UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Self-Potential Surveys Near Several Denver Water Department Dams

by

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Introduction

This report describes self-potential (SP) measurements made near several dams in the Denver water Department system. The surveys were conducted as part of a project to determine whether or not SP measurements might be useful in monitoring the flow of water around dams. The study has relevance to the problem of induced seismicity due to water impoundment by man-made reservoirs and the detection of leaks in dams or dam abutments.

water flow through rocks produces electrical currents by means of the streaming potential mechanism. In general, water flowing towards a region will produce a positive anomaly in that area. Thus, one might expect the region downstream of a dam to be more positive than the region on the reservoir side of a dam.

All measurements were made using a 10 megohm input impedance voltmeter (Keithley Model 1300) and lead-lead chloride (Pb-PbCl2) electrodes (Petiau and Dupis, 1980). A fixed reference electrode site was chosen for each survey, and all measurements were made with respect to this point when possible. Electrodes were buried in moist ground without watering. Before and after surveying a line, the electrodes were placed on a damp sponge and the voltage differences recorded. These data were used to compute electrode and drift corrections. Measurements were usually made every 5 meters. The voltage was observed until a stable reading was obtained. If the signal was very noisy, the mean of the maximum and minimum reading was used. The data presented in this report are unsmoothed unless otherwise noted.

Electromagnetic measurements using Slingram method were made on selected lines to aid in interpreting the SP results. This technique utilizes a loop-loop configuration excited at a frequency of about 39.2 khz. A Geonics Model EM-31 instrument was used which measures earth conductivity. The instrument can be used with the coils oriented either on line with (parallel mode) or transversehale to (perpendicular mode) the survey line. If not specified, the data presented were obtained using the parallel mode. The technique has an investigation depth of about 6 m making it useful for the detection of shallowly buried conductors such as pipes.

Field work was conducted at four sites: Ralston Reservoir, Upper Long Lake, Gross Reservoir, and Dillon Reservoir. All dams are earth filled and located in sedimentary rocks with the exception of Gross Reservoir--the latter being a reinforced concrete, gravity arch dam situated in igneous rock.

Ralston Reservoir

Ralston Reservoir is located about 5 miles north of Golden, Colorado in Jefferson County (Figure 1). The reservoir is contained by an earthen filled dam which rests on Pierre Shale. In the vicinity of the dam, the Pierre Shale strikes roughly north-south with a dip of from 50 to 80 degrees to the west (Van Horn, 1957;Van Horn, 1972). A hogback along the eastern shore of the reservoir is formed by a Tertiary mafic monzonite intrusive called Ralston dike.

SP measurements were made on the lines shown in Figure 2. Figures 3, 4, and 5 contain the SP lines parallel the dam axis, while Figures 6 and 7 show the lines perpendicular to the dam axis. Lines parallel to the dam axis are plotted from left to right when viewed from a point on the downstream side of the dam. Lines approximately perpendicular to the dam axis are plotted in the direction of stream flow. This convention has been used throughout this report. All data were measured using the point at the east end of line A as a reference. EM-31 conductivity data for some of the lines are shown in Figures 8 and 9. The results of each line are summarized below.

Line B Figure 3

This line displays a -15 mV long wavelength anomaly on its south end.

Line D Figure 3

The data are very noisy, but a broad -20 mV anomaly centered near 45 m is discernible.

Line G Figure 4

The south end of the line has a -40 mV peak to trough (PTT) anomaly. Near 200 m the potential begins to drop to -5 mV.

Line H Figure 4

A central high rises 30 mV above the end values. The anomaly may be similar to that of line G, but with the southern minimum lying presumably unobserved off the end of the line. The conductor seen in the EM-31 data (Figure 8) near 160 m is of undetermined origin.

Line I Figure 4

The small (15 mV PTT) anomaly does not fit into the overall picture. It may be due to localized effects and is not considered important.

Line E Figure 5

A very distinctive dipolar anomaly is seen on this line. The negative trough is associated with the outlet valve house. Crossing to the south side of the outlet tunnel the anomaly increases dramatically. The EM-31 data (Figure 8) show a very good conductor near the SP negative suggesting the source of the anomaly is a buried pipe.

Line C Figure 5

A narrow positive feature can be seen near 20 m. The EM-31 data (Figure 8) becomes more conductive to the north. The cause of this conductivity anomaly is not clear.

Line J Figure 5

A very pronounced negative anomaly which is part of a dipolar feature is seen as the pipes coming from the outlet valve house (35 m) are crossed.

Line M Figure 6

This line features a broad minimum near the dam crest. The positive anomaly is due to some pipes which are also seen in the EM-31 data (Figure 9). The EM-31 anomaly near 200 m on this line is caused by a large metal gate.

Line N Figure 6

The maximum near 105 m corresponds with the maximum seen in line M near 100 m. The fact that the anomaly is broader here, suggests that the source is deeper than on line M. The pipe which crosses the road here is known to go below the lake level.

Line L Figure 6

The positive anomaly at the beginning of the line corresponds with the positive seen on line E, and is quite localized. It is attributed to a buried pipe.

Line K Figure 7

The dramatic anomaly is the same as seen on line J, except that the outlet pipes are crossed in the opposite direction. Significant EM-31 anomalies (Figure 9) show the presence of multiple conductors.

Line A Figure 7

The voltage increases about 20 mV in the downstream direction. This might be due to water flow toward the toe of the dam. A similar feature was not seen on the other dam abutment.

Line D Figure 7

There is a small negative gradient in the downstream direction. This is opposite to the effect seen on line A.

Line P Figure 7

A 20 mV decrease is seen as the dam is approached. This is similar to the 30 mV minimum seen on line M near the dam.

Interpretation

The significant SP anomalies appear to be due to the presence of buried pipes particularly near the outlet valve house. The anomalies near the downstream end of the pipes are usually negative. These anomalies are characterized by very short wavelengths and amplitudes of 30 mV or more. The Sato-Mooney (1960) theory of SP anomalies caused by Eh potential gradients can be used to explain these anomalies. While made of concrete, the outlet tunnel connecting two regions of differing Eh potential, is probably a good conductor because of the metal pipes in it. The inlet end of the tunnel is located in a reducing environment below water level, while the outlet end of the tunnel is in an oxidizing environment. These two regions furnish chemical species to be oxidized and reduced at their respective ends of the tunnel. The tunnel links these two reaction cells together by transporting electrons from the oxidation reaction to the reduction reaction. The net result is to have a negative potential near the outlet end of the tunnel. This process is often corrosion. It is also possible to have SP sources produced along a man-made conductor by localized Eh potential variations due to changes in soil chemistry.

No anomalies which could be related to water flow through the rocks in the vicinity of the dam could be seen. This is either due to the high conductivity of the Pierre Shale and overburden (0.020-0.035 mho/m) observed by the

EM-31, as conductive rocks generally have lower streaming potential coefficients, or the absence of any water flow around Ralston Dam.

Upper Long Lake

Upper Long Lake is located in Jefferson County about 5 miles north of Golden, Colorado (Figure 1). The lake is formed by a natural depression in the flank of Ralston dike. An earthen levee has been added to the eastern shore line of the lake to increase its storage capacity. Water from Long Lake Ditch enters the lake via a tunnel cut through Ralston dike.

Ralston dike is a mafic monzonite intrusive of Tertiary age (Van Horn, 1957) which intrudes the Pierre Shale. To the east of Upper Long Lake the Pierre Shale strikes roughly north-south parallel the shore line. East of the lake the beds are overturned with a dip of 48 degrees to the west.

Self-potential and EM-31 measurements were made on four lines shown in Figure 10. Three of the lines 0 N, 100 S, and 200 S run perpendicular to the shore of Upper Long Lake, while the fourth line 0 E run parallel the lake edge on an access road. A fixed reference at the north end of line 0 E was used for all of the SP measurements. The results of each line are described below.

Line 0 N Figure 11

There is a small decrease of the SP signal to the east.

This trend is superimposed with several small scale features. The sharp -25 mV anomaly at 60 m has an accompanying conductivity anomaly caused by an abandoned water supply line. Small positive features are seen near 75 m, 115-135 m, and 160-185 m. These features correspond with water seeps which occur along bedding planes in the Pierre Shale. The seeps are quite visible and cause the grass near them to grow vigorously. A second conductivity anomaly can be seen near 175 m which is probably due to a water seep at this location. A large conductivity anomaly is seen at the east end of this line as well as line 100 S and 200 S, which is attributed to the presence of Lower Long Lake where all the lines terminate. The lake increases the water content of the surrounding soil thereby increasing its conductivity.

Line 100 S Figure 12

The most prominent feature on this line is the 60 mV SP anomaly near 70 m. A small EM-31 conductivity feature is associated with this anomaly. It is interpreted as being due to the same pipe line seen on profile 0 N. Two positive features associated with water seeps are seen at 120-155 m and 170-185 m, the latter having a modest conductive anomaly. A conductivity increase is seen as Lower Long Lake is approached. A general decrease in voltage occurs in this direction.

Line 200 S Figure 13

This line exhibits no large SP anomalies. A general decrease in voltage down the hillside is reversed at the east end of the line as the electrode is placed in moister soil. A small negative anomaly (-10 mV) is associated with the buried water line at 55 m, as well as a small conductivity anomaly. Water seeps at 150 m and 165 m produced two small positive SP anomalies and the accompanying EM-31 anomalies. Seeps between 65 m and 105 m produced a small positive feature, but the correlation between the seep location and the SP anomaly is not as good as at the 150 m and 165 m locations.

Line 0 E Figure 14

This line follows the edge of the Upper Long Lake embankment. The SP data show no clear anomalies which can be associated with any geologic features. The EM-31 conductivity measurements observed a three-fold increase in conductivity near 150 m. The cause of this change is not clear.

Interpretation

The three lines perpendicular to the lake embankment show a gradual decrease in the SP signal in the downhill direction. This effect is opposite to what one would expect if there was a fluid flow down the slope producing streaming potential sources. The water seeps are due to enhanced permeability conductivity along bedding planes. Water seeping out of Upper Long Lake encounters these permeable zones and flows up the westward facing dip slopes until the surface is encountered, and then flows out onto the surface.

The zones of increased permeability are due either to jointing or compositional changes in the Pierre Shale. The increased water content produces the observed conductivity anomalies. Poldini (1939) and Corwin and Hoover (1979) have reported positive SP signals associated with wet soil. The observations at Long Lake support this conclusion.

A strong SP anomaly was seen over the abandoned water line which is crossed by line 0 N, 100 S, and 200 S. The source of this anomaly is confirmed by the EM-31 measurements. These anomalies are probably due to corrosion of the abandoned water line. A regional decrease in the SP signal was observed in traversing down the hill to the east of Upper Long Lake. These anomalies are probably not associated with electrokinetic sources produced by water flow out of Upper Long Lake.

Gross Reservoir

Gross Reservoir is formed by a 275 foot high reinforced concrete, gravity-arch dam across South Boulder Creek five miles south-west of Boulder, Colorado (Figure 15). The dam is anchored in Precambrian Boulder Creek granodiorite (Wells, 1967). The western end of the dam cuts through a quartz monzonite dike. No mapped faults intersect the study area.

A reference electrode was placed near the base of the dam on the east end of line A (Figure 16). This electrode was used as a reference for lines A, B, C, D, E, F, and G. A second reference point near the east dam abutment on the south end of line H was used for lines H, I, and J. Due to the rugged terrain along the eastern abutment, no attempt was made to tie the two reference points together. EM-31 conductivity measurements were made along line C.

Line C Figure 17

This line has a very dramatic positive anomaly (+250 mV) over pipes leading from the diversion tunnel outlet (25 m). A second, smaller positive anomaly (+150 mV) is seen near the set of pipes (85 m) which lead to the outlet valve house. These two anomalies are superimposed on a negative trend near 160 m. The EM-31 conductivity profiles (Figure 18) show large conductivity anomalies in the range from 20 m to 80 m for both orientations of the instrument. The conductivity anomaly near 0 m is caused by the presence of the dam face.

Line D Figure 17

This line has a marked negative anomaly of -160 mV centered across the creek from the outlet valve house.

Line B Figure 19

This line goes down the slope leading to the base of the dam. An increase in voltage of over +100 mV is seen along the profile. One might suspect that this anomaly is due to a streaming potential effect caused by the flow of water around the west end of the dam towards its base. However, line E (Figure 19) does not show a similar behavior. The anomaly is therefore attributed to a negative potential near the west end of the dam. (See line F, Figure 20).

Line A Figure 19

A large negative anomaly (-130 mV) was observed near the terminus of the diversion tunnel (-105 m). This is in marked contrast with the +250 mV anomaly seen on line C (Figure 17) where the diversion tunnel is crossed (25 m). The short wavelength feature near 30 m occurs near the face of the dam. Its source is not clear.

Line E Figure 19

The east end of this line has a large negative anomaly which corresponds to the negative anomaly seen on line D (Figure 17) near 60 m. Line E terminates at the 100 m mark on line D.

Line F Figure 20

This line is characterized by a broad negative anomaly (-100 mV) which is offset from the crest of the dam by a few tens of meters. The small negative feature at 275 m is also seen on line G near 55 m. The sharp negative (-90 m) near 330 m is due to a buried drain pipe.

Line G Figure 20

The negative anomaly near 55 m corresponds with the minimum on line F at 274 m.

Line H Figure 21

The data are rather noisy, but a broad negative (-20 mV) anomaly near 50 m of undetermined origin can be seen.

Line I Figure 21

This line has no remarkable features which are understood. Negative anomalies are associated with each end of the line.

Line J Figure 21

The data are very noisy, but the central portion of the profile appears to be negative (-25 mv) with respect to the ends. The location of this maximum offset is about 20 m upstream from the dam crest.

Interpretation

The larger observed anomalies are associated with the diversion and outlet tunnels and accompanying pipes. Corrosion of these structures probably produces the anomalies. These anomalies are much larger than any of the others seen in the survey.

Broad, low amplitude negative anomalies were seen along lines perpendicular to the ends of the dam. These may be due to corrosion effects in the concrete, or due to streaming potential effects. Modelling of the anomalies produced by water flow around the dam abutments might help in distinguishing between these two models.

Dillon Reservoir

Dillon Reservoir is located near the town of Dillon, Colorado about 60 miles west of Denver (Figure 22). A large earthen dam rests on Lower Cretaceous and Upper Jurassic sedimentary rocks (Tweto,1973). The dam is comprised of two sections. The larger section to the west of triangulation station First is readily seen from interstate highway I-70. The section to the east of First is smaller and less visible. The Dakota Sandstone crops out between these two sections of the dam and forms the small hill on which First is located.

The tow drain at the base of the western portion of the dam is usually dry, but the eastern section toe drain collects water at a rate of about 20 gallons/minute. The probable source of this water is a flow path through the highly fractured Dakota Sandstone in the vicinity of the dam.

SP measurements were made along the lines shown in Figures 23 and 24. Three separate SP reference points were used for the survey. For lines A, B, and C the reference is at the east end of line C. Lines D and E used a reference at the north end of line D. All work on the eastern section of the dam (lines F through N) used a reference on the west end of line F. No attempt was made to tie all of the reference points together.

Line A Figure 25

Several small positive spikes of unknown origin are seen at 20 m, 50 m, 75 m, 115 m, 280 m, 320 m, 350 m, and 380 m. The line is unremarkable with the exception of a large negative anomaly (-80 mV) near 410 m caused by a buried irrigation pipe. This pipe was also detected by the EM-31 measurements. Another dramatic EM-31 anomaly at 170 m is due to a steel fence. A general decrease in conductivity of about 30% exists between the conductivity maximum near 240 m and the lower values between 320 m and 380 m.

Line B Figure 26

There is a hint of a broad negative anomaly (-20 mV) centered at 120 m, but the noisy nature of the data makes its presence questionable.

Line C Figure 27

The most prominent feature is a -20 mV negative anomaly at 140 m followed by a +30 mV swing. The cause of these anomalies is not clear. The corresponding conductivity data show only modest changes with small increases centered at 60 m and 180 m. The short wavelength, high amplitude anomalies between 320 m and 370 m are probably due to very noisy data. The potentials recorded in the region were subject to sever temporal variations. Due to the increased noise it was not possible to continue the line across the toe of the dam.

Line D Figure 28

There is a large negative anomaly (-80 mV) near 100 m which is due to the buried outlet tunnel. A small conductivity anomaly is seen near the outlet tunnel abutment (120 m). The EM-31 anomalies at 200 m and 250 m are due to a buried telephone line and a metal fence respectively.

Line E Figure 28

There is a large negative anomaly (-80 mV) at 60 m similar to that seen on line D. It is probably associated with corrosion involving the outlet tunnel. There are no remarkable EM-31 anomalies.

Line F Figure 29

There is a positive transition of about +30 mV between 130 m and 200 m. The cause is not clear. The conductivity increases markedly near 200 m at the center of the toe drain possibly due to increased moisture content caused by water seepage. This suggests that the source of the water is to the west of the 200 m point--possibly in the jointed Dakota Sandstone outcrop near the crest of the dam.

Line G Figure 30

The data are quite noisy with a general decrease to the north. The conductivity anomaly at 5 m is due to a buried telephone line.

Line H Figure 30

In spite of the noisy data, the -37 mV minimum at 30 m seems real, but its cause is not clear. Conductivity increases to the north possibly because of water drainage in that direction. The conductivity low at the north end of the line is due to a barbed wire fence.

Line I Figure 31

This line runs parallel and within several meters of the center of the drain system. There is a positive feature between 20 m and 60 m with an associated conductivity increase suggesting that these anomalies are due to a region of increased water content.

Line J Figure 31

There is a general decrease in potential towards the north.

The negative anomaly at 70 m appears to be associated with a power line support. The conductivity anomalies at both ends of the line are due to a buried telephone cable and a barbed wire fence.

Line K Figure 32

The SP profile increases downhill (toward the north) and is possibly due to streaming potential effects caused by water flow. The small conductivity anomaly near the start of the line is due to a buried telephone line.

Line L Figure 32

As in the previous line, the SP value increases down hill suggesting a streaming potential source. The EM-31 anomaly is due to a buried telephone line.

Line M Figure 33

This line is very similar to the two previous lines.

Line N Figure 33

The SP line is similar to the three previous lines. The conductivity anomaly at the beginning of the line is due to the buried telephone line, and the anomaly at 55 m is caused by a buried cable TV line.

Interpretation

The data from lines A, B, and C show no features of significance. The two lines near the outlet tunnel have the large characteristic anomalies which have been seen near other outlet tunnels. They are probably due to corrosion and Eh potential effects as described previously.

The data near the eastern portion of the dam are slightly more interesting. Line K, L, M, and N, which are outside of the collection region for the toe drain, appear to exhibit anomalies due to water flow down the hill (northward) away from the dam. Line G, H, I, and J, on the other hand, are in the drained region. Ground water is collected by the toe drain system thereby eliminating the streaming potential effect.

Summary

The results of the SP measurements at four dam sites have revealed several interesting anomalies. The largest anomalies were seen in the vicinity of the outlet tunnels. These are typically, but not always, negative. They are due either to corrosion of the metal in the tunnel, or to an oxidation-reduction reaction pair which uses the tunnel as a means of coupling electrons between these reactions. The inlet end of the tunnel in the reducing environment would be the site of the oxidation reaction, and the outlet end of the tunnel in the oxidizing environment would be the site of the reduction reaction. Additionally, there were anomalies associated with the corrosion of buried pipes. These represent a noise source which will be present at most dam sites.

Ralston and Gross dams had a small negative anomaly associated with the crest of the dam. The cause of this anomaly is not clear. It may be due to water flow around the end of the dam, but modelling will be necessary to test this hypothesis.

Electrofiltration effects were probably seen along the eastern section of Dillon dam where there is a flow of water which most likely comes from the jointed sandstone outcrop near the middle of the dam crest. In regions where there is a toe drain system, this anomaly is eliminated. Because the drain provides such a good flow path for the seepage, it eliminates the percolation of water through the ground and consequent electrofiltration effects.

Seepage along bedding planes in the Pierre Shale at Upper Long Lake produced small positive anomalies due to the increased moisture content of the soil. This phenomenon has been previously reported in the literature.

While no anomalies were seen which could be unequivocally attributed to water flow near the dams, this does not completely rule out the possibility of the self-potential method being useful for detecting dam leaks. All of the sites studied are not considered to have leaks, thus the method has not been tested in a suitable situation. Furthermore, most of the sites (Ralston, Long Lake, and Dillon) were in fairly conductive sedimentary rocks which would minimize streaming potential effects.

Acknowledgment

This study would not have been possible without the help of Roger Grette who assisted with the field work and data reduction. We would like to thank several employees of the Denver Water Department for their cooperation: Quentin Hornback for discussing the geology and suitability of the various sites; R. D. Panessi for granting access to the land; Wally Wilcox, Terry Mast, and Raymond Weaver for familiarizing us with the peculiarities of the dams.

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Figure Captions

Figure 1 Location map of Ralston Reservoir and Upper Long Lake. The boxes show the locations of the traverse maps in Figures 2 and 10.

Figure 2 Location map of traverses near Ralston Reservoir. The line which is marked with a "boat" at each end is a reference line for the survey. It provides a means of easily aligning the data plots. The "boats" are also plotted on the data traverses which cross this line.

Figure 3 Ralston SP lines B and O parallel dam axis.

Figure 4 Ralston SP lines G, H, and I parallel dam axis.

Figure 5 Ralston SP lines E, C, and J parallel dam axis.

Figure 6 Ralston SP lines M, L, and N perpendicular dam axis.

Figure 7 Ralston SP lines K, A, D, and P perpendicular dam axis.

Figure 8 Ralston EM-31 conductivity lines E, C, and H parallel dam axis.

Figure 9 Ralston EM-31 conductivity lines M and K perpendicular dam axis.

Figure 10 Location map of traverses near Upper Long Lake.

Figure 11 Long Lake SP and EM-31 conductivity profiles for line 0 N. The horizontal lines indicate the locations of the seeps in Figures 11, 12, and 13.

Figure 12 Long Lake SP and EM-31 conductivity profiles for line 100 S.

Figure 13 Long Lake SP and EM-31 conductivity profiles for

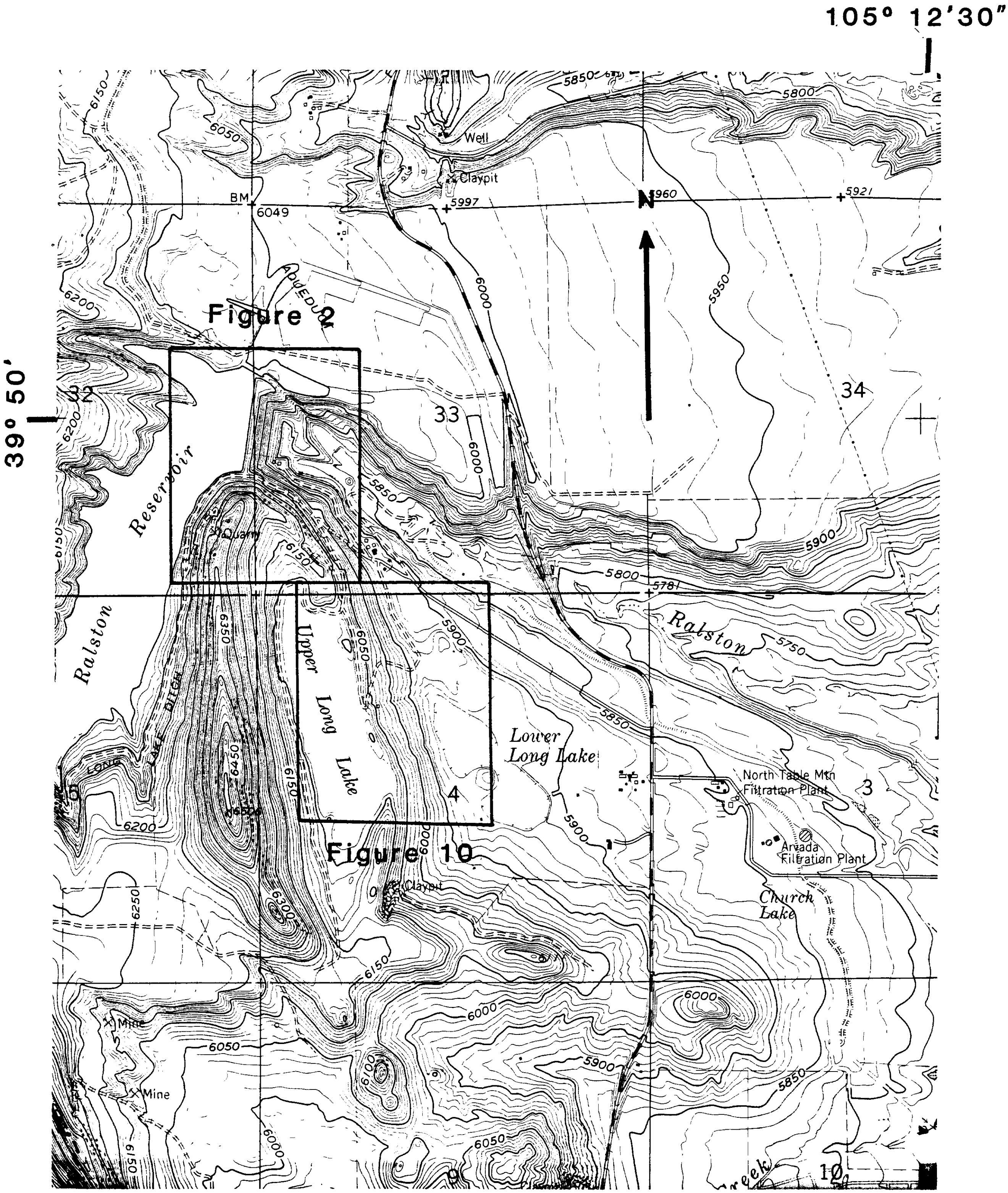
profiles for line F.

Figure 30 Dillon Reservoir SP and EM-31 conductivity profiles for lines G and H.

Figure 31 Dillon Reservoir SP and EM-31 conductivity profiles for lines I and J.

Figure 32 Dillon Reservoir SP and EM-31 conductivity profiles for lines K and L.

Figure 33 Dillon Reservoir SP and EM-31 conductivity profiles for lines M and N.



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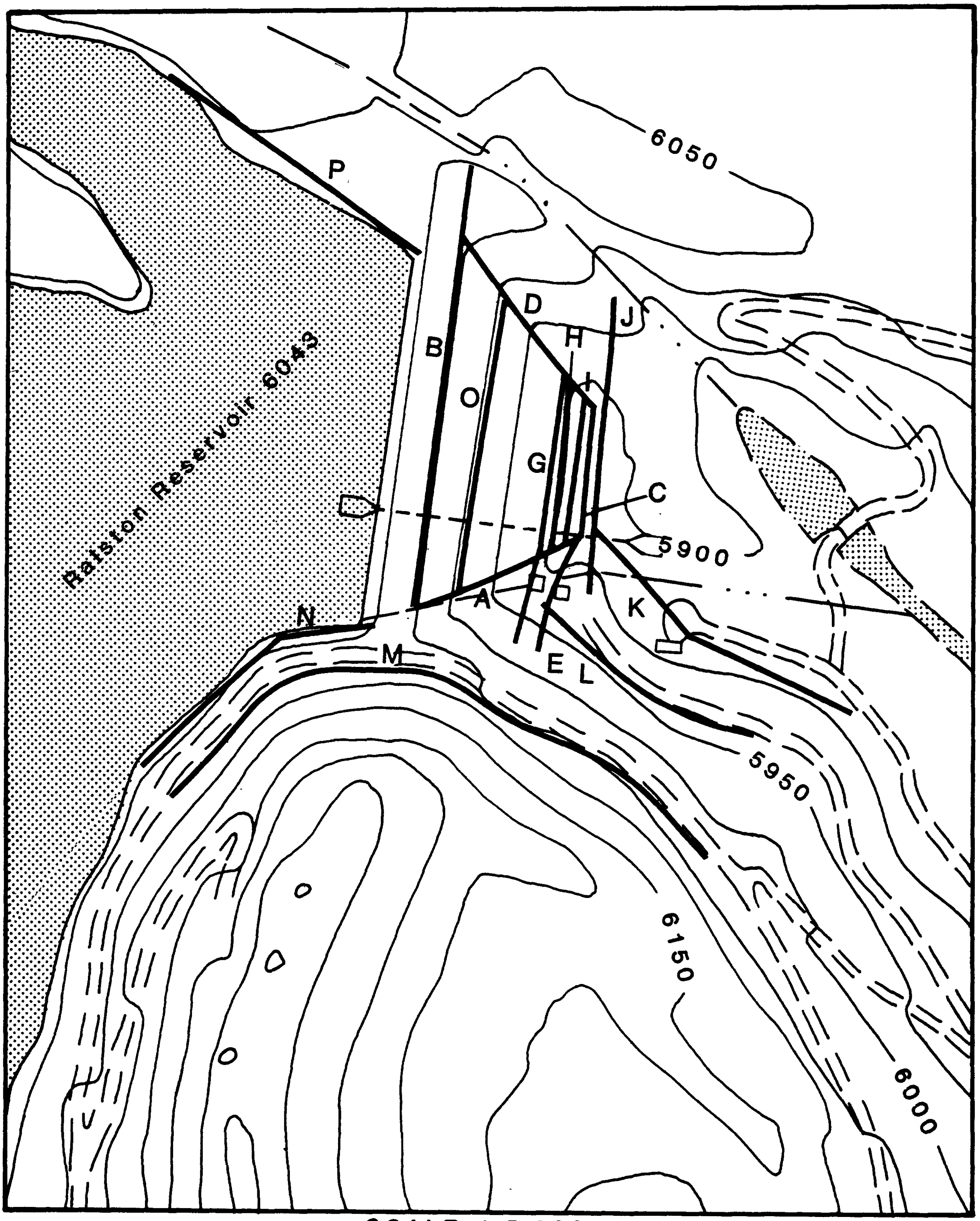
NATIONAL GEODETIC VERTICAL DATUM OF 1929



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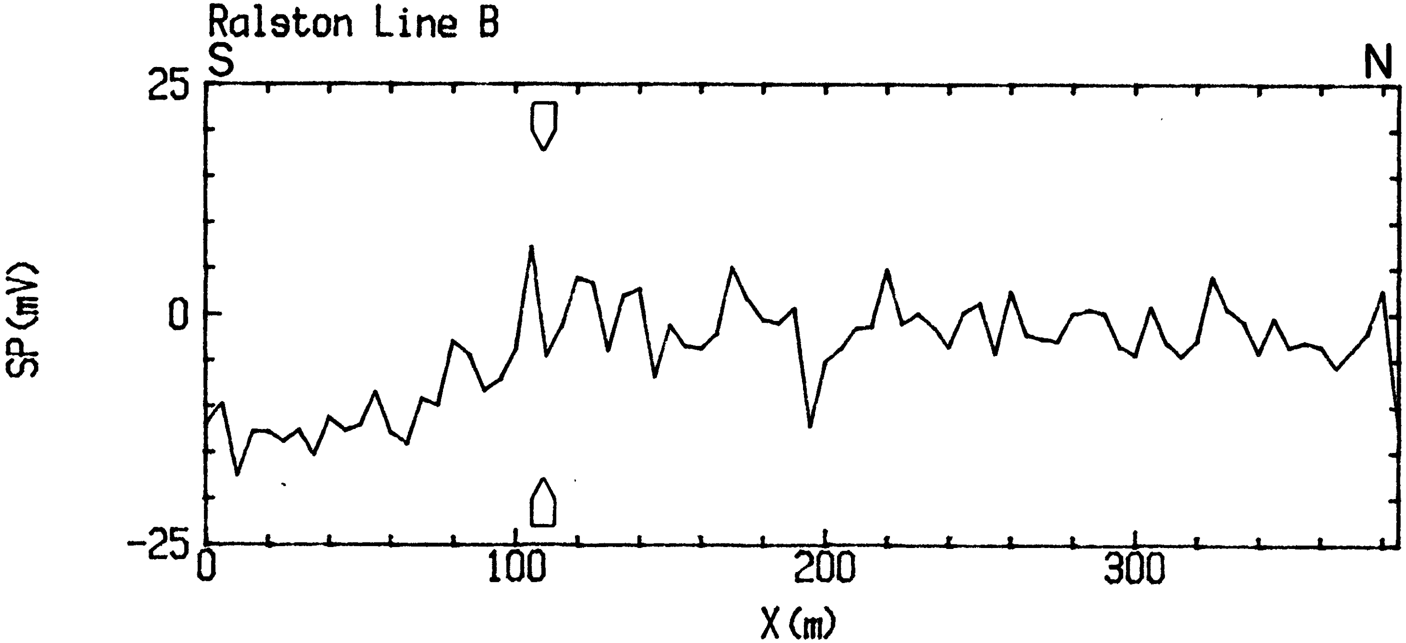
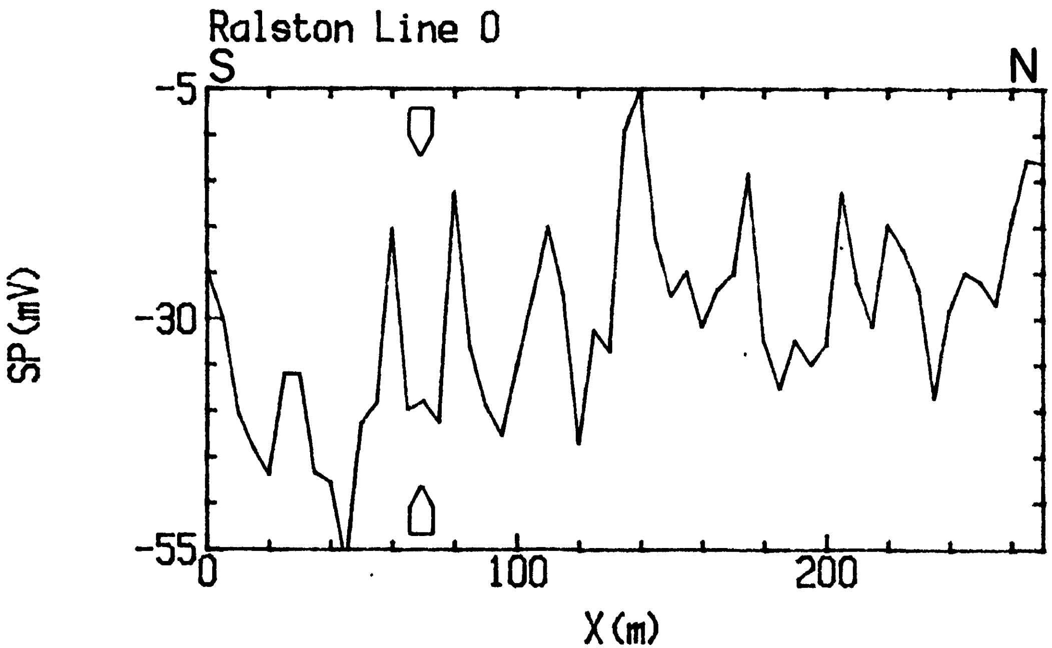
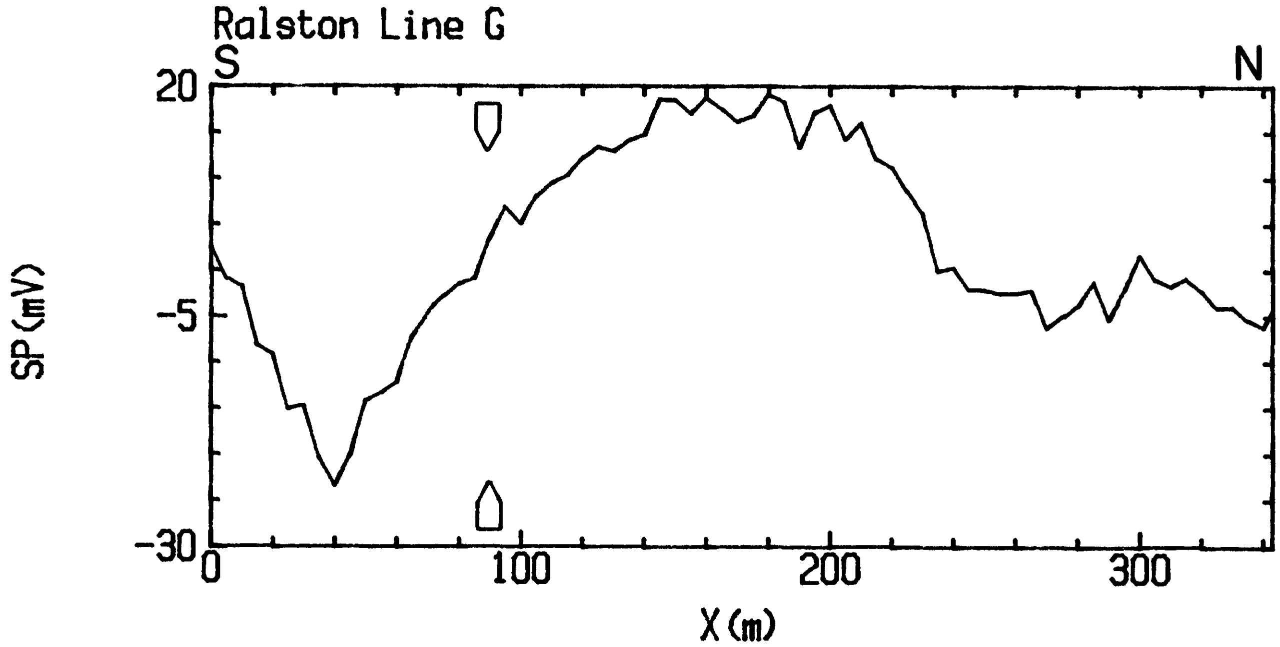
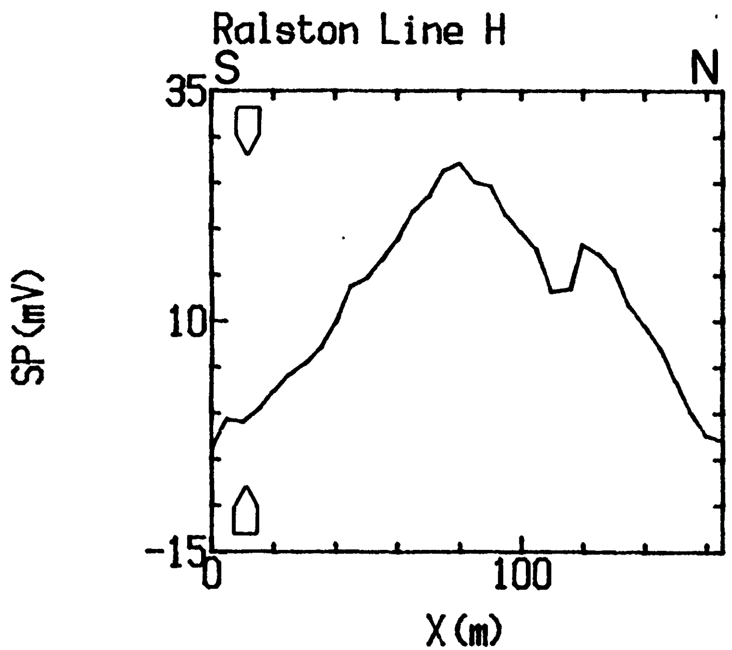

Ralston Line B
S
N
25
0
-25
SP (mV)
0
100
200
300
X (m)

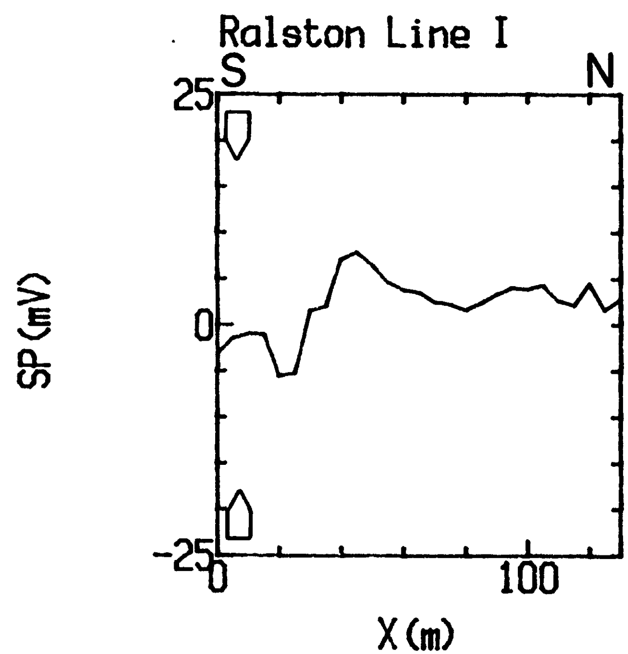

Ralston Line O
S
N
-5
-30
-55
SP (mV)
0
100
200
X (m)



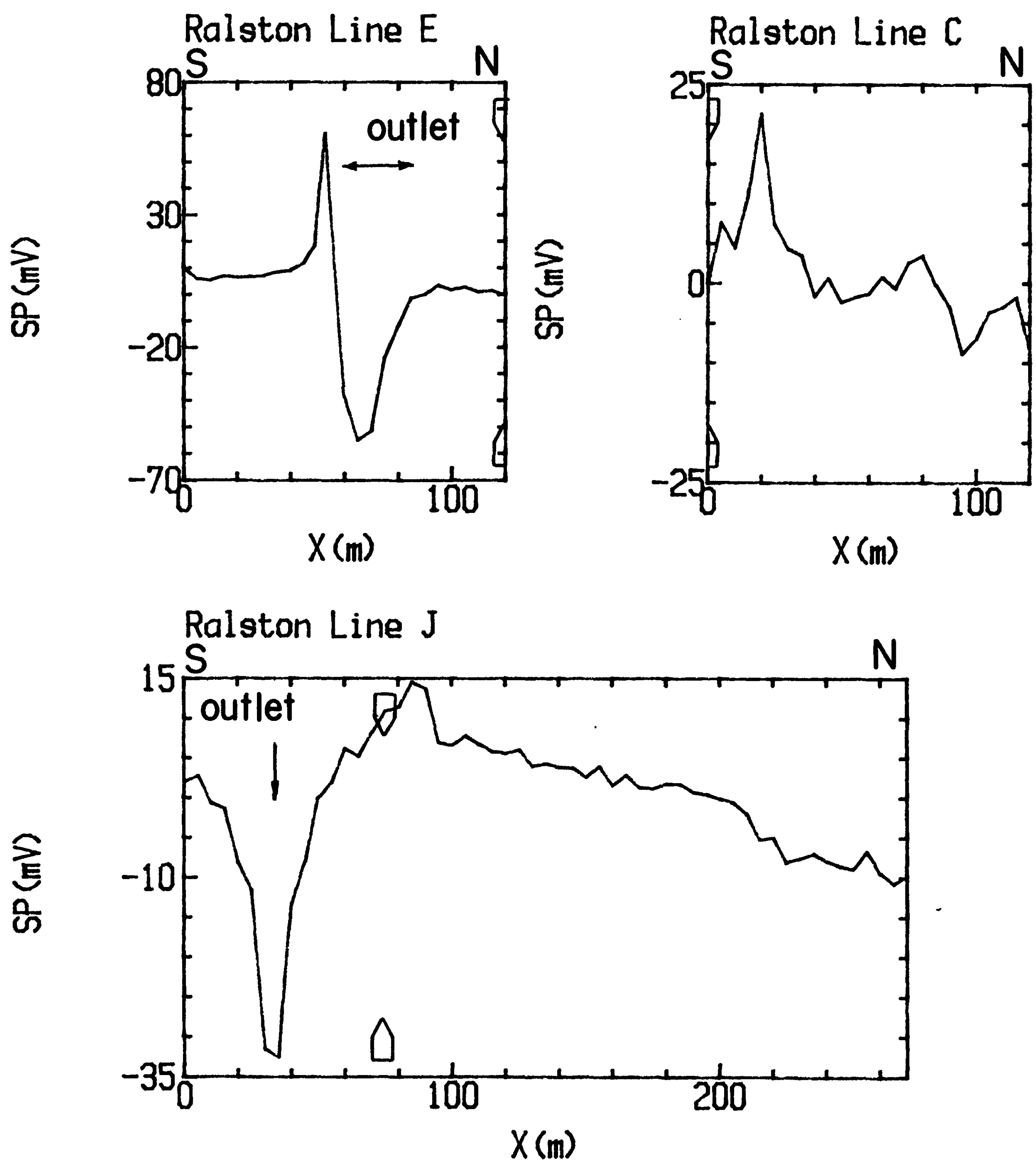
Ralston Line G
S
N
20
-5
-30
0
100
200
300
X (m)
SP (mV)



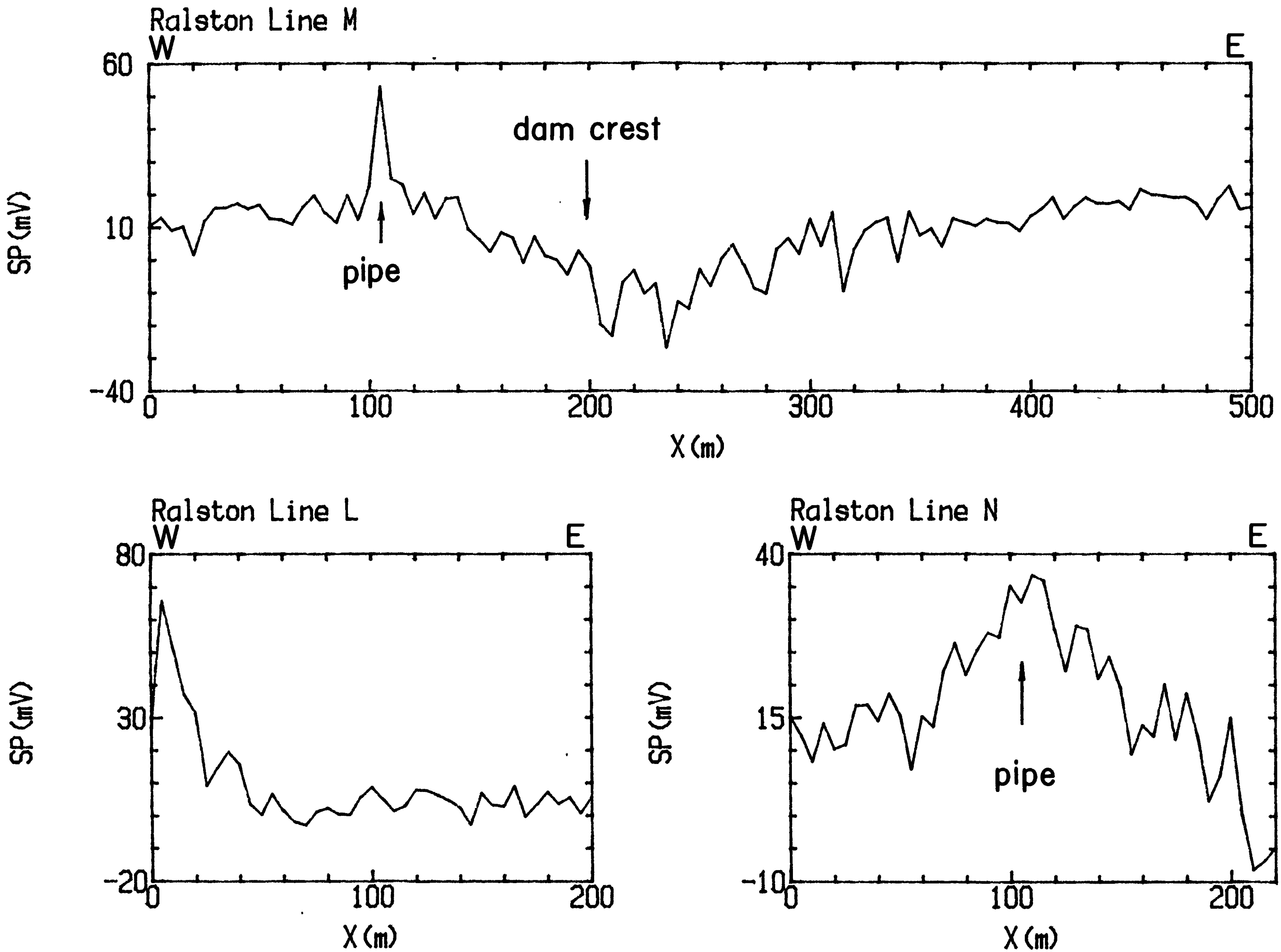
Ralston Line H
S
N
35
10
-15
0
100
X (m)
SP (mV)



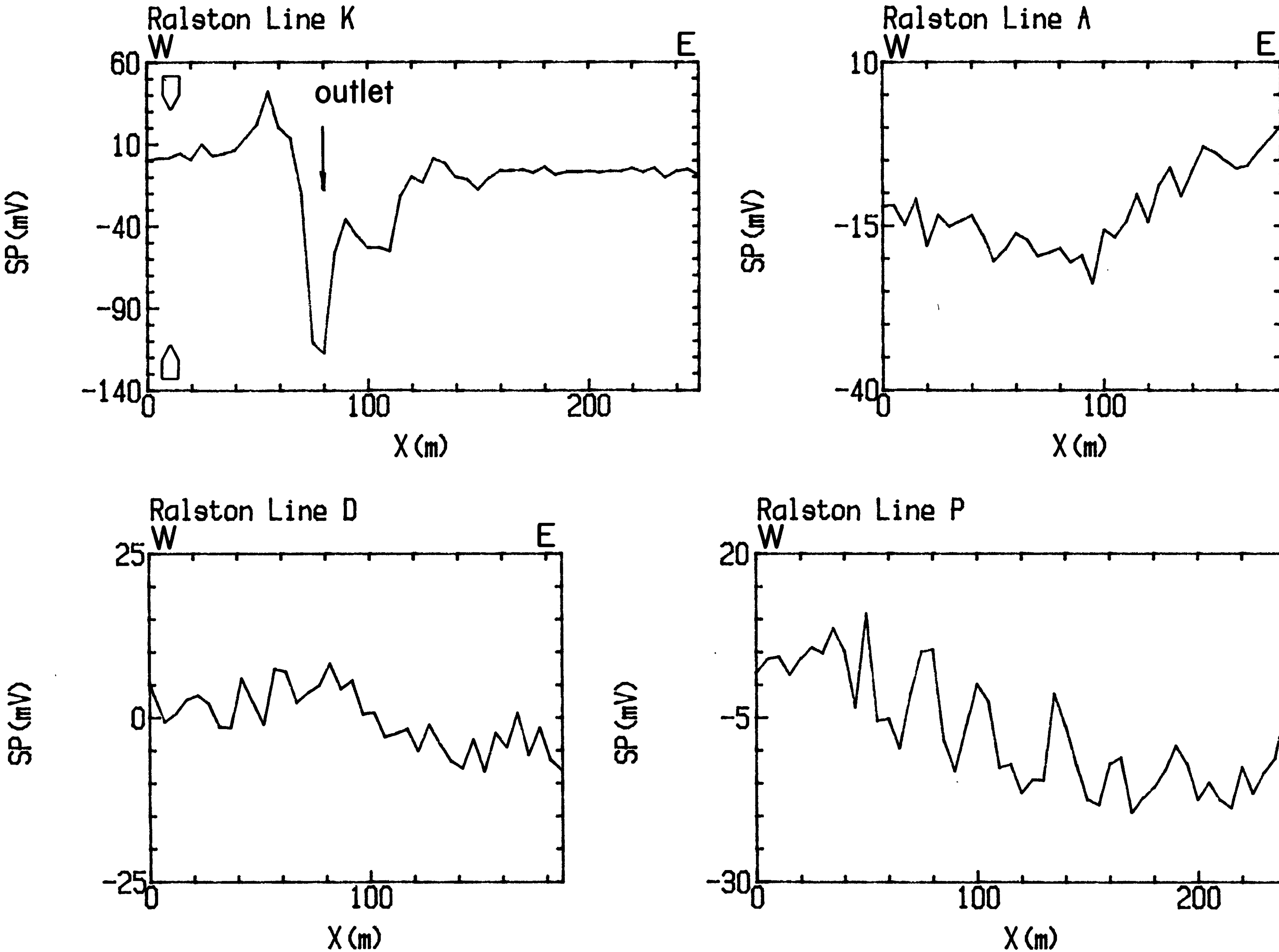
Ralston Line I
S
N
25
0
-25
0
100
X (m)
SP (mV)

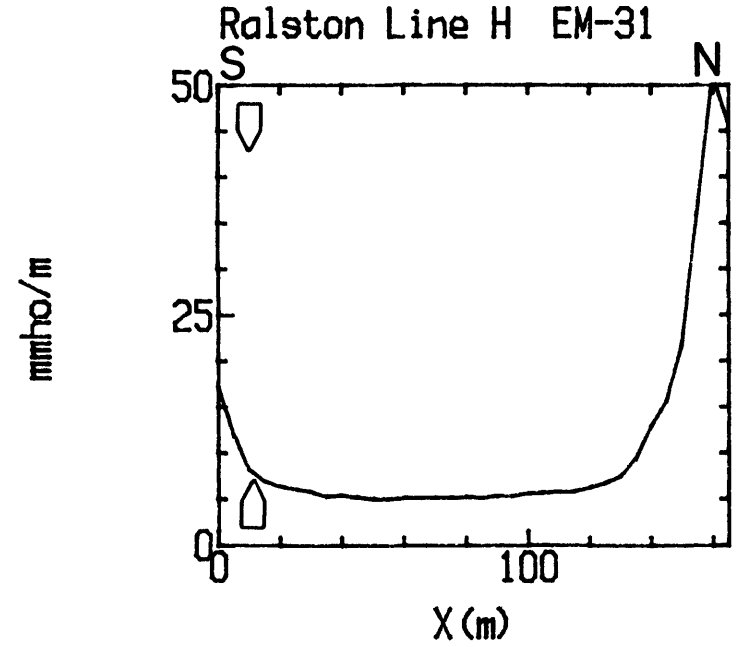


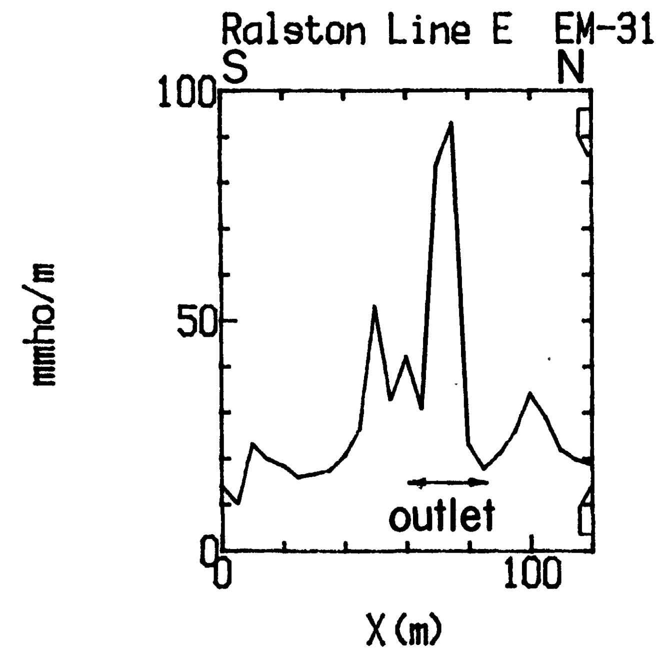
Ralston Line E
S
N
80
30
-20
-70
0
100
outlet
SP (mV)
X (m)
Ralston Line C
S
N
25
0
-25
0
100
SP (mV)
X (m)
Ralston Line J
S
N
15
-10
-35
0
100
200
outlet
SP (mV)
X (m)

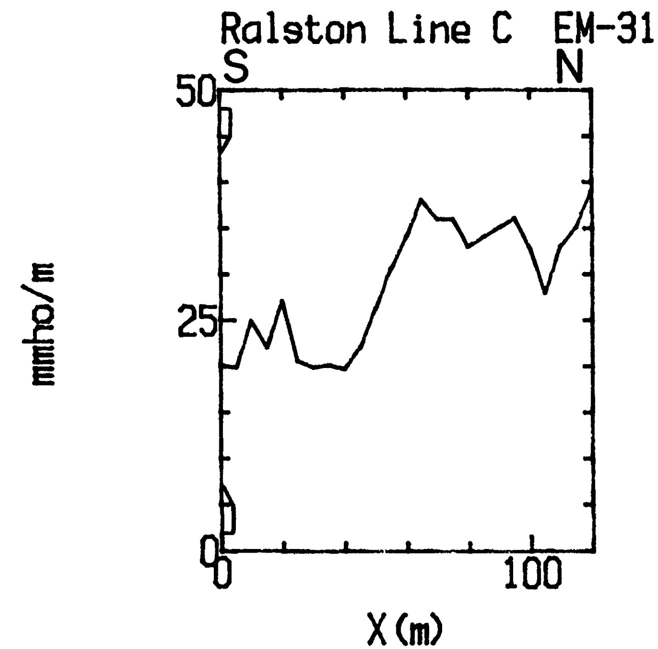

Ralston Line M
W
E
60
10
-40
SP (mV)
dam crest
pipe
0
100
200
300
400
500
X (m)
Ralston Line L
W
E
80
30
-20
SP (mV)
0
100
200
X (m)
Ralston Line N
W
E
40
15
-10
SP (mV)
pipe
0
100
200
X (m)

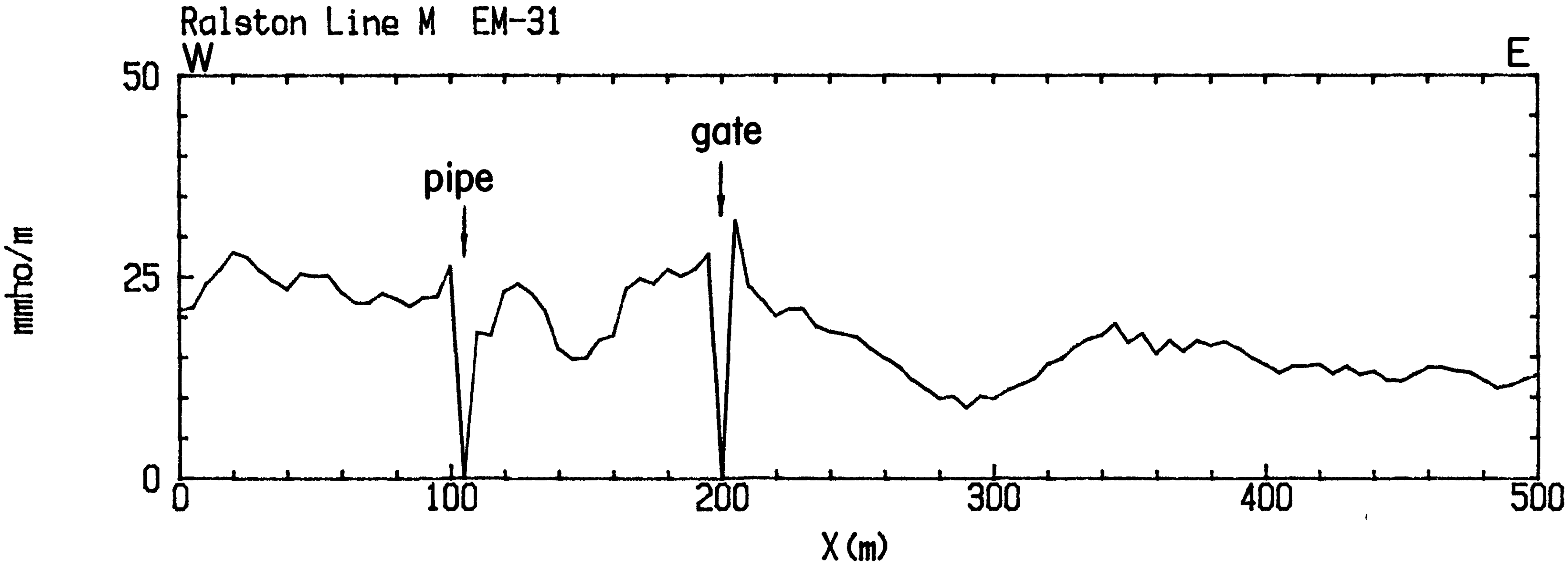
6

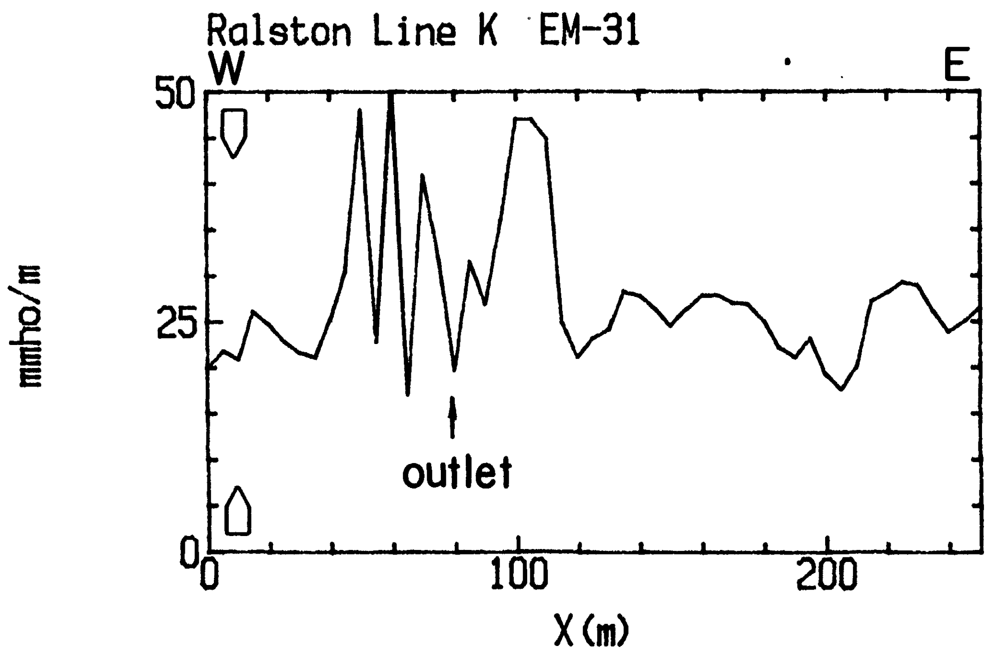

Ralston Line K
W
E
outlet
60
10
-40
-90
-140
0
100
200
X (m)
SP (mV)
Ralston Line A
W
E
10
-15
-40
0
100
X (m)
SP (mV)
Ralston Line D
W
E
25
0
-25
0
100
X (m)
SP (mV)
Ralston Line P
W
E
20
-5
-30
0
100
200
X (m)
SP (mV)


Ralston Line H EM-31
S
N
50
25
0
0
100
X (m)
mmho/m

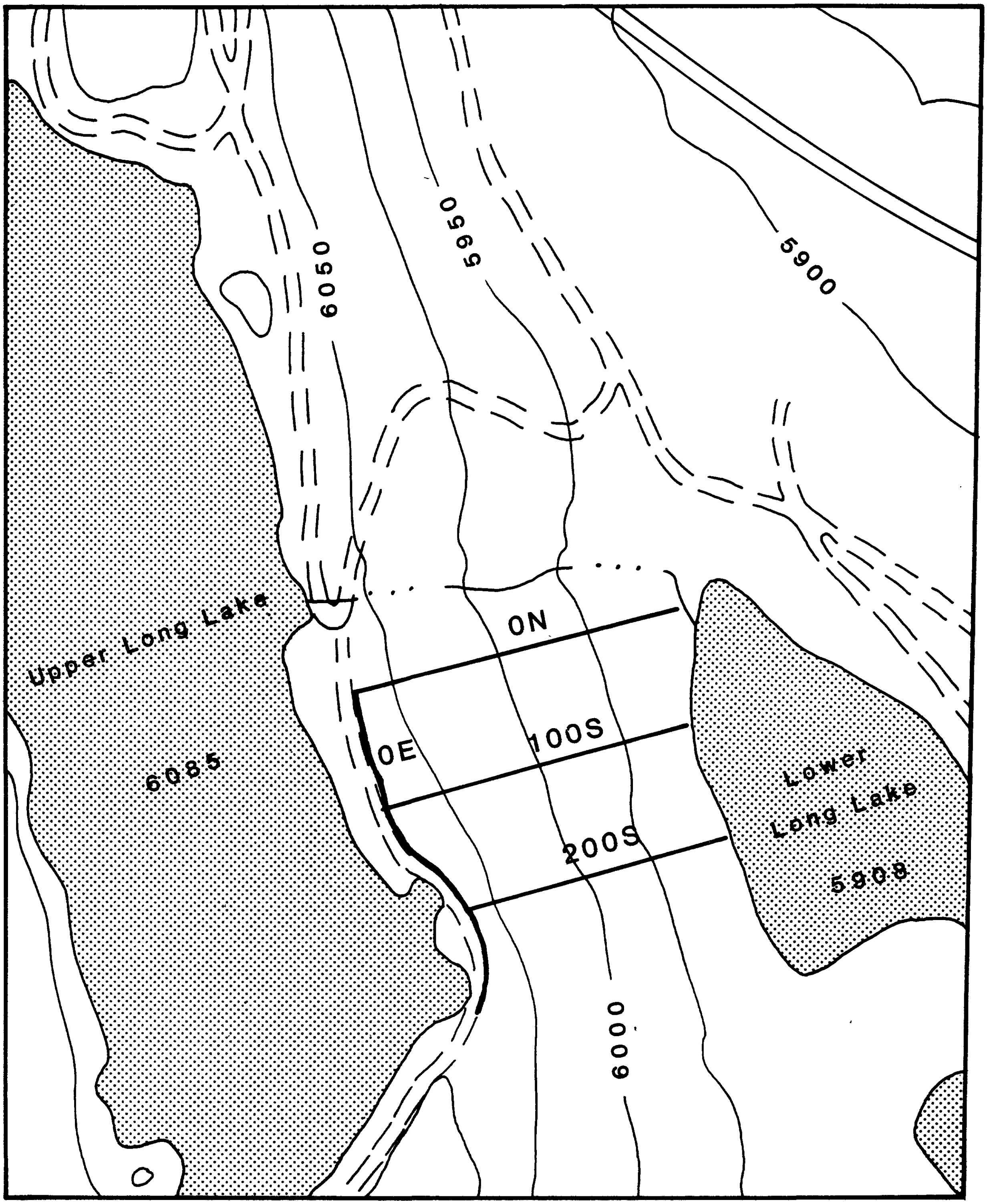

Ralston Line E EM-31
S
N
100
50
0
0
100
outlet
X (m)
mmho/m


Ralston Line C EM-31
S
N
50
25
0
0
100
X (m)
mmho/m


Ralston Line M EM-31
W
E
50
25
0
mmho/m
pipe
gate
0
100
200
300
400
500
X (m)


Ralston Line K EM-31
W
E
50
25
0
mmho/m
outlet
0
100
200
X (m)

1D



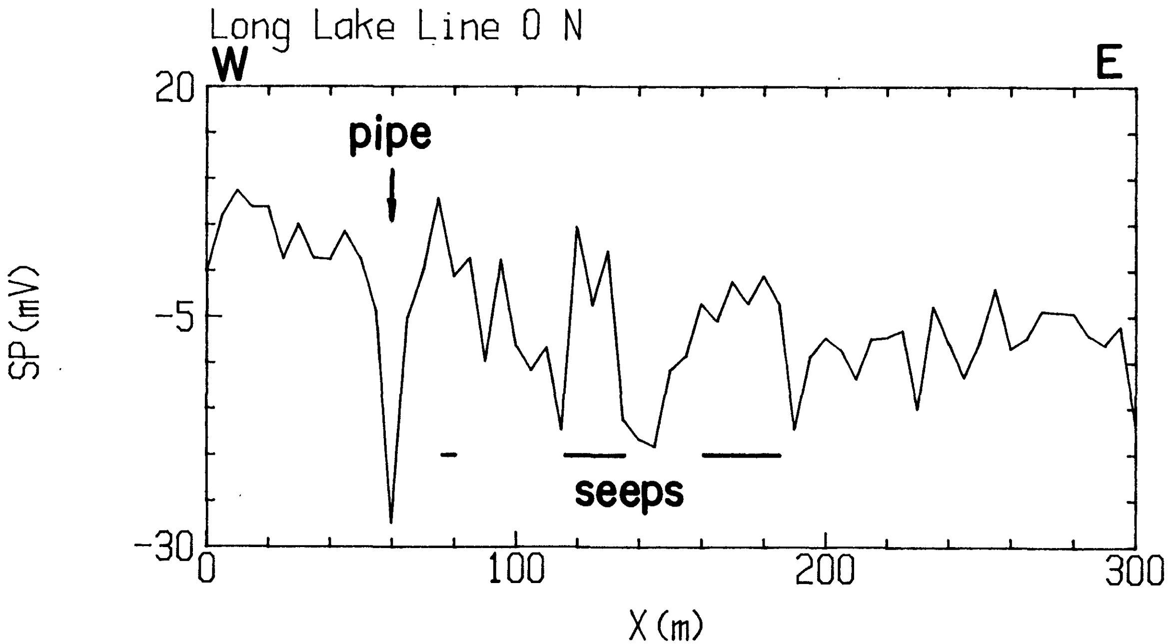
SCALE 1:5,000

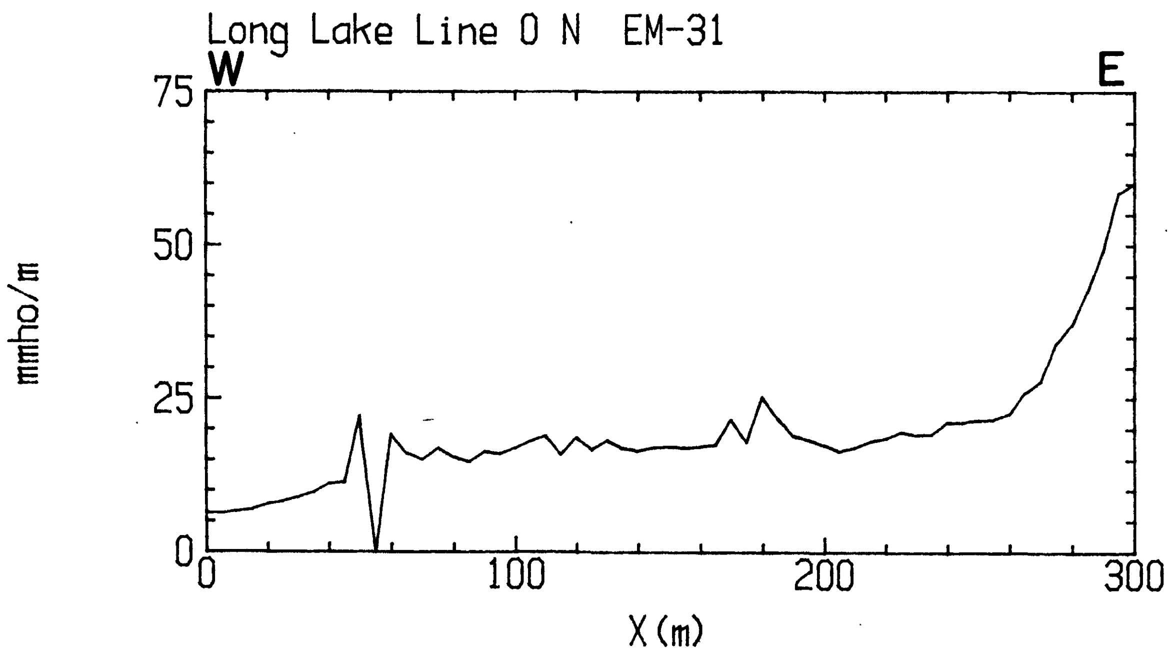
0 1000 2000 FEET

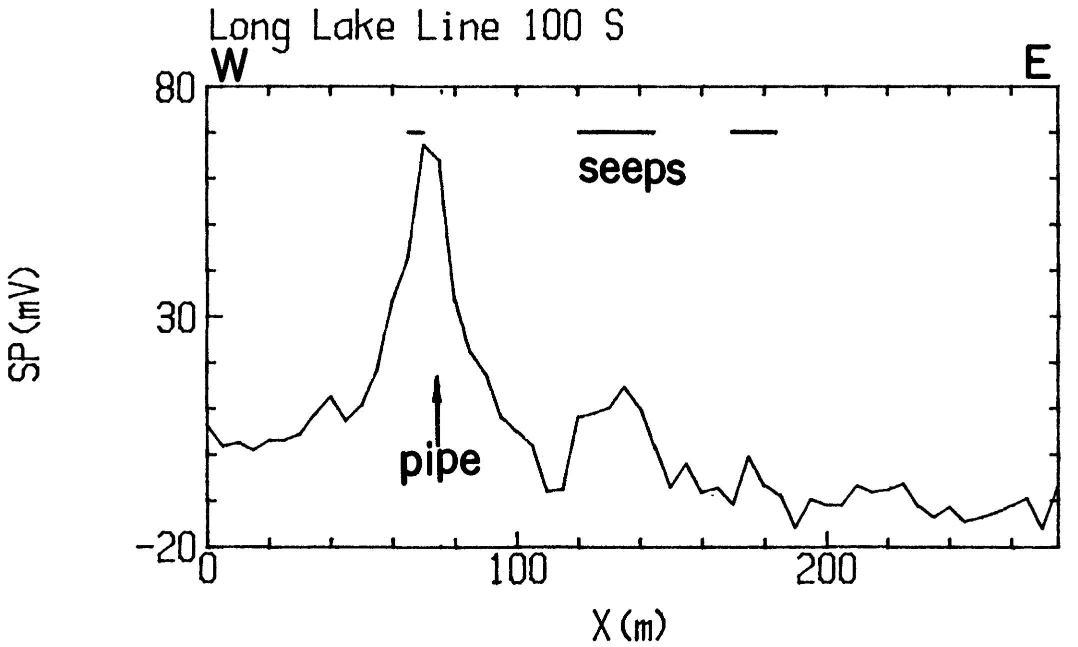
0 500 METERS

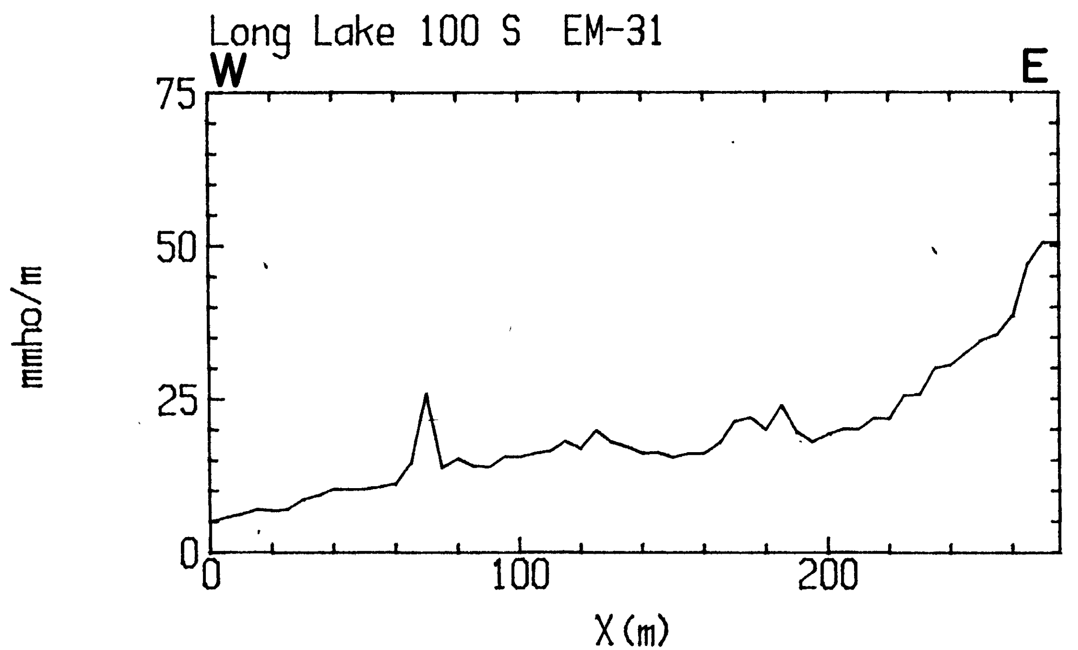
CONTOUR INTERVAL 50 FEET

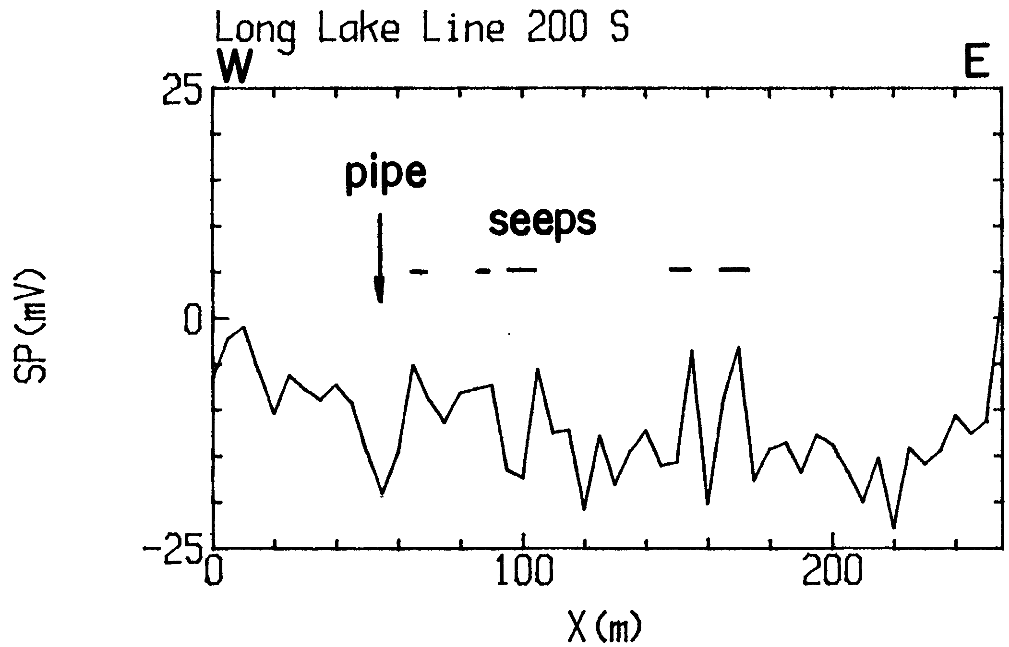
1C

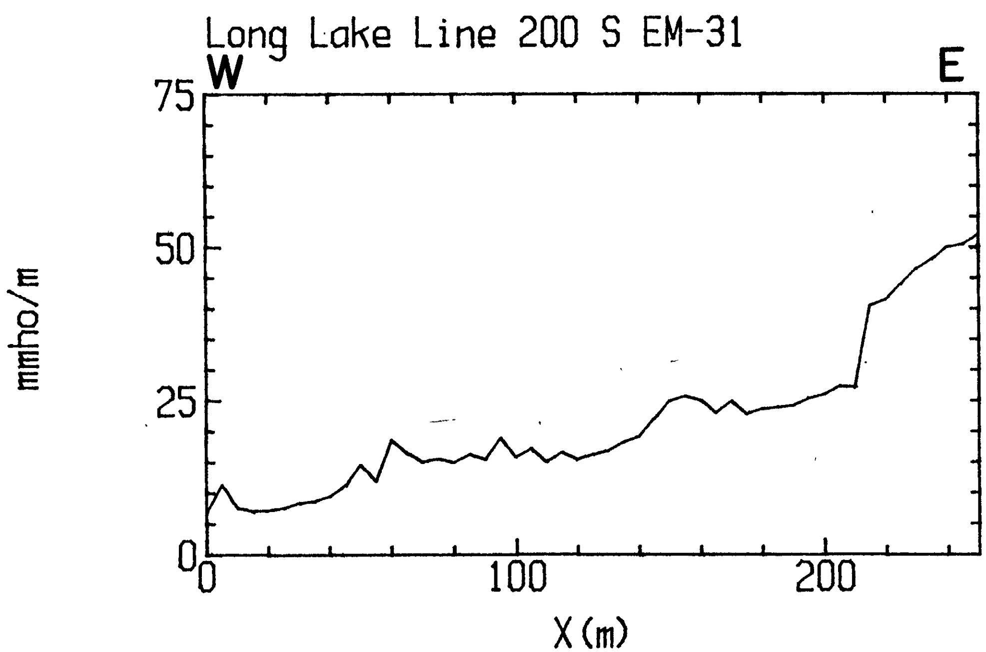

Long Lake Line 0 N
W
E
20
-5
-30
SP (mV)
pipe
seeps
0
100
200
300
X (m)

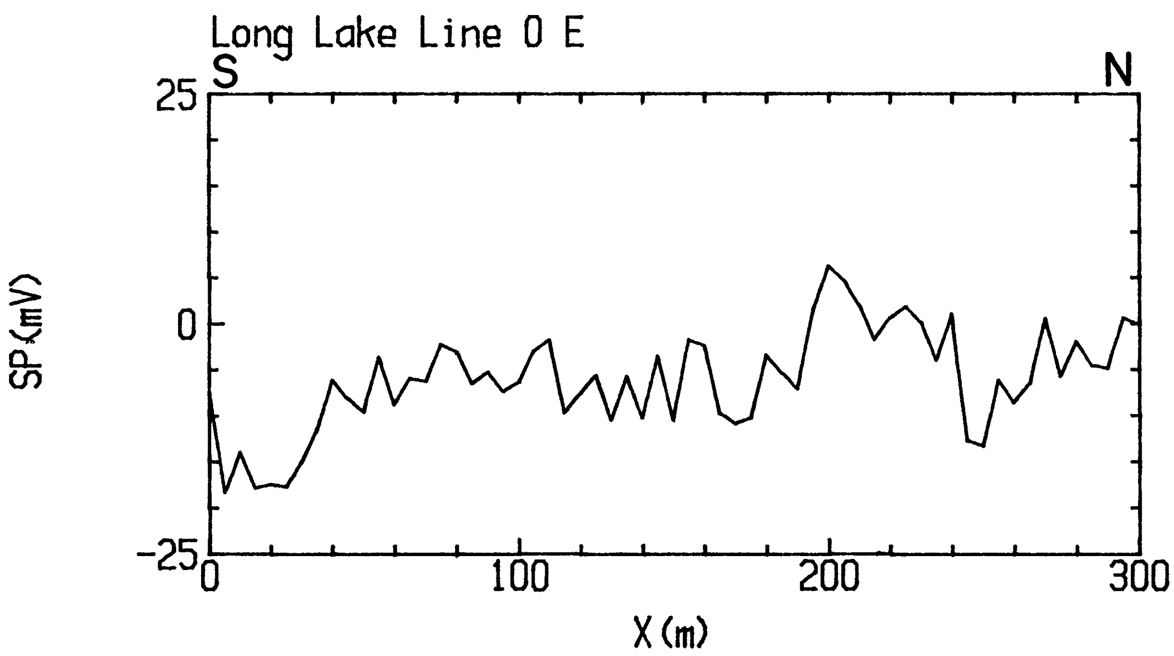

Long Lake Line 0 N EM-31
W
E
75
50
25
0
mmho/m
0
100
200
300
X (m)

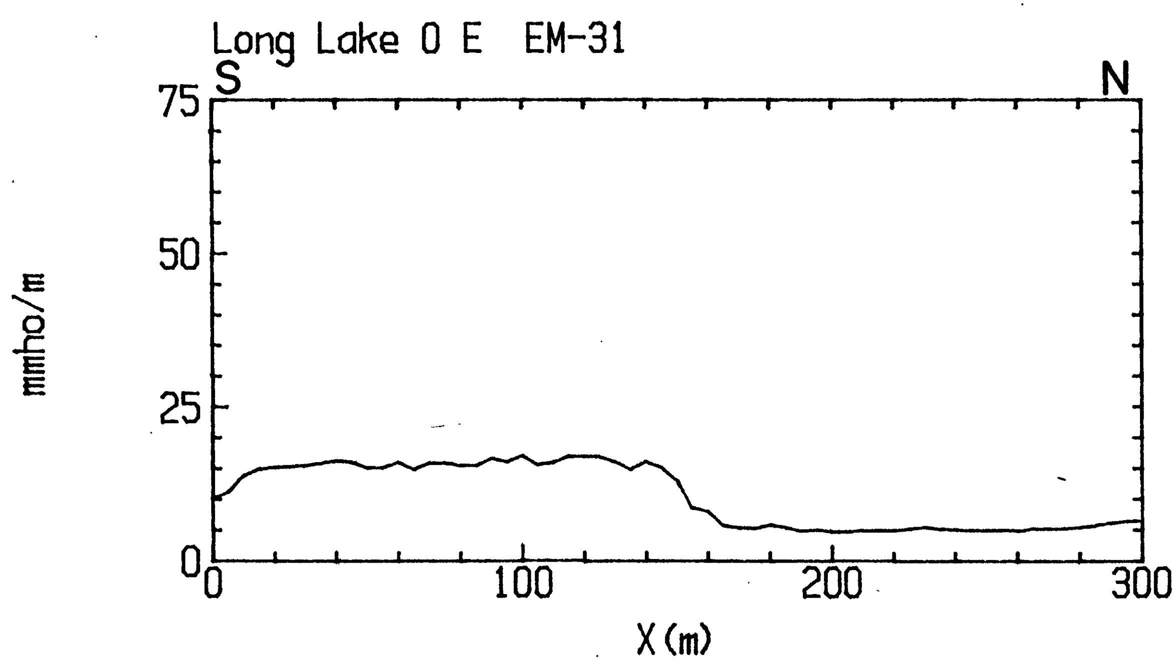

Long Lake Line 100 S
W
E
SP (mV)
80
30
-20
seeps
pipe
0
100
200
X (m)

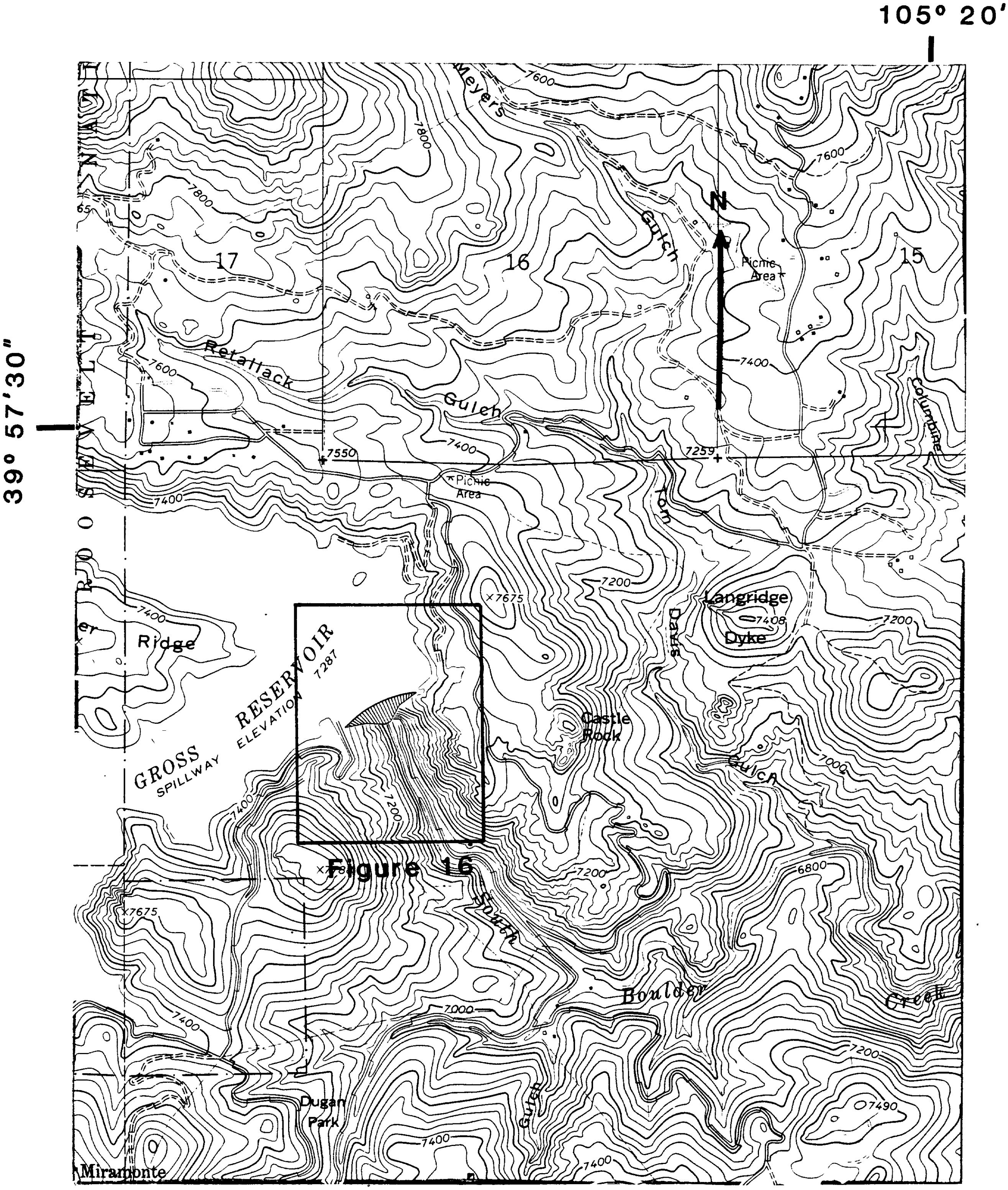

Long Lake 100 S EM-31
W
E
mmho/m
75
50
25
0
0
100
200
X (m)


Long Lake Line 200 S
W
E
25
0
-25
SP (mV)
pipe
seeps
0
100
200
X (m)


Long Lake Line 200 S EM-31
W
E
75
50
25
0
mmho/m
0
100
200
X (m)


Long Lake Line 0 E
S
N
SP (mV)
25
0
-25
0
100
200
300
X (m)


Long Lake 0 E EM-31
S
N
mmho/m
75
50
25
0
0
100
200
300
X (m)



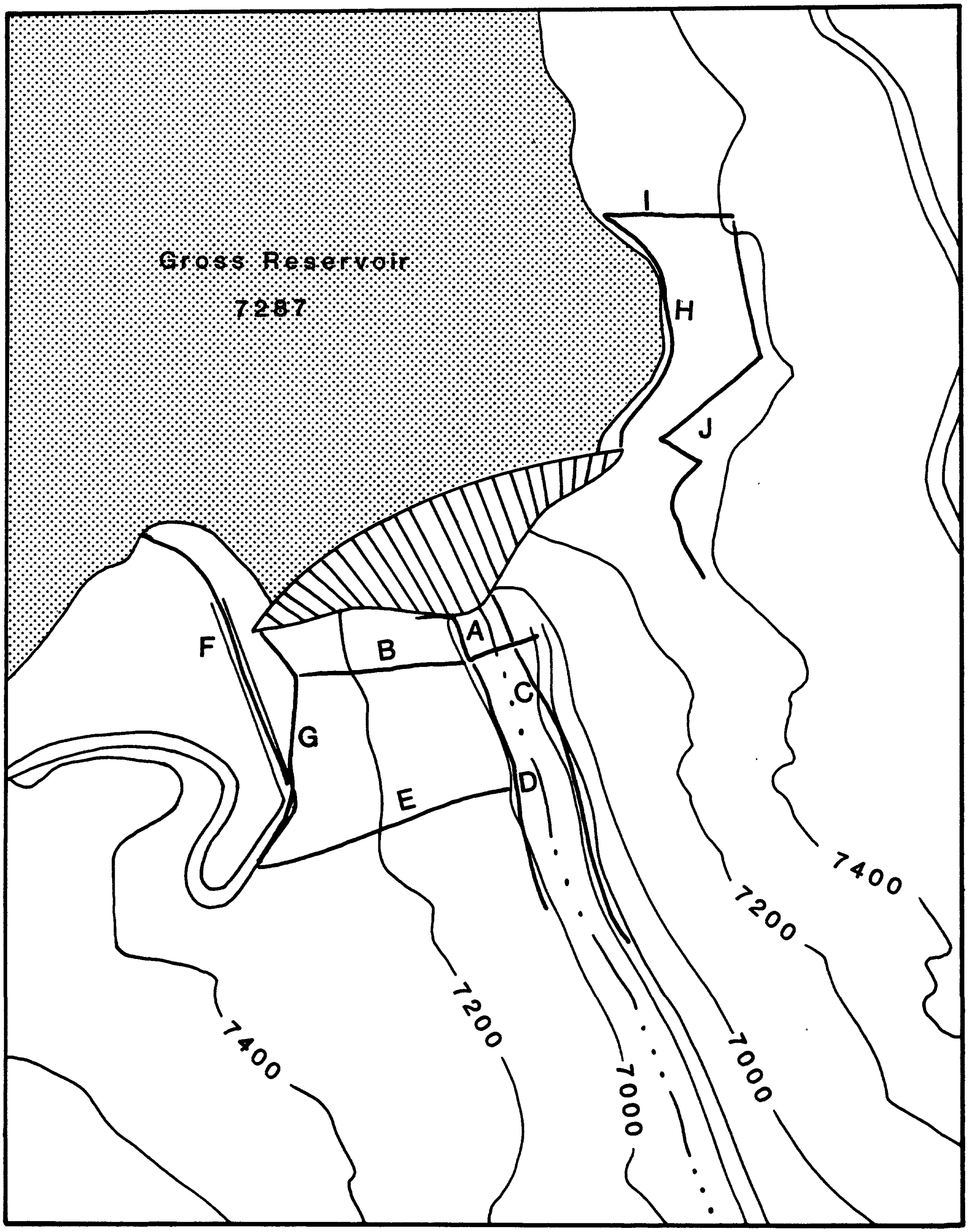
SCALE 1:24 000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

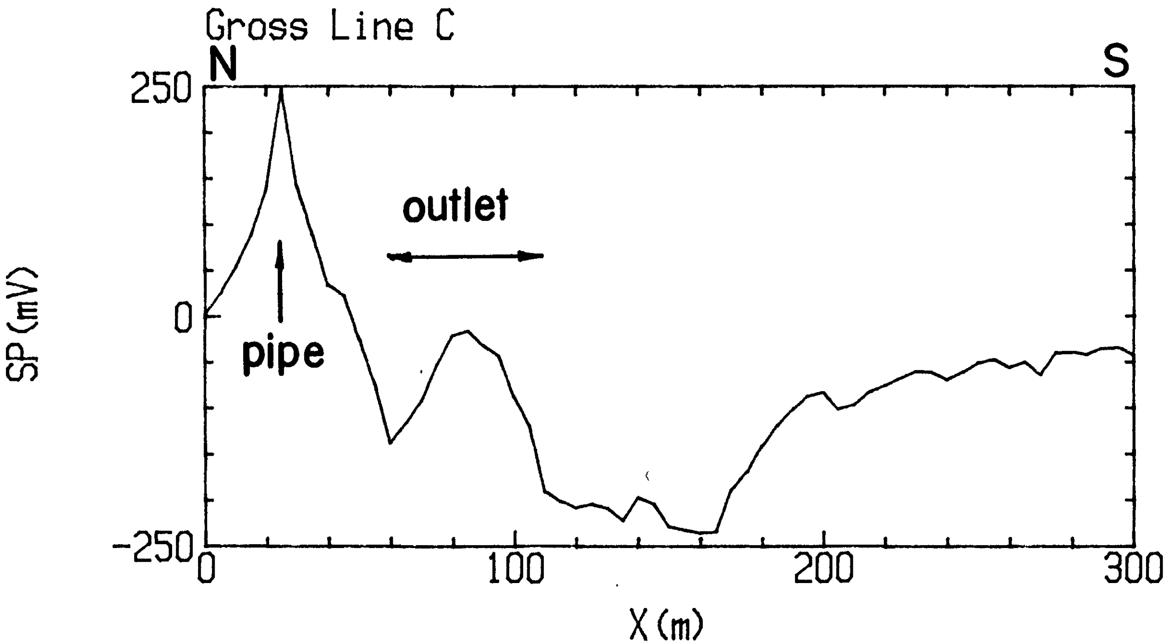


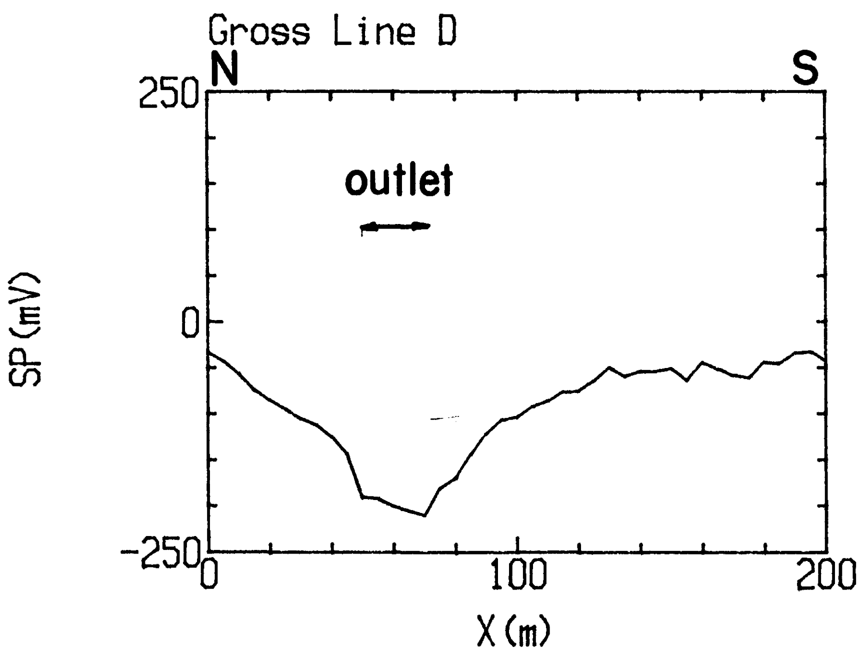
SCALE 1:5,000

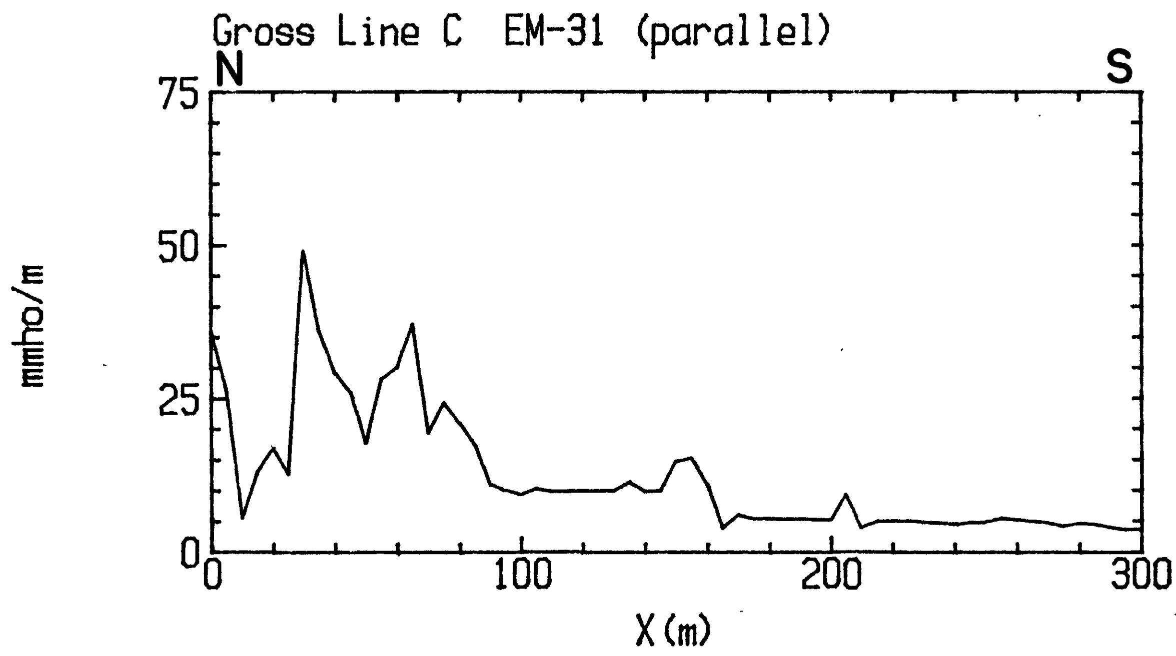
0 1000 2000 FEET

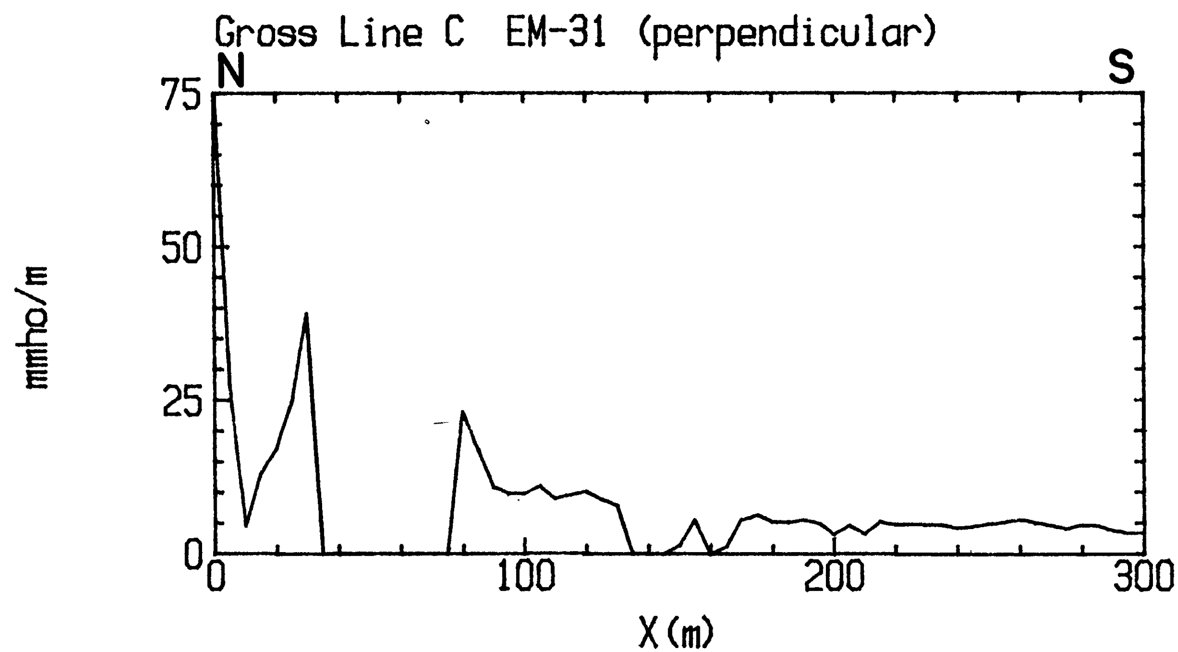
0 500 METERS

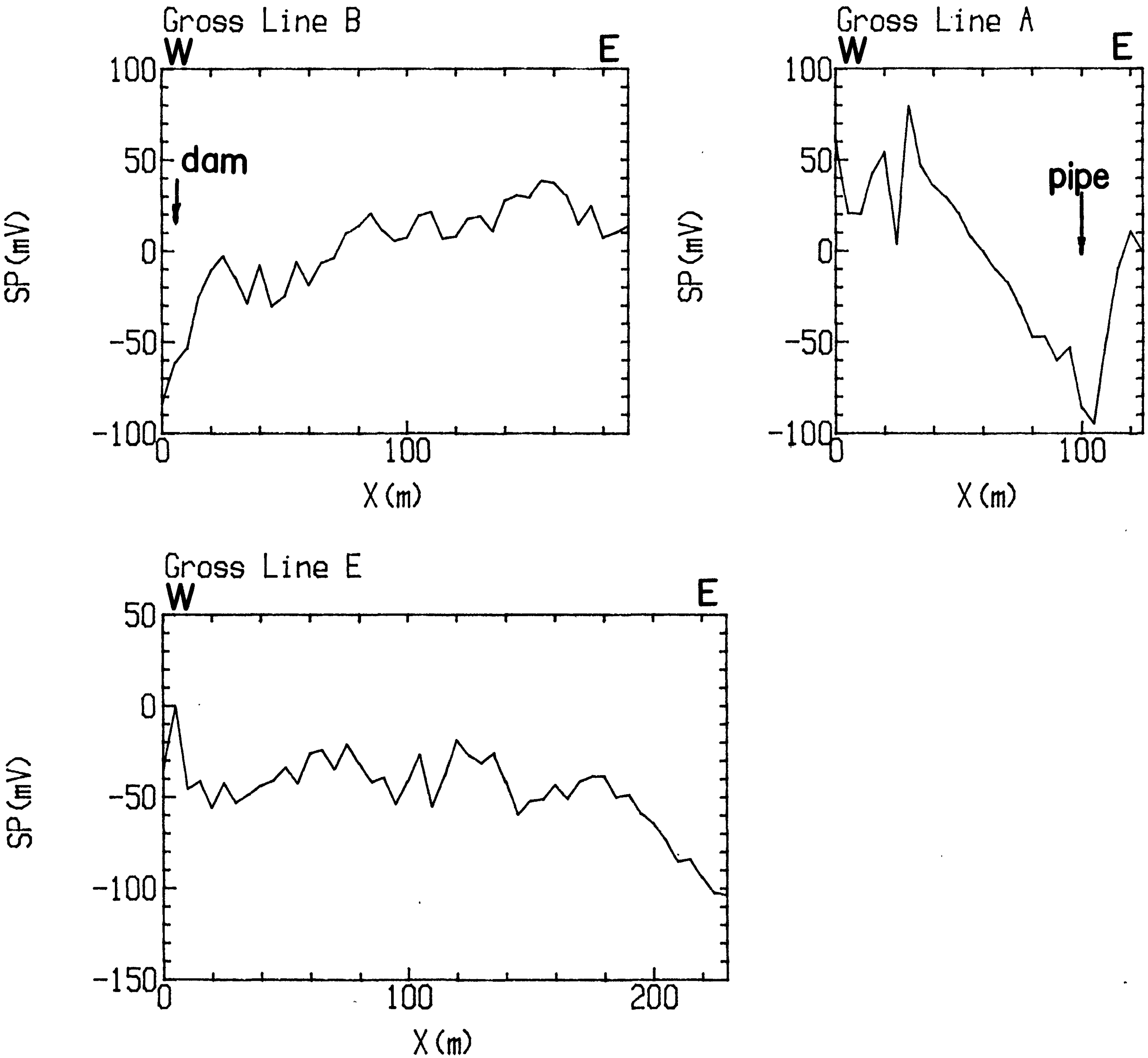
CONTOUR INTERVAL 200 FEET

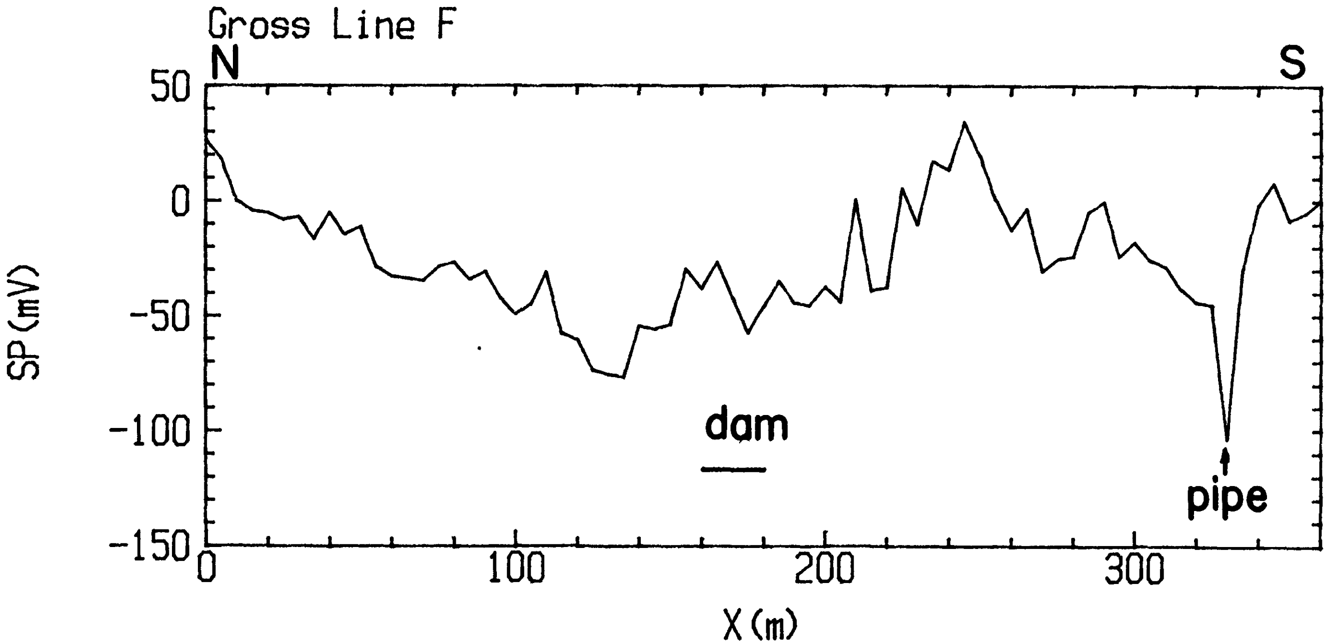

Gross Line C
N
S
250
0
-250
0
100
200
300
X (m)
SP (mV)
outlet
pipe

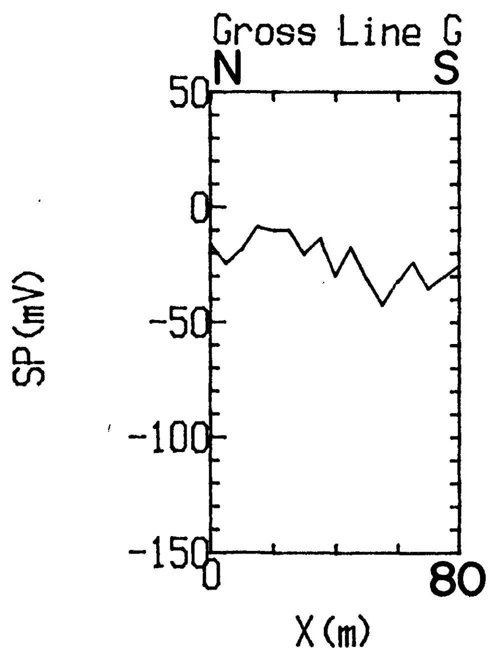

Gross Line D
N
S
250
0
-250
0
100
200
X (m)
SP (mV)
outlet

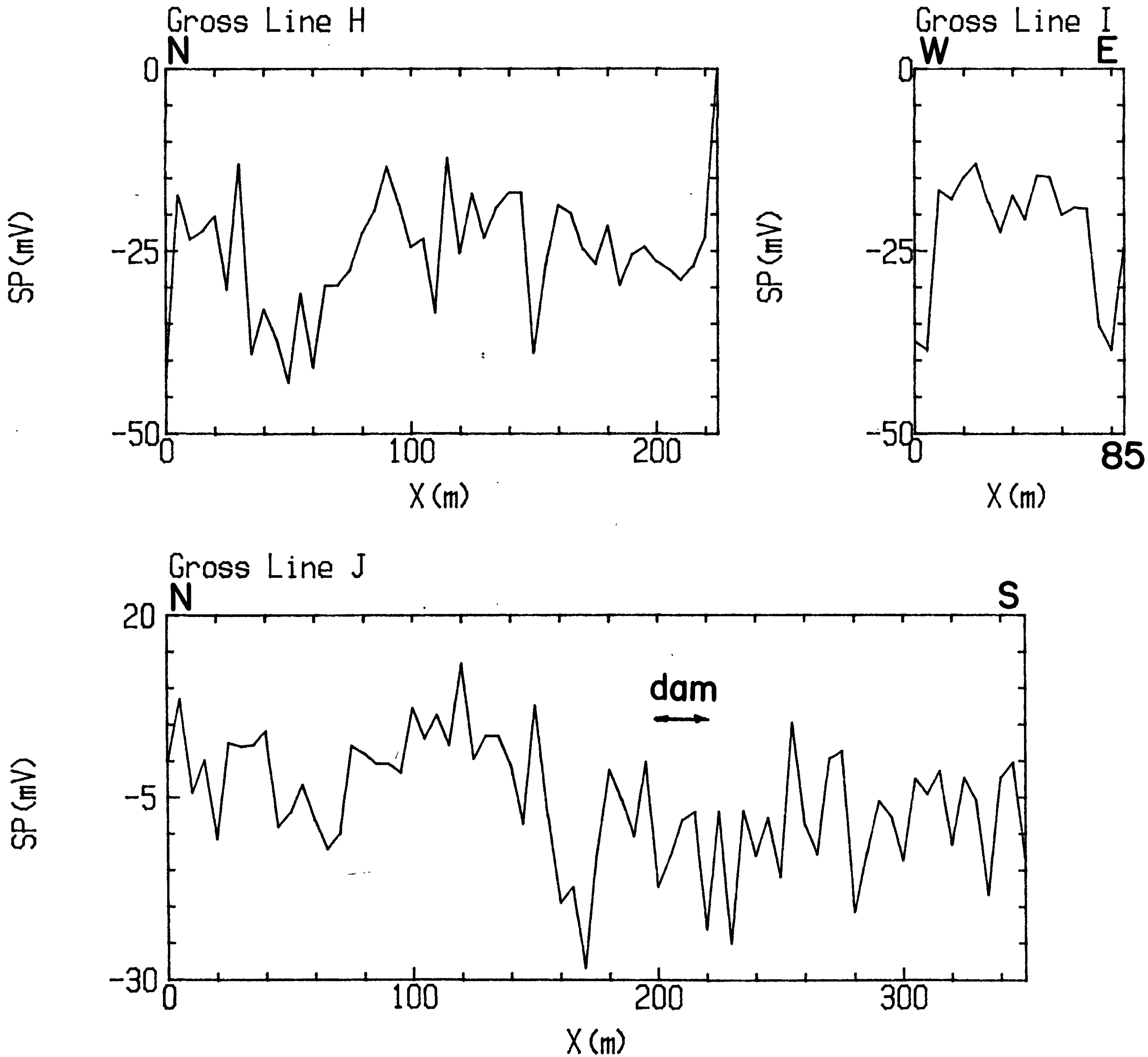

Gross Line C EM-31 (parallel)
N
S
mmho/m
75
50
25
0
0
100
200
300
X (m)

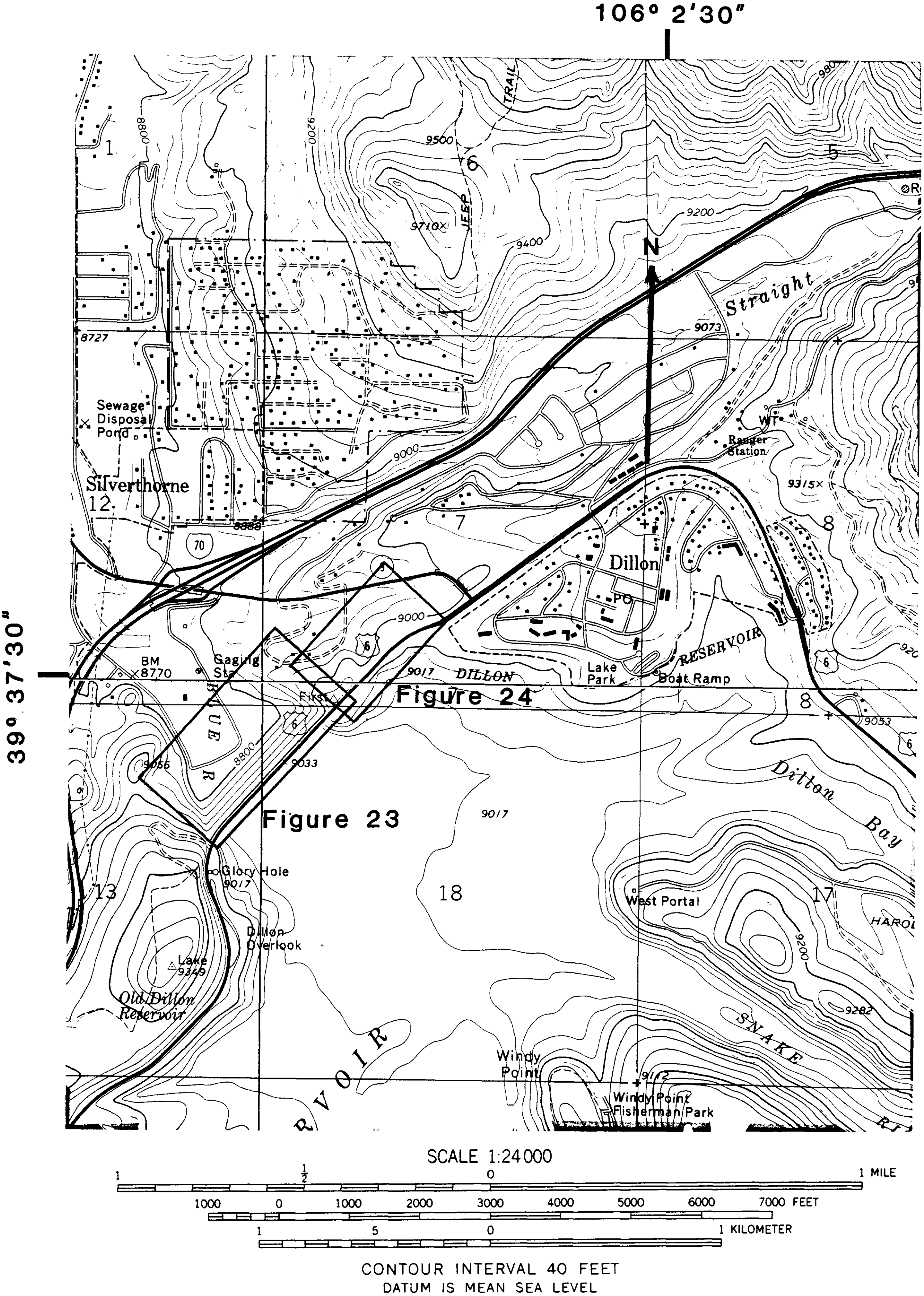

Gross Line C EM-31 (perpendicular)
N
S
mmho/m
75
50
25
0
0
100
200
300
X (m)

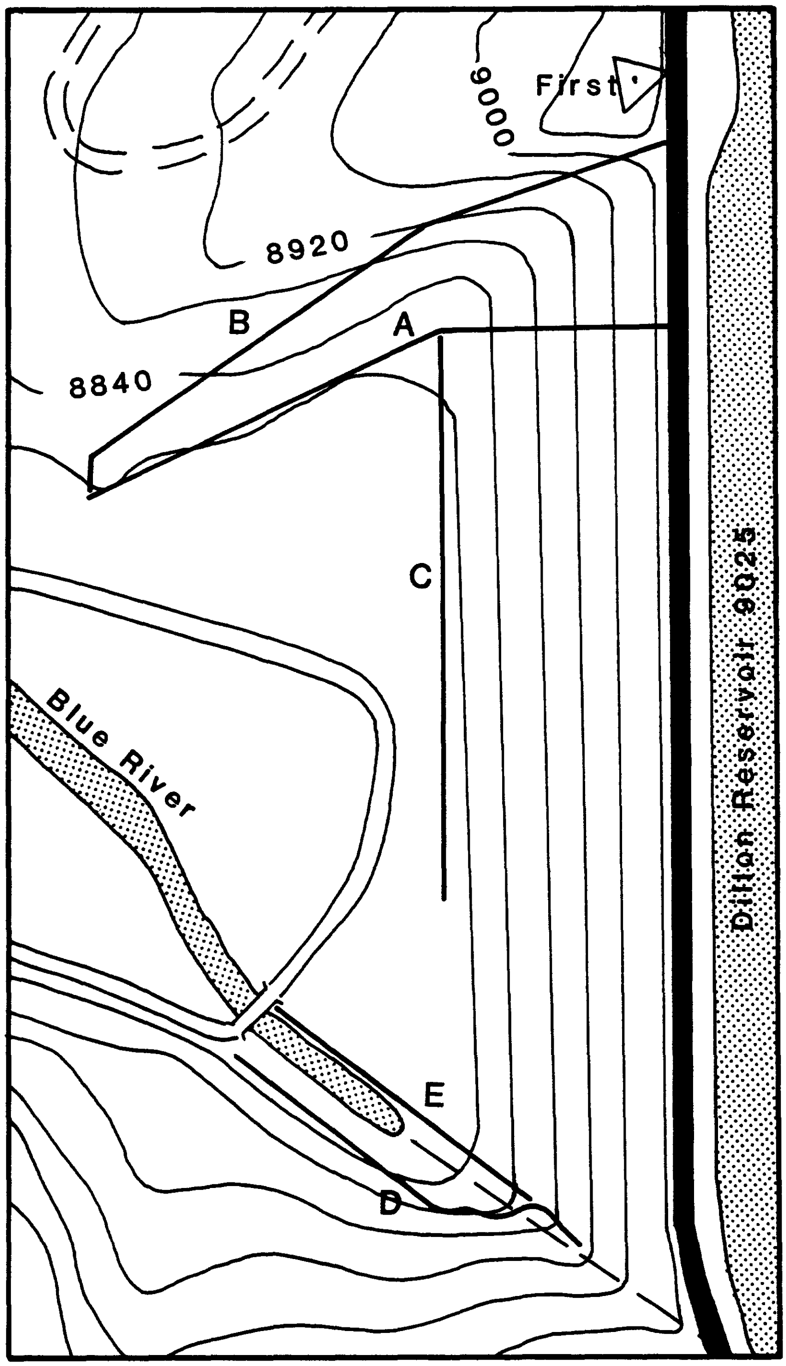

Gross Line B
W
E
dam
SP (mV)
100
50
0
-50
-100
0
100
X (m)
Gross Line A
W
E
pipe
SP (mV)
100
50
0
-50
-100
0
100
X (m)
Gross Line E
W
E
SP (mV)
50
0
-50
-100
-150
0
100
200
X (m)


Gross Line F
N
S
50
0
-50
-100
-150
0
100
200
300
SP (mV)
X (m)
dam
pipe


Gross Line G
N
S
50
0
-50
-100
-150
0
80
SP (mV)
X (m)


Gross Line H
N
0
-25
-50
0
100
200
X (m)
SP (mV)
Gross Line I
W
E
0
-25
-50
0
85
X (m)
SP (mV)
Gross Line J
N
S
20
-5
-30
0
100
200
300
X (m)
SP (mV)
dam


106° 2'30"
39° 37'30"
N
Figure 24
Figure 23
Silverthorne
Sewage Disposal Pond
Dillon
PO
RESERVOIR
DILLON
Lake Park
Boat Ramp
Ranger Station
Straight
Dillon Bay
West Portal
Glory Hole
Dillon Overlook
Old Dillon Reservoir
Lake 9349
Windy Point
Windy Point Fisherman Park
SNAKE
BM 8770
Gaging Sta
First
BLUE R
JEEP
TRAIL
70
6
9500
9710
9400
9200
9073
9000
9017
9033
9056
8800
8727
8888
9315
9053
9282
9112
SCALE 1:24000
1 MILE
7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

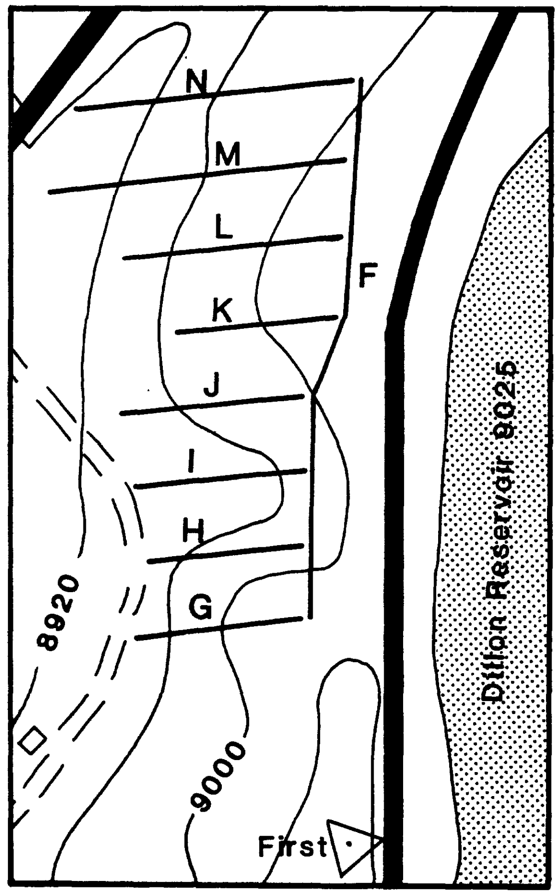


SCALE 1:5,000

0 1000 2000 FEET

0 500 METERS

CONTOUR INTERVAL 40 FEET

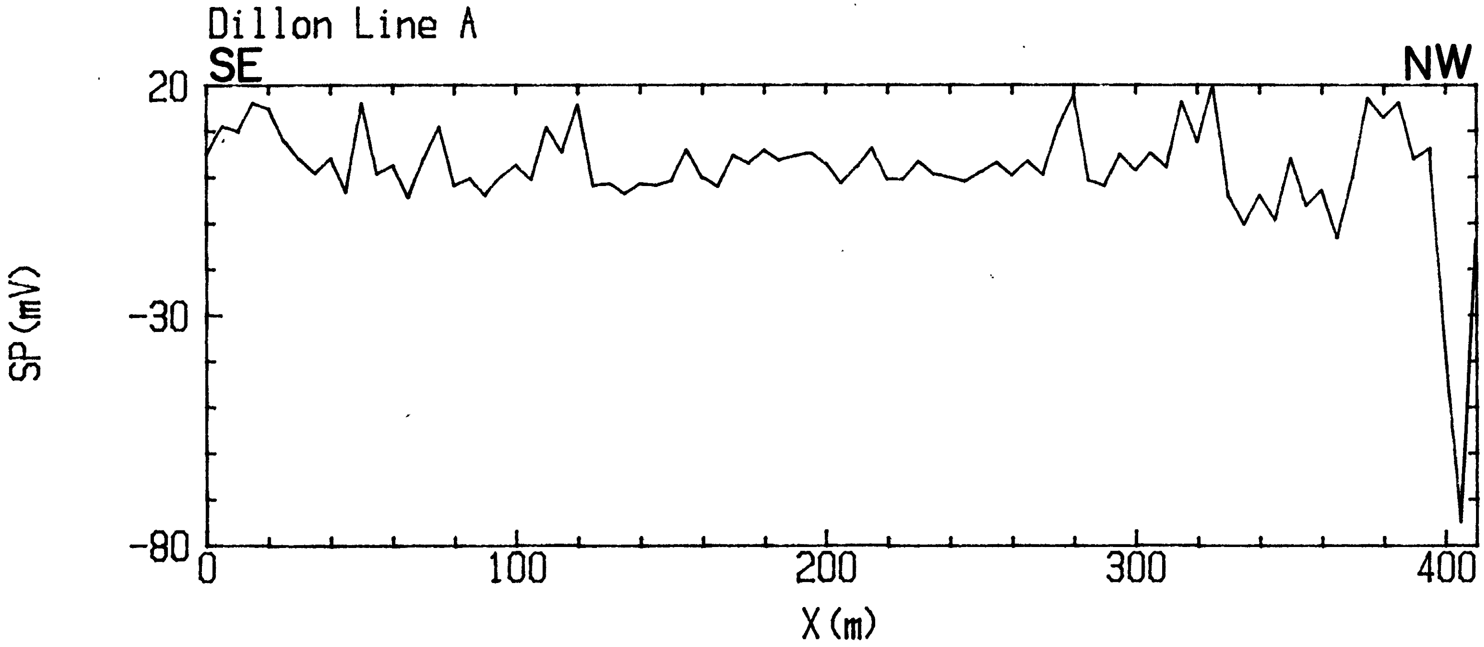


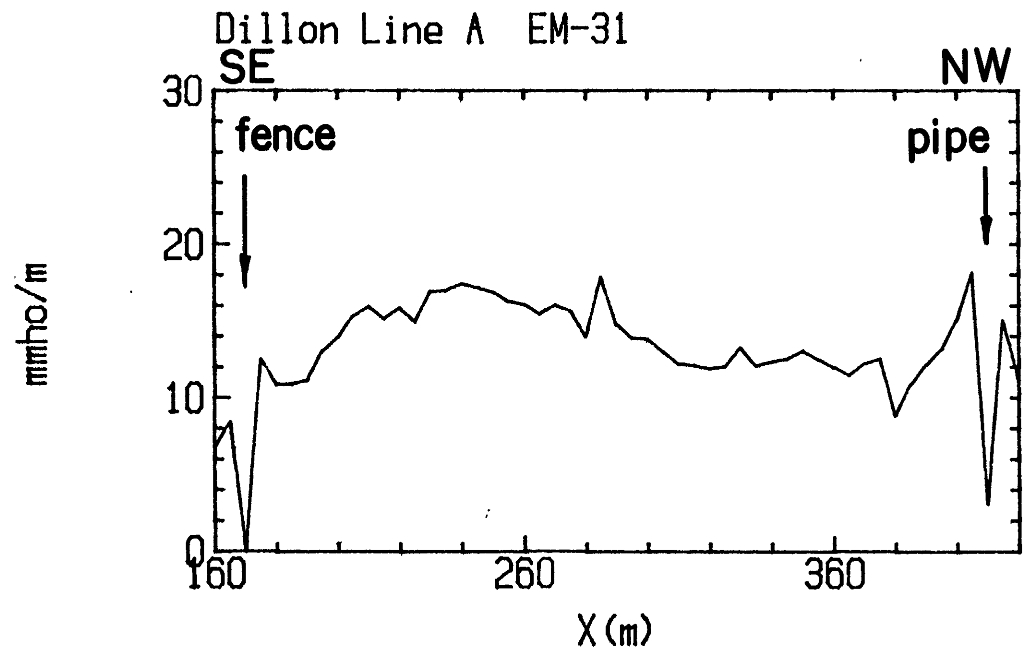
SCALE 1:5,000

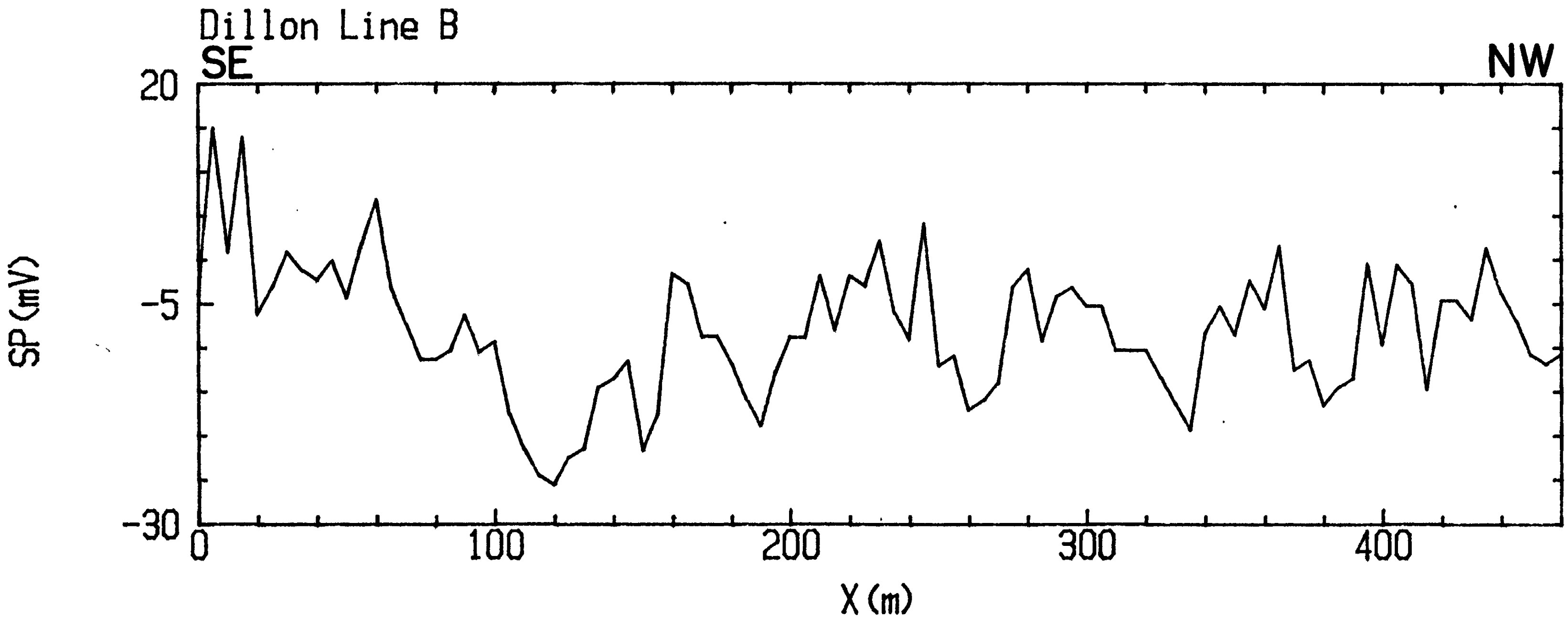
0 1000 2000 FEET

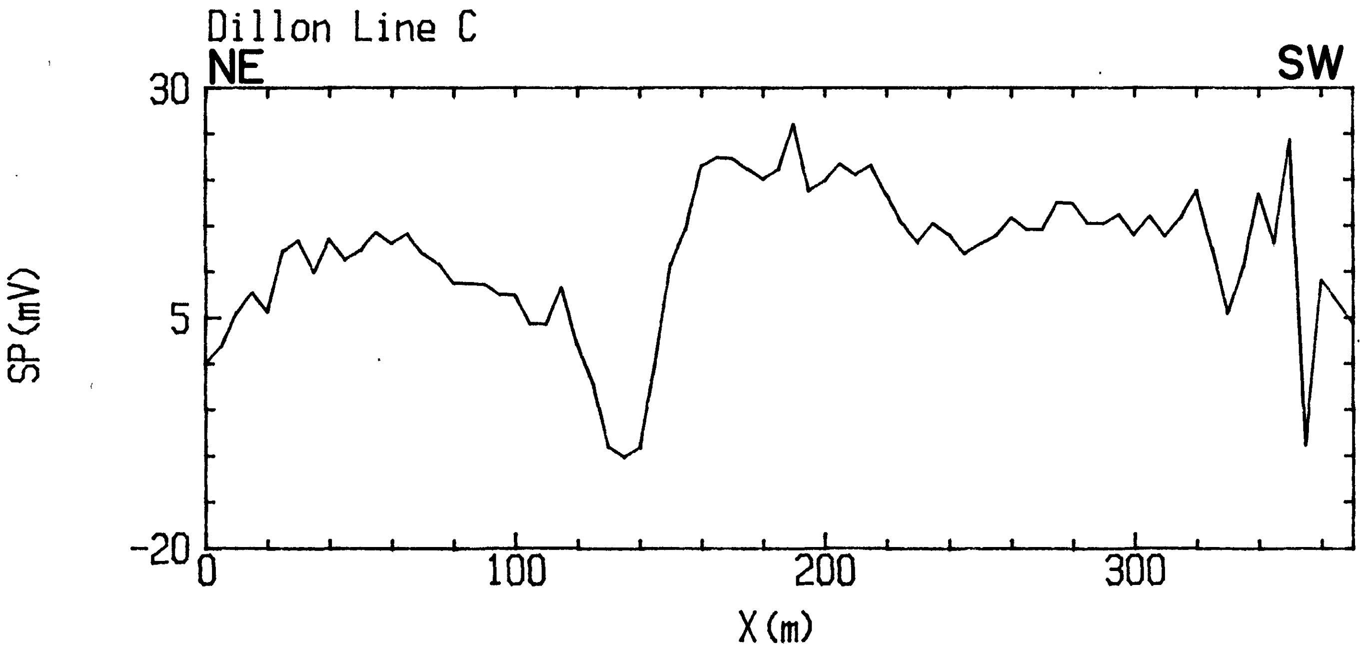
0 500 METERS

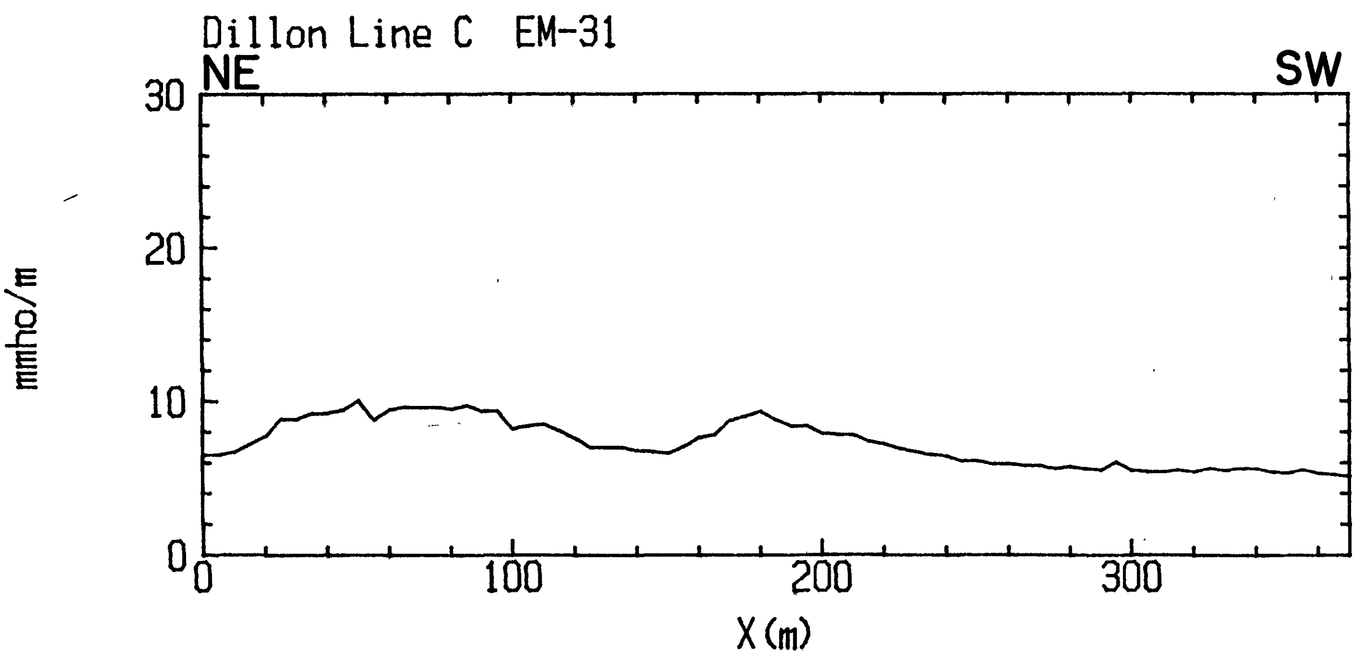
CONTOUR INTERVAL 40 FEET

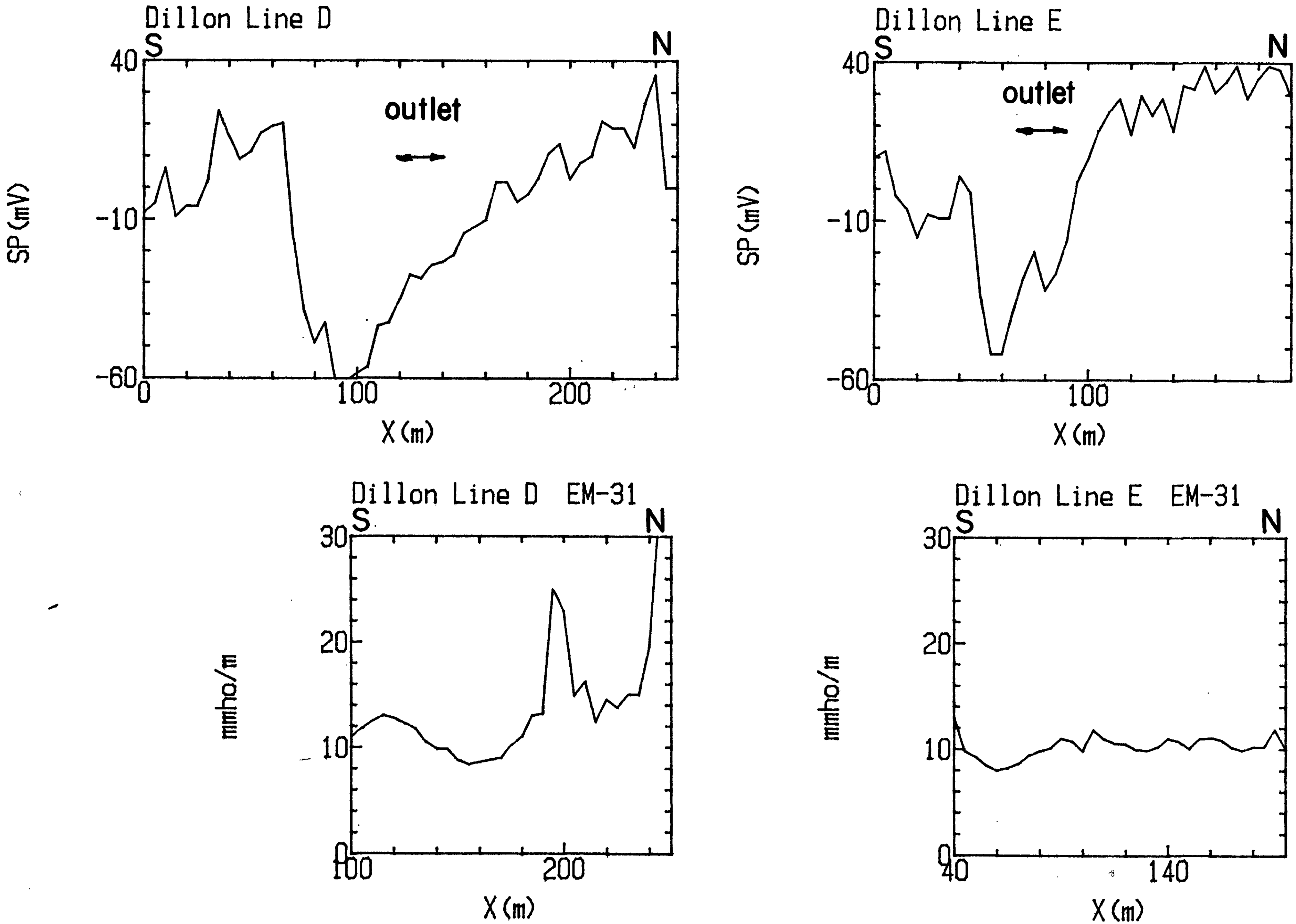

Dillon Line A
SE
NW
20
-30
-80
SP (mV)
0
100
200
300
400
X (m)

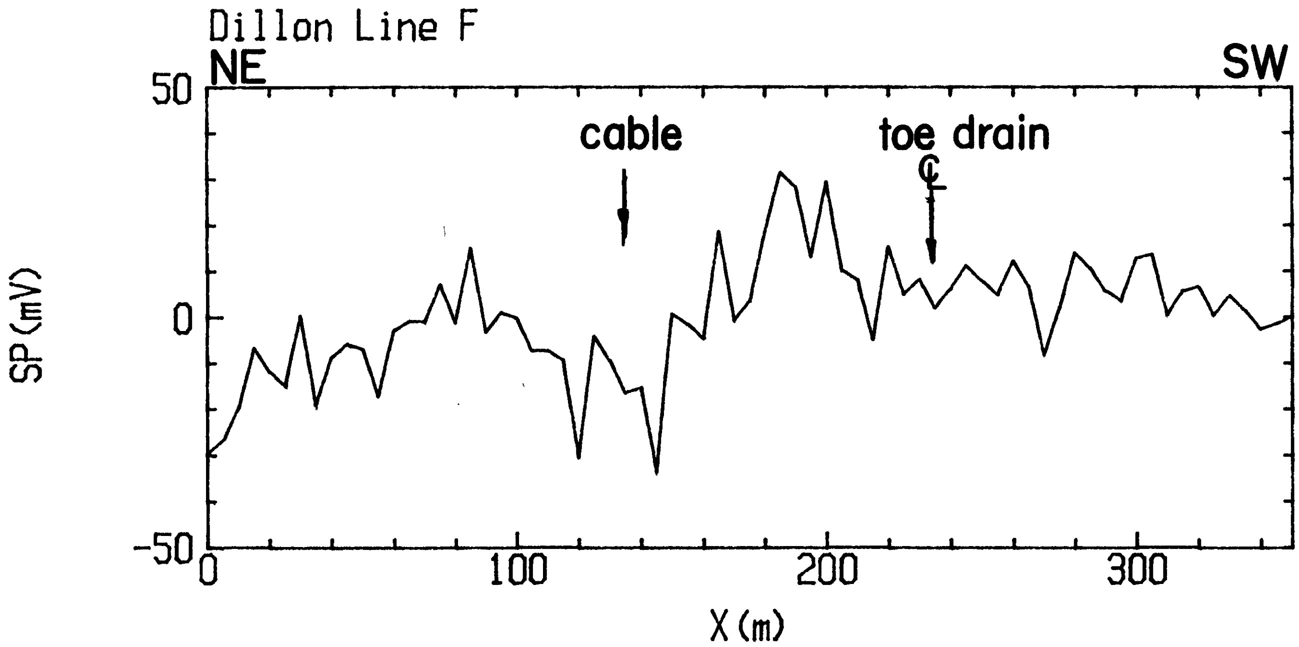

Dillon Line A EM-31
SE
NW
fence
pipe
30
20
10
0
mmho/m
160
260
360
X (m)

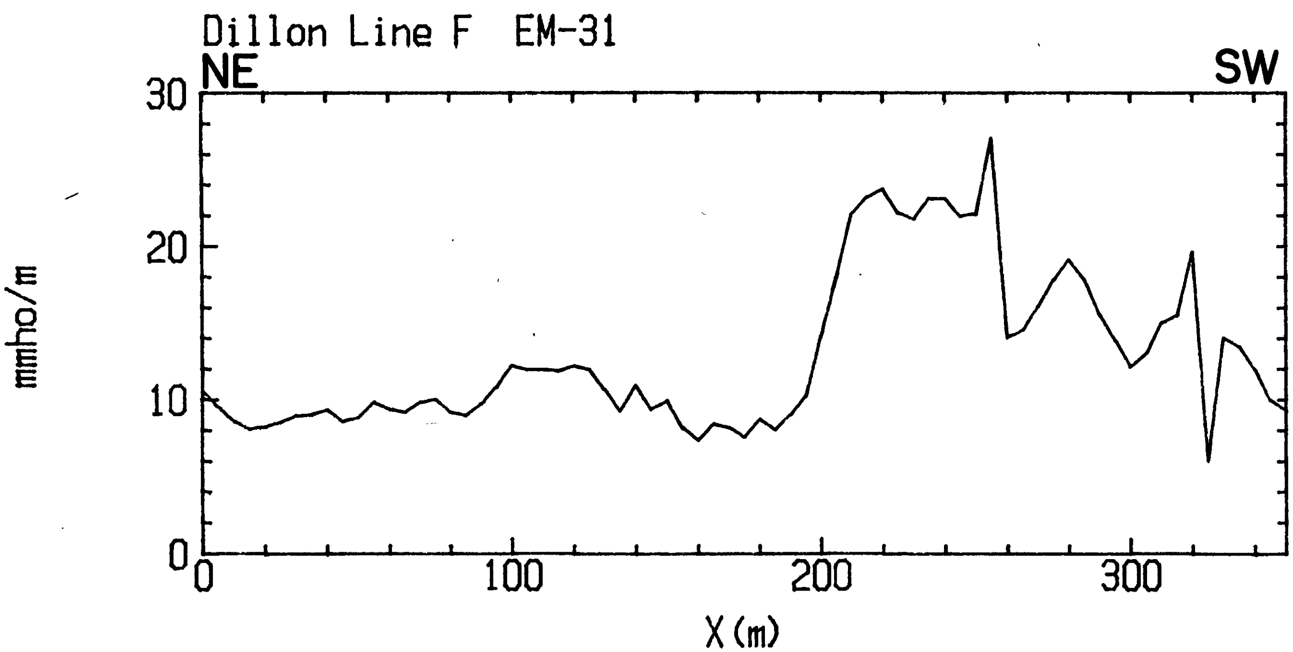

Dillon Line B
SE
NW
20
-5
-30
SP (mV)
0
100
200
300
400
X (m)

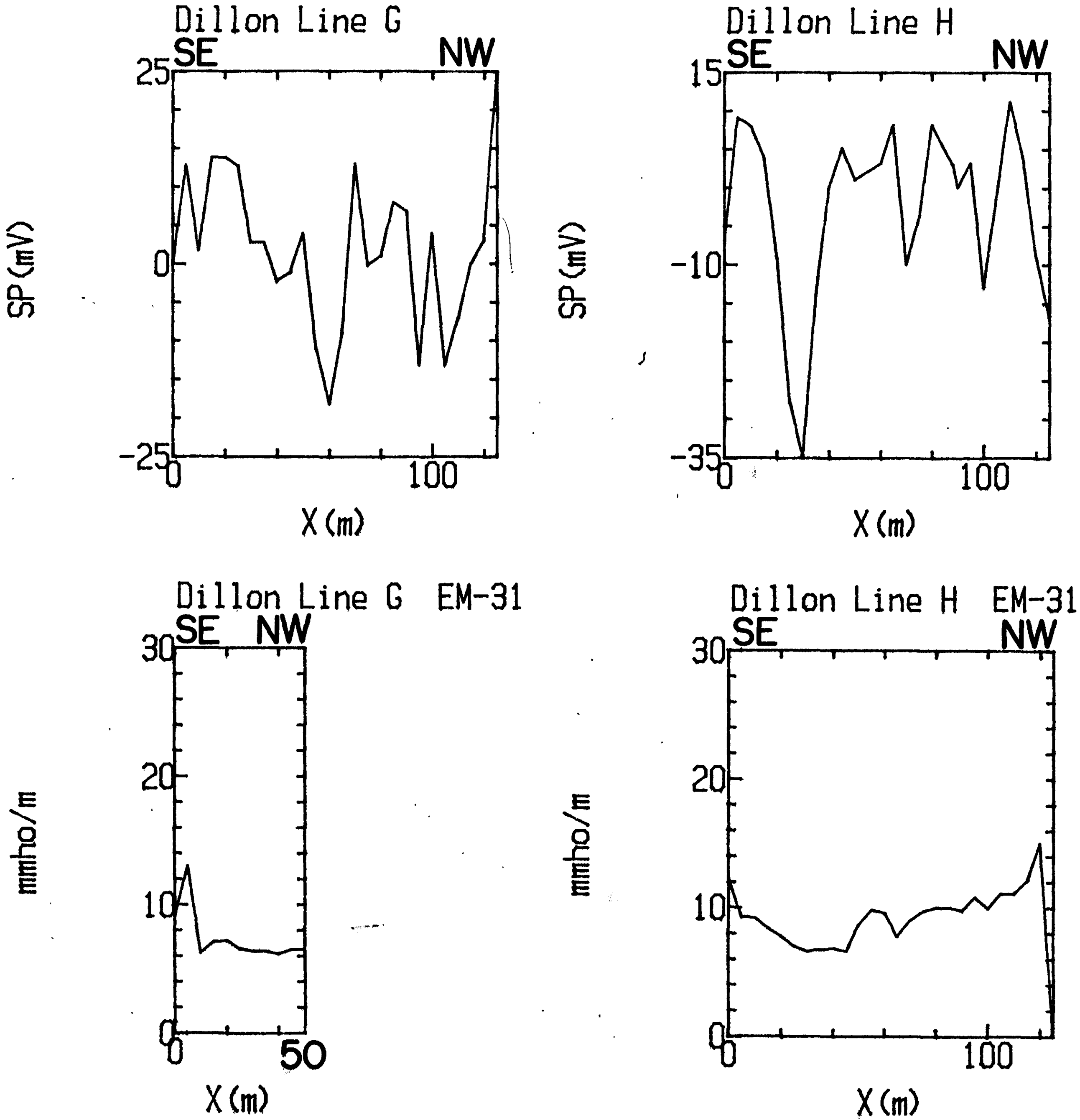

Dillon Line C
NE
SW
30
5
-20
0
100
200
300
X (m)
SP (mV)


Dillon Line C EM-31
NE
SW
30
20
10
0
0
100
200
300
X (m)
mmho/m

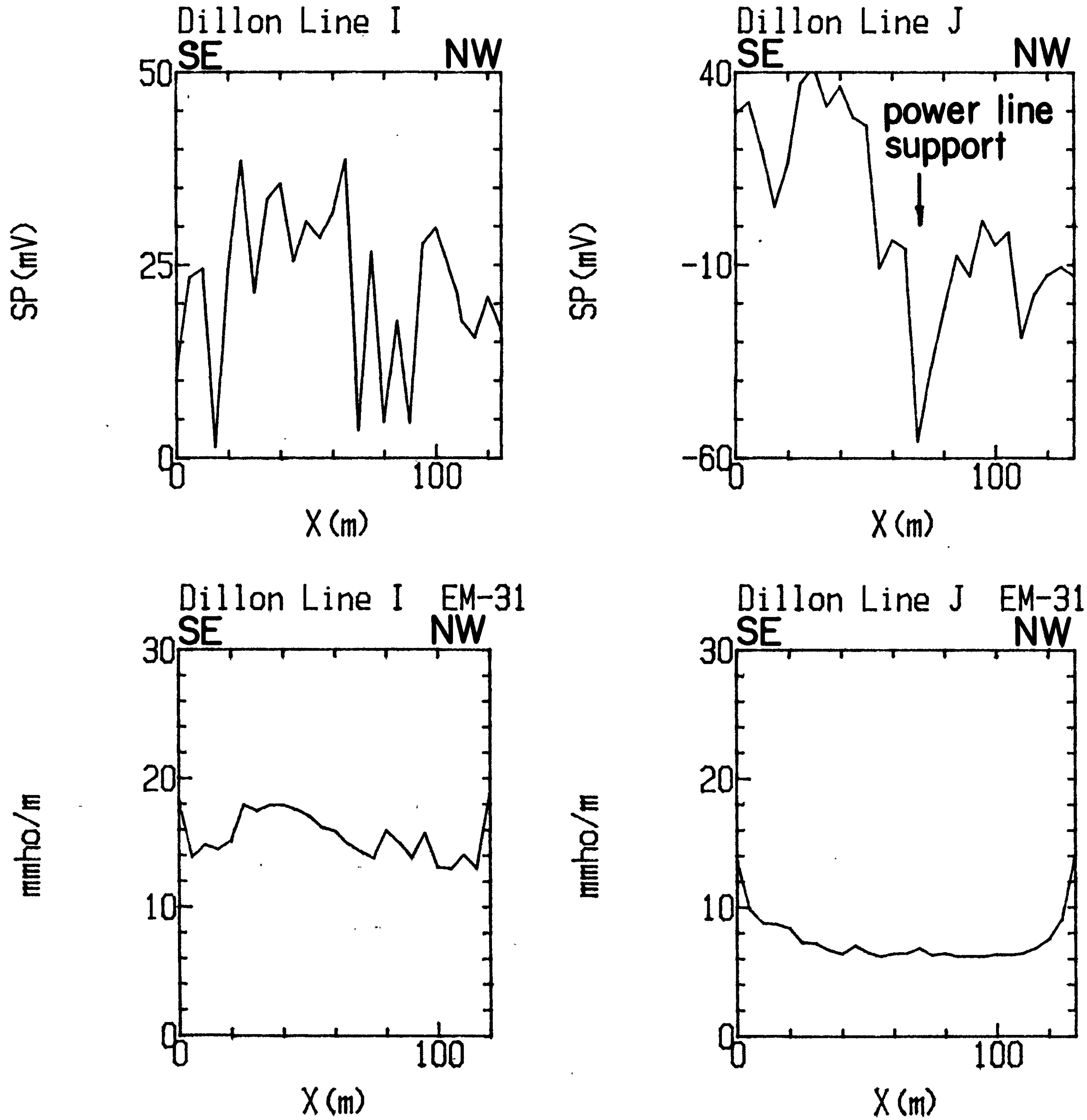

Dillon Line D
S
N
outlet
SP (mV)
40
-10
-60
0
100
200
X (m)
Dillon Line E
S
N
outlet
SP (mV)
40
-10
-60
0
100
X (m)
Dillon Line D EM-31
S
N
mmho/m
30
20
10
0
100
200
X (m)
Dillon Line E EM-31
S
N
mmho/m
30
20
10
0
40
140
X (m)

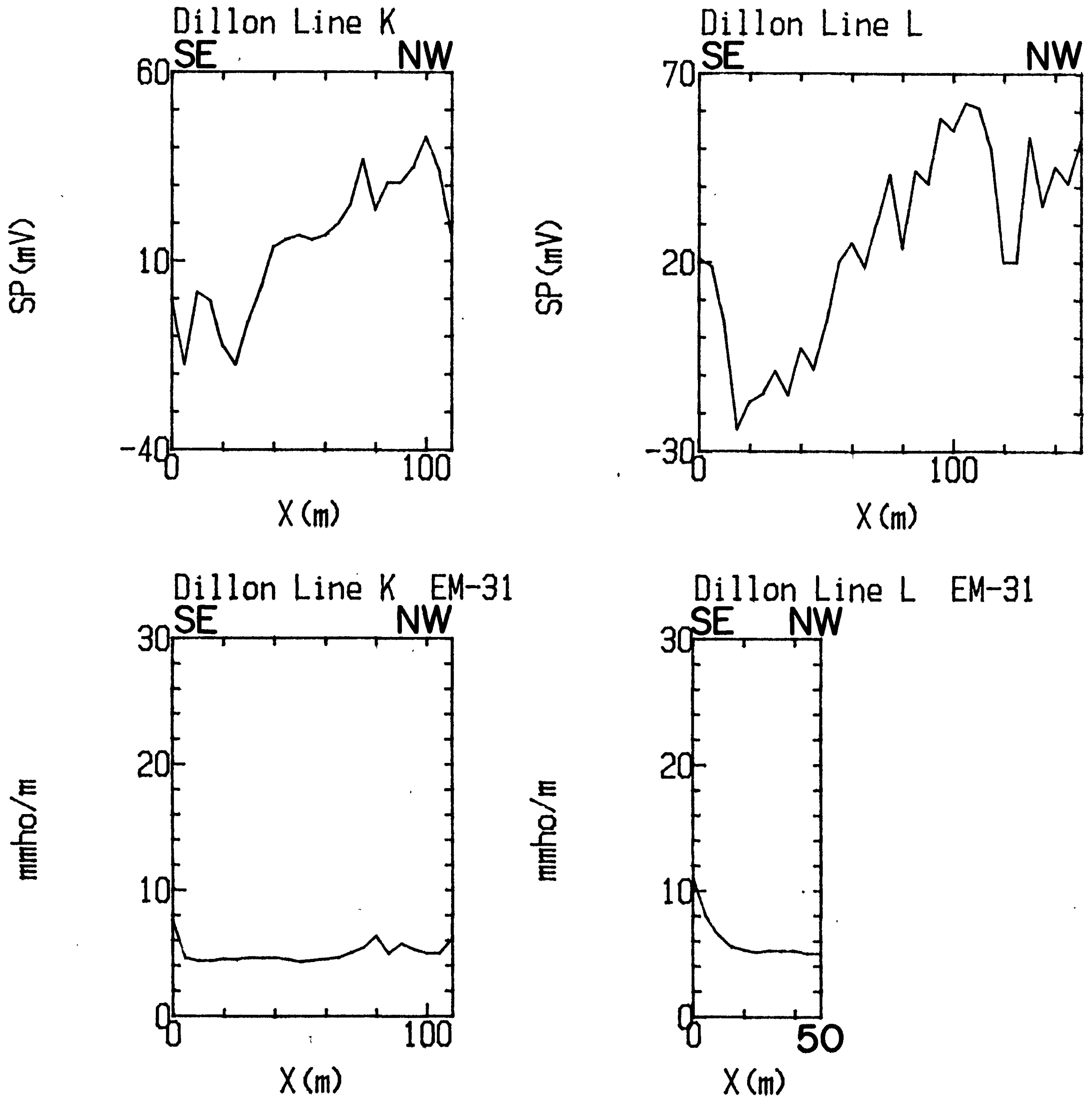

Dillon Line F
NE
SW
cable
toe drain
SP (mV)
50
0
-50
0
100
200
300
X (m)

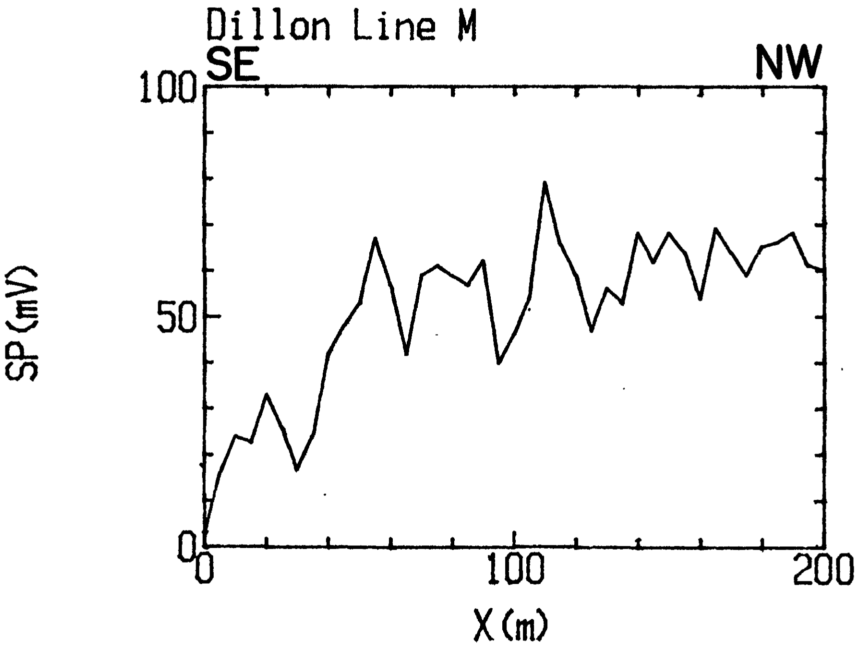

Dillon Line F EM-31
NE
SW
mmho/m
30
20
10
0
0
100
200
300
X (m)

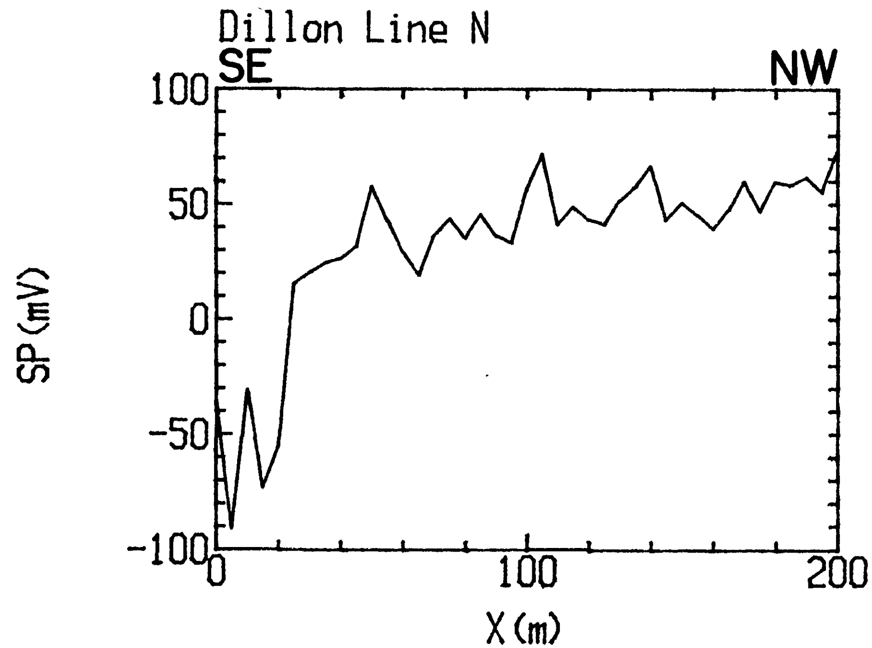


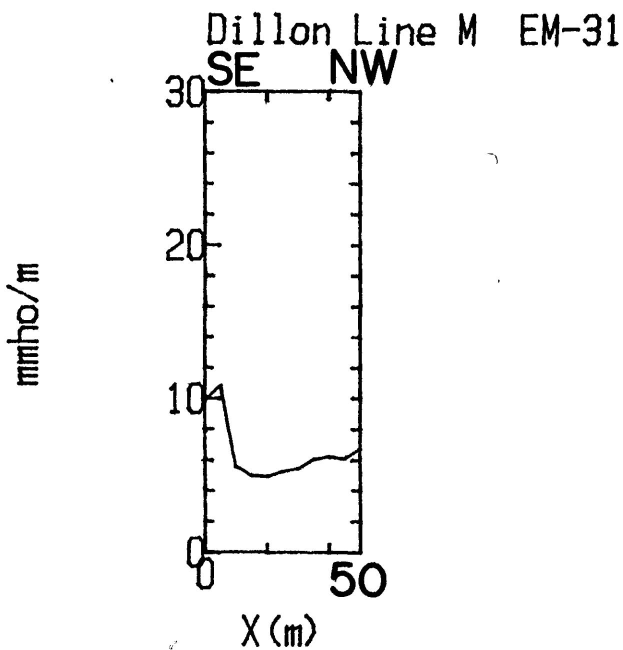
Dillon Line G
SE
NW
SP (mV)
25
0
-25
0
100
X (m)
Dillon Line H
SE
NW
SP (mV)
15
-10
-35
0
100
X (m)
Dillon Line G EM-31
SE
NW
mmho/m
30
20
10
0
0
50
X (m)
Dillon Line H EM-31
SE
NW
mmho/m
30
20
10
0
0
100
X (m)

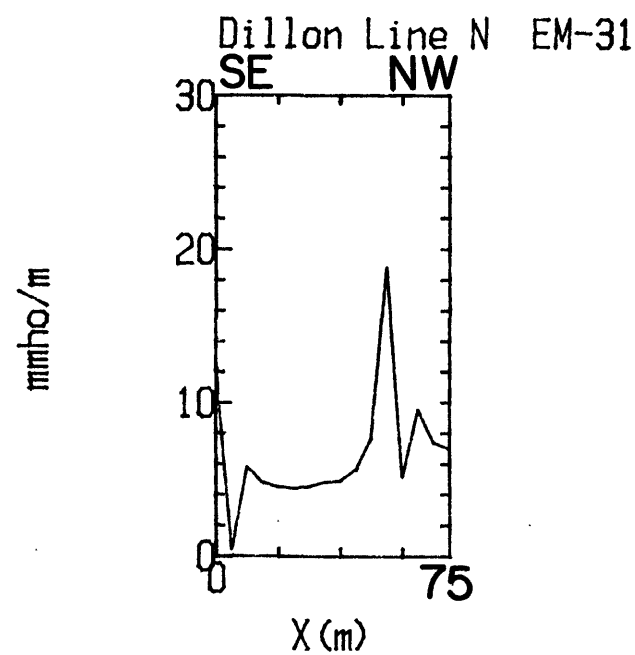

Dillon Line I
SE
NW
SP (mV)
50
25
0
0
100
X (m)
Dillon Line J
SE
NW
power line support
SP (mV)
40
-10
-60
0
100
X (m)
Dillon Line I EM-31
SE
NW
mmho/m
30
20
10
0
0
100
X (m)
Dillon Line J EM-31
SE
NW
mmho/m
30
20
10
0
0
100
X (m)


Dillon Line K
SE
NW
SP (mV)
60
10
-40
0
100
X (m)
Dillon Line L
SE
NW
SP (mV)
70
20
-30
0
100
X (m)
Dillon Line K EM-31
SE
NW
mmho/m
30
20
10
0
0
100
X (m)
Dillon Line L EM-31
SE
NW
mmho/m
30
20
10
0
0
50
X (m)


Dillon Line M
SE
NW
SP (mV)
100
50
0
0
100
200
X (m)


Dillon Line N
SE
NW
SP (mV)
100
50
0
-50
-100
0
100
200
X (m)


Dillon Line M EM-31
SE
NW
mmho/m
30
20
10
0
0
50
X (m)


Dillon Line N EM-31
SE
NW
mmho/m
30
20
10
0
0
75
X (m)