and the ionosphere. With distance the currents generated begin to blanket the electromagnetic spectrum usable in this technology. Noise from these sources are 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. The water path to be mapped has to be 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.

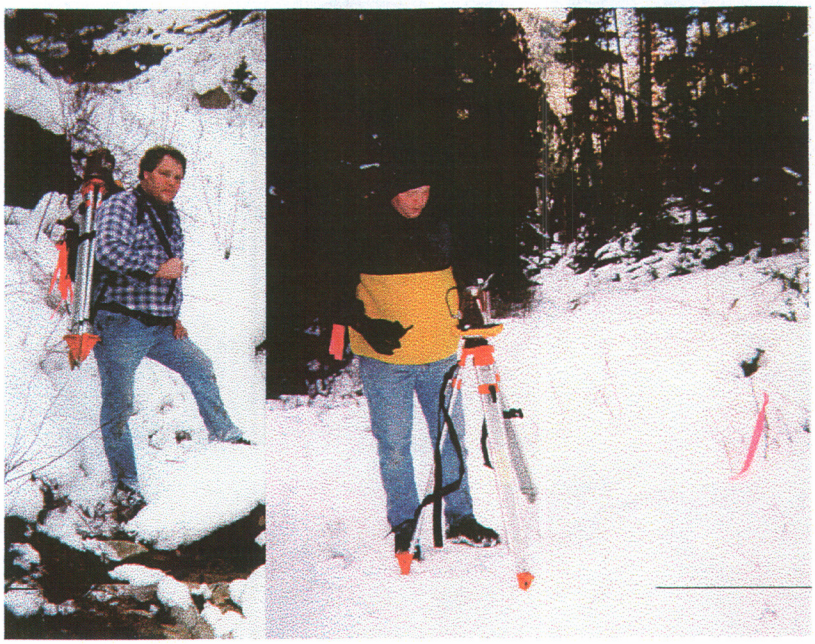
At least one of the electrodes must be in contact with the water being tracked. The second electrode can be in contact with the water to establish the flow path between two points. However if the subsurface path is an unknown then it is better if the return electrode does not bias the flow of electricity 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 current is filtered and controlled to provide a locked frequency between the transmitter and receiver. Output voltage and current are controlled, monitored, and recorded during the survey, and corrections are made for any transmitter drift. All readings are locked to a base station and corrected for diurnal drift.

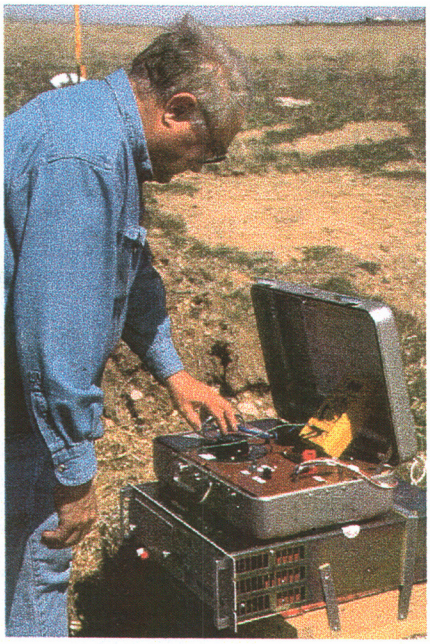
Data is collected at each station using a special receiver. The receiver consists of a coil and a filtered amplifier. The magnetic signal picked up in the coil is correlated with the transmitter signal and filtered for noise. Magnetic field measurements consist of magnitude and direction of the magnetic 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.

Data Reduction

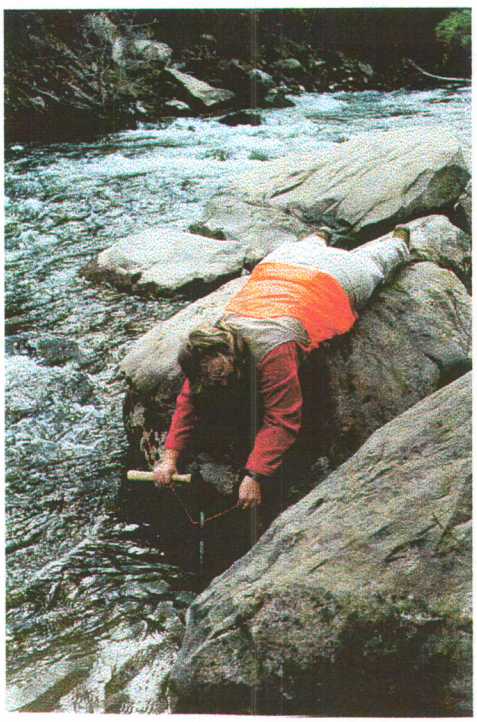


Analysis of the data is a multifaceted process. Voltage and current of the transmitter are controlled, monitored, and recorded using a portable computer during the survey. These recorded readings are used to correct for any transmitter drift. All readings are locked to a base station and corrected for diurnal drift. Both of these corrections are the same as standard linear correction made to all geophysical data.

- A base station reading is taken as often as possible during the day. The drift measured at the base is assumed to be linear and is simply subtracted from the reading. This compensates for instrument drift and some of the spheric variations.
- The transmitter current can be is monitored by taking current readings every minute through the day with a portable computer. Data at individual stations is normalized to a constant current, usually 1 amp.



The data interpretation can be facilitated and enhanced by various treatments. These are standard mathematical manipulations that are applied equally to all data to remove regional and other effects. For example: First, current bleeding from the conductor such as a 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 station's 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.

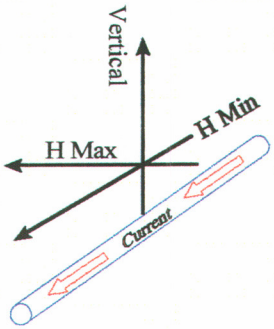


The data can be presented in various forms such as linear or logarithmic. The preferred method is linear but in a few cases where the anomalies are substantial and tend to overwhelm the smaller anomalies, logarithmic is then preferred. All data in this report are linear unless specified otherwise.

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. If the conductor is straight, field strength measured on a line perpendicular to the conductor will increase until it is directly over the conductor then decrease at the same rate.

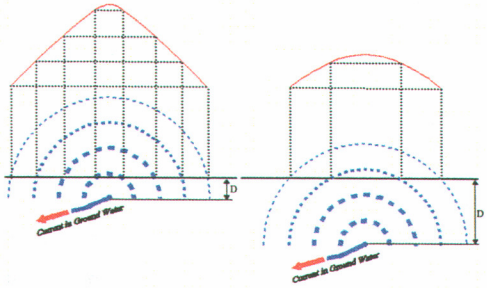


The direction of electrical current flowing in the ground represents the path of the groundwater or channel. Electric current flows in the same direction as the minimum horizontal magnetic field or perpendicular to the maximum horizontal magnetic field. The direction of electric current flow is directly correlatable to 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 or 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 examples are how possible features will show up when site data is plotted in a manner similar to that of a contour map. When possible a Figure is show that corresponds:

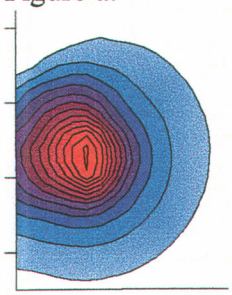
a. A non-perturbed field, where no conductor is energized, would form a contour map composed of concentric circles around the point where the water is energized.

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 along a vertical fault, will also form the "V" contour but with a somewhat lower gradient as fields generated at the lower portions of 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 a.



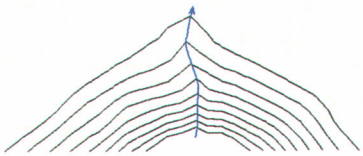


Figure b.

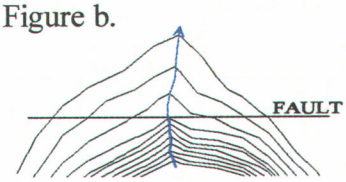
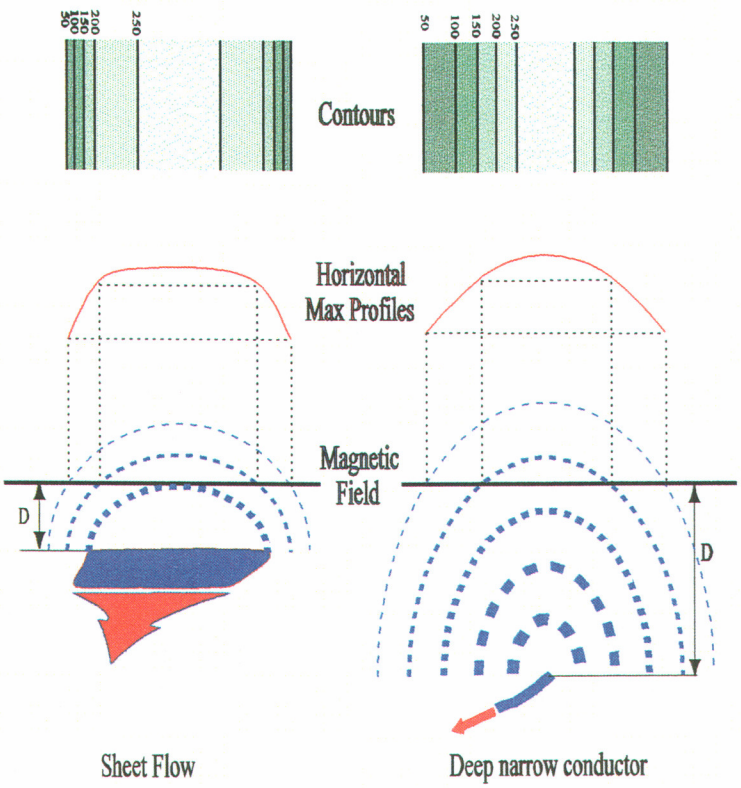


Figure c.

Figure 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.

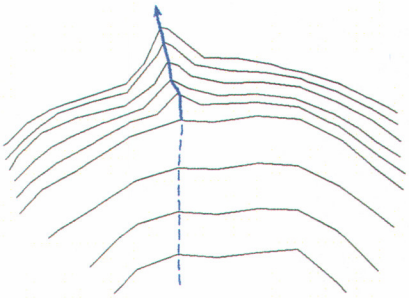


Figure e.

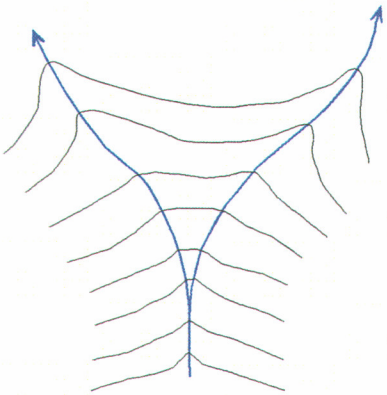


Figure f.

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 c)

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 an broad low intensity anomaly that outlines the clay liner and thus this anomaly can by modeled and removed.

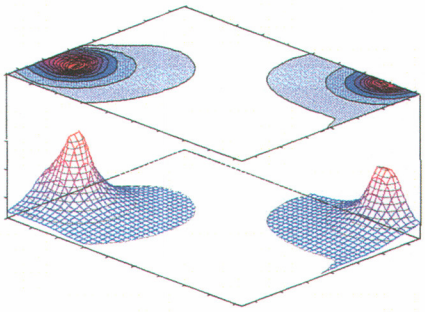


Figure j.

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 Figure 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 can not be used with field data. The most common reason that this valuable tool can not be used is that the data spacing is to wide. Generally it is not practical to use close station spacing in an area where preliminary data is just outlining the water channels for the first time.

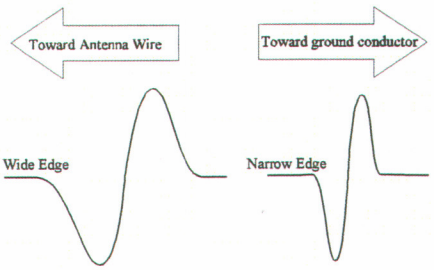


Figure k..

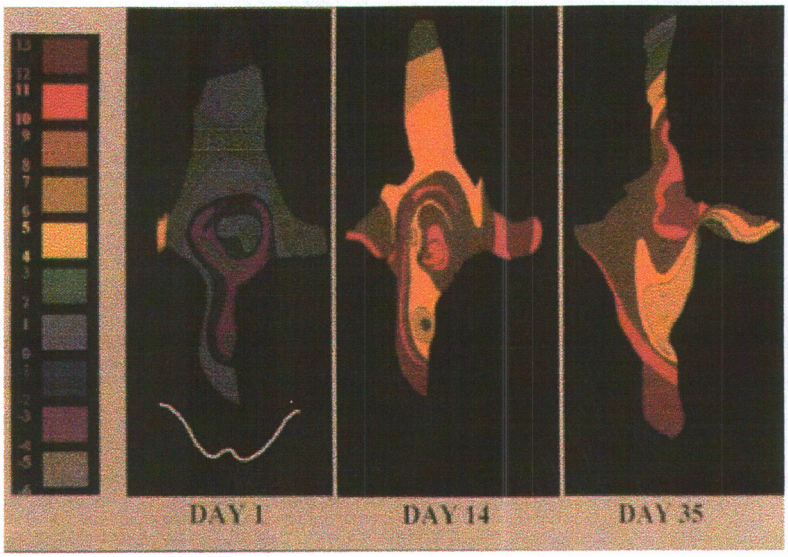
l. Width of the horizontal magnetic field is proportional to depth and width of the channel.

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

n. Local intensity increases in either of 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 taking the difference or ratio of the readings.

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.



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 the magnetic field over time provides 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 decreases in subsurface flow, changes in salinity, or any change in the groundwater that affects any of its electrical properties.

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.

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

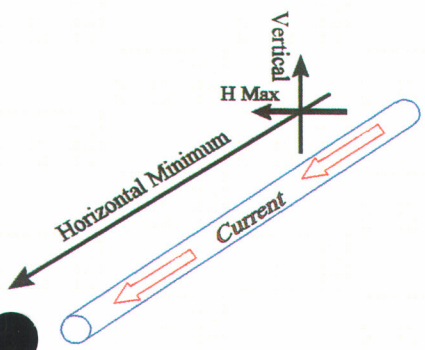


Figure r.

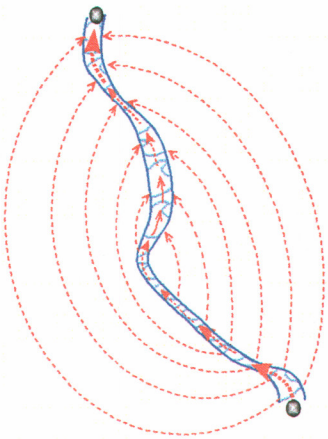


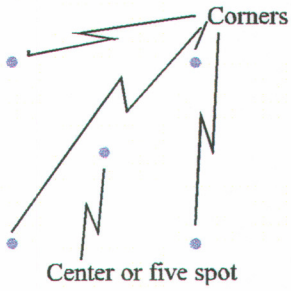
Figure s.

The simple case will rarely exist. Interpretation of the field measurements must therefore 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 preforming a precursory analyzation of 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 also expand and contract. As is observed in several cases the path of the water may split following several paths. Other conductors may also exist in the area and may be energized. All these things must be taken into consideration during the interpretive phase, and some prejudgment, hopefully correct, during the data gathering phase.

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

Data Collection and Analysis



The normal preliminary survey of an area is made by taking magnetic readings at the grid coordinates and at the center of each square or the five spot.

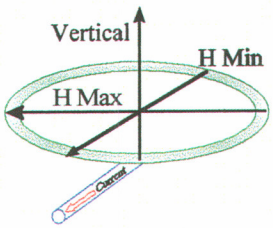
Wells, seeps, springs, or other types of water sources are energized with approximately one amp. Variation in current are corrected by normalizing all the data to one amp to correct any current drift. Drift is calculated by monitoring transmitters output at random intervals.

A second correction is made for diurnal variations. This correcting is calculated by repeated readings at a base station. Base station readings are taken a minimum of three times daily, morning, noon, and evening.

Readings at stations affected by known long continuous conductors are collected but may not be included in the final analysis as they can provide misleading results. These included interference from the wire connecting the electrodes and the fence or row of electrodes. Additionally, sources of interference could be power lines, communication lines, water pipes, and multiple linear sources in the area. Readings that are not obviously associated with known manmade conductors are not excluded from the final presentation.

The values measured at each station are:

1. Location in northing and easting,
2. Minimum magnetic value and bearing,
3. Maximum magnetic value and bearing,
4. Vertical magnetic value,
5. Time, and
6. Any adjacent cultural feature.



Grid Data and Detailed Profiles

The preliminary or regional data is generally gathered on a north-south/ east-west oriented grid with 100 foot spacing. 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 does not provide detailed information defining channels or the edges of channels.

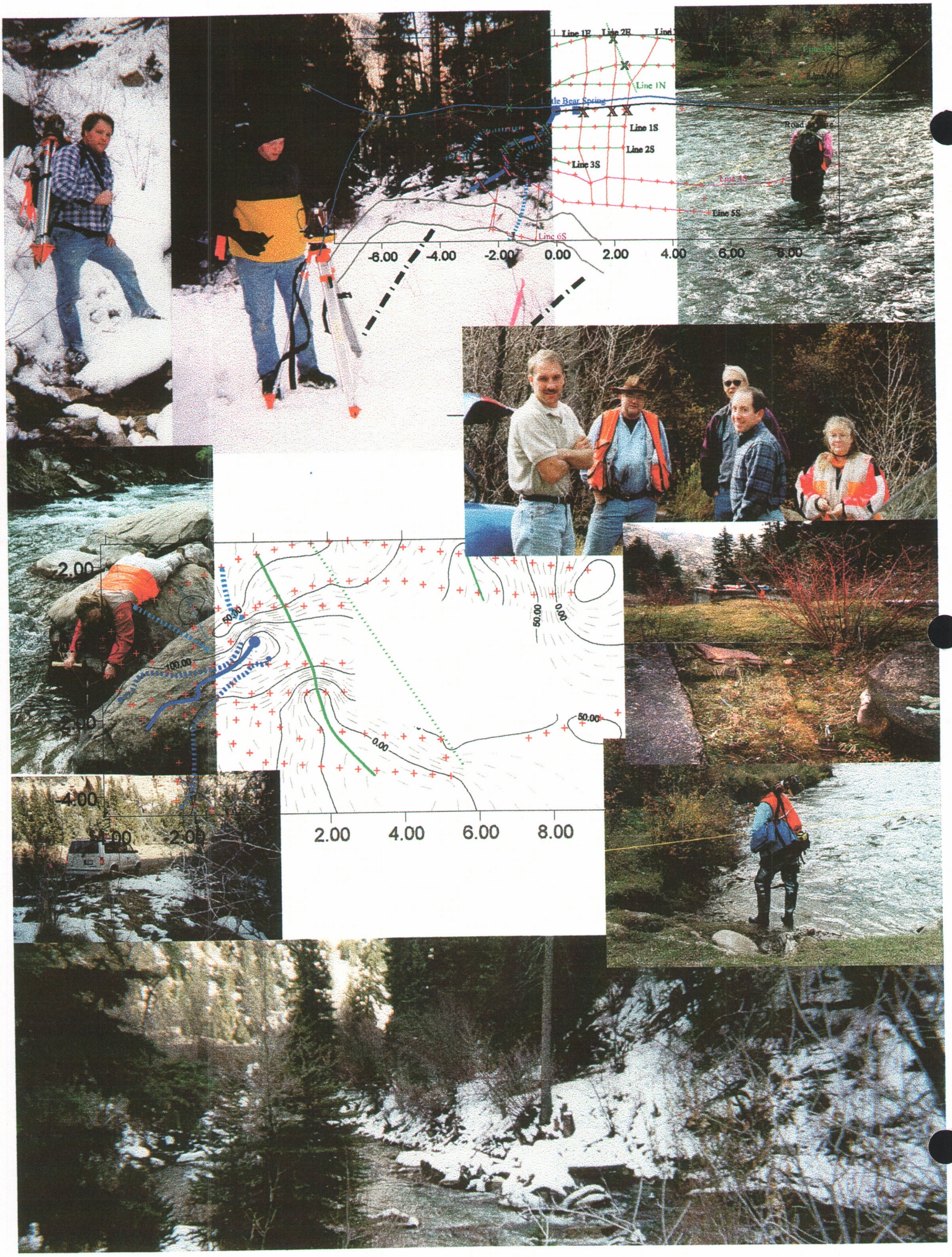
In some surveys rather than using a grid, profiles are used that are oriented with respect to the feature being studied. The profile can be straight or curved. The decision to use straight or curved profiles is generally a decision based on the topography of the area being studied. Flat terrain lends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

Detailed profiles taken perpendicular to the path of the channel or water, as determined by the original survey data, provides the information needed for 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 indicates the existence of groundwater channels.

For the best results supplemental readings are taken along selected profiles in locations where initial data indicates the existence of groundwater channels. Detailed or supplemental profiles are located by using the initial grid. Data collected along profiles running north-south or east-west are spaced at 25 foot intervals. Diagonal profiles running north-west to south-east or north-east to south-west are spaced using 23.5 foot intervals This spacing was chosen because it was an even division, 1/4 or 1/6th, of the distance between the corners of the square. Thus the corners and the five spot are re-occupied to assure that the magnetic values for the profiles can be correlated with the regional data. This permits the comparison and verification of data. These two spacing intervals provide sufficient information to locate subsurface water-related features to within about 25 feet.

If more precise information is required in one location for planning or engineering information at five foot data spacing can be used. This detailed spacing along a profile will provide details that are relative to approximately five feet. These types of profile must be chosen to run perpendicular to the subsurface channel or groundwater flow to provide the greatest accuracy.

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 assures quality in the data and allows all parts of the survey to be calibrated the same.


Line 1E
Line 2E
Line 1N
Little Bear Spring
Line 1S
Line 2S
Line 3S
Line 6S
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
Line 5S
Road
-2.00
-4.00
100.00
50.00
0.00
2.00
4.00
6.00
8.00