Mapping of Metallic Groundwater Contaminant Flow Through Earth Resistivity Methods
Northfield, MN and Aniwa, WI

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Senior Integrative Exercise

March 10, 1986

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> "Since water seems to be what everyone most needs for all purposes, we study to find out first of all what kinds of soil supply us with meagre or abundant springs, what signs too we have that these can be struck further below the surface, how their supplies are conveyed from fountains or well, and which provide harmful or healthy water."

Translation By: H. Plommer
in: Vitruvius and Later Roman Building Manuals,
Caimbridge University Press, 1973, p. 43

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ABSTRACT

The relative ease with which electrical current flows through the earth is dependent upon the amount of water held in pore spaces of earth materials and the amount of ions in the groundwater. This fact is the basis of mapping groundwater differences by earth resistivity. Differences in groundwater resistivity in the vicinity of the old Northfield landfill and an arsenic storage site near Aniwa, Wisconsin were mapped. The results show a contamination plume downflow of each site. Water samples from monitoring wells at both sites confirm the presence of the plumes and give precise amounts of contamination.

KEYWORDS: Earth Resistivity, Contaminant Plume,
Monitoring Well

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INTRODUCTION

Groundwater contamination has become a problem of epic proportions in the U.S. "In 1976 the United States was producing and placing in landfills more than 360 million tons of household, commercial and municipal solid waste per day" (Griffin, 1976, p. 1262). There are now more than 100,000 active and inactive landfills in the U.S. (Cherry, 1983). Almost all of these are contributing a mix of organic and inorganic chemicals and elements to the surrounding groundwater. In addition to and including landfills, the Office of Technology Assesment estimates that there may be at least 10,000 hazardous waste sites in the U.S. (Magnuson, 1985). To help combat this menace to public health and the environment, knowledge of where the groundwater contaminant sources are and where the contaminants are moving to, is of vital importance. I mapped areas of contamination near known or suspected comtaminant sources by using earth resistivity.

Why Resistivity

First, to address the question: why use earth resistivity methods to study groundwater contamination? Resistivity is a fundamental property of a material which characterizes that material almost as completely as its density (Earth Resistivity Manual, 1979). Thus it is possible to determine different groundwater types without drilling. Earth resistivity can be used to great advantage resistivity is an inherent property and not dependent on the geometry of the sample. Resistivty can be expressed as:

$$\rho = \frac{RA}{L}$$

where is resistivity, R is resistance in ohms, A is cross-sectional area of the mass, and L is the length of the mass (Barnaal, 1982). In most geological field work, resistivity is expressed in ohm-meters. Thus resistivity is a fundamental property of the material and independent of the volume, whereas resistance depends upon the shape and size of the specimen (Earth Resistivity Manual. 1979). It is inherent in the definition that resitivity is a property of homogenous material. Since this is rarely the case in field conditions, the term apparent resistivity is used in earth resistivity studies.

The basis for the success of the electrical resistivity method rests on this fact: earth materials are good conductors of electricity in proportion to their content of (a) water, and (b) dissolved salts and/or free ions (Instruction Manual, 1979). For this reason, massive rocks with relatively little fracturing are poor conductors because of low water content. Clean gravels and sands also exhibit high resistivity because water contained by them will be relatively free of dissolved ions. By contrast, moist clays and clay soils contain both water and dissolved ions hence they are good electrical conductors (low in conjunction with monitoring wells, and, by itself, it holds several advantages over traditional well monitoring.

Resistivity methods are much cheaper than drilling wells. Resistivity investigations can be carried out in a short amount of time, and they have minimal impact on the environment. The equipment is light and portable, and the qualitative interpretation of the data is very simple (Mooney, 1980).

Resistivity methods can be used to locate contaminant plumes. Wells can then be sunk in the places of highest interest to determine the precise amount of contamination. The preliminary use of resistivity safeguards against the expense of drilling wells in needless locations.

BASIC THEORY OF RESISTIVITY

It is helpful to think of the concept of resistivity as being related to electrical resistance, but it is important to realize that they are not the same thing. The electrical resistivity of a material is defined as the resistance in ohms, between opposite faces of a unit cube of that material (Earth Resistivity Manual, 1979). Figure 1 demonstrates that the voltage difference ($V_1 - V_2$) across a resistive material will induce a current (I) to flow through that material. It can be shown that the resistance (R) depends upon the length of the cylinder (L), its cross-sectional area (A), and a characteristic of the resistive material (ρ), its resistivity (Figure 1) (Mooney, 1980). Whereas

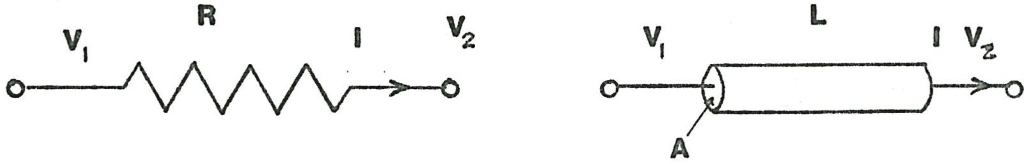
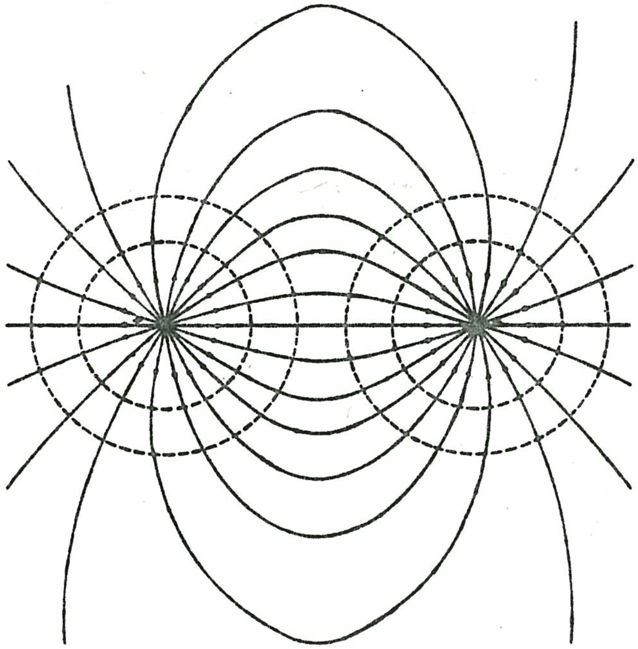


Figure 1 **After Mooney, 1980**

Voltage difference causing a current to flow across a resistor. The resistance of that resistor is dependent upon length and cross-sectional area.

Figure 2



Equipotential Surfaces

Electric Field Lines

Plan view of the earth showing current flow. After Earth Resistivity Manual, 1979.

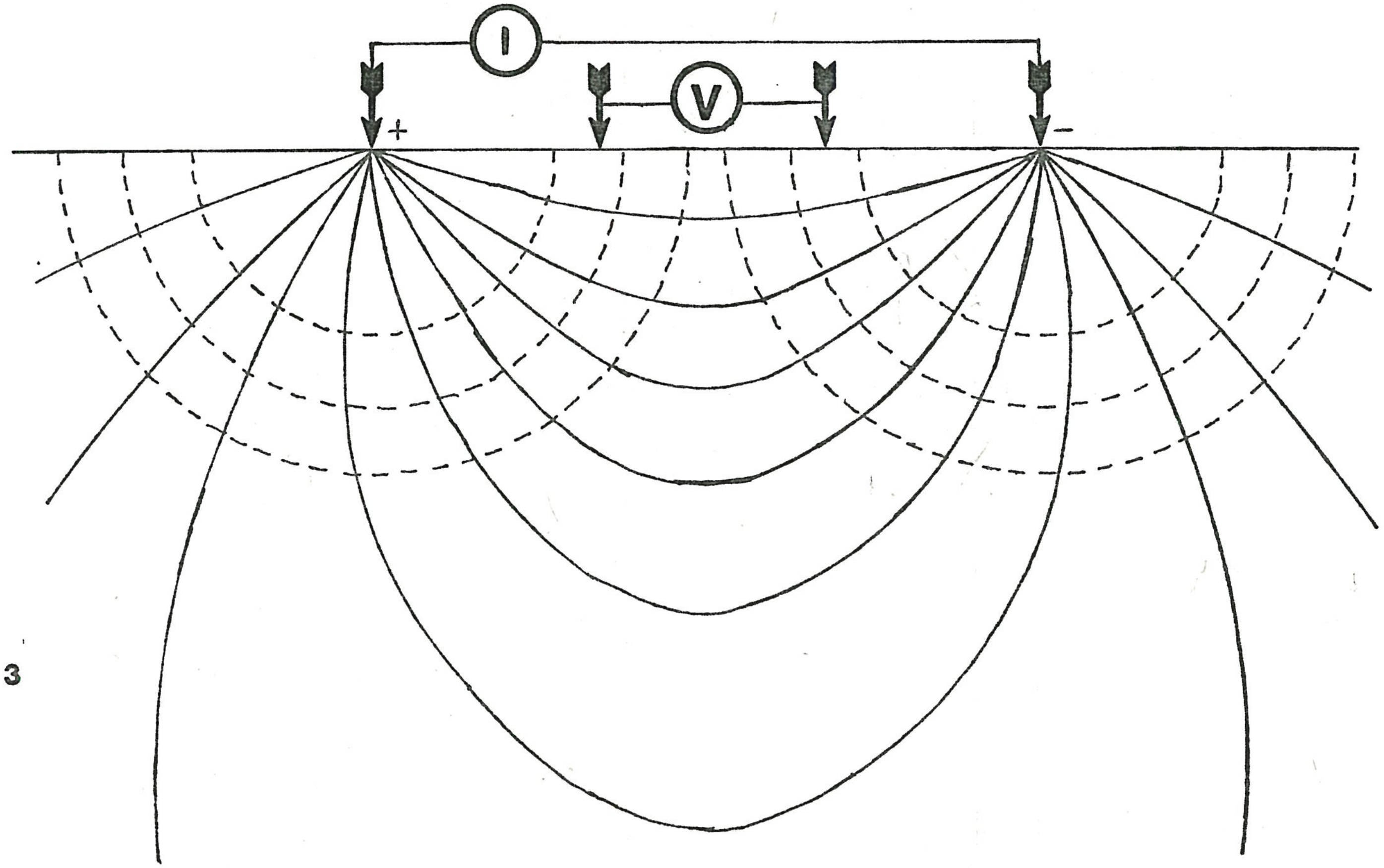
resistivity materials) (Instruction Manual, 1979).

It is the search for dissolved ions in the pore spaces of earth materials that is the basis of this project. Assuming the subsurface conditions to be fairly constant throughout each field site, then variations in resistivity are attributed to variations in groundwater resistivity (Urish, 1983). Most contaminant plumes contain a much higher ionic content than the native groundwater and thus a lower resistivity (Urish, 1983). This relative difference in resistivities can be measured and mappped.

This search was carried out using a Bison Model 2350 Earth Resistivity Instrument. The Bison 2350 is connected by wire to four electrodes which are set a predetermined distance apart from each other and pushed into the ground to a depth of 20 to 30 cm. Electrical current generated by a battery is forced to flow into the ground through two of these electrodes. The resulting voltage drop produced by this current in the earth is measured across the other two electrodes (Instruction Manual, 1979).

Current flows from one electrode to the other along electric field lines as shown in Figures 2 and 3. In these figures the potential (voltage) difference is measured between the middle electrodes.

Figure 3



Vertical Cross-section

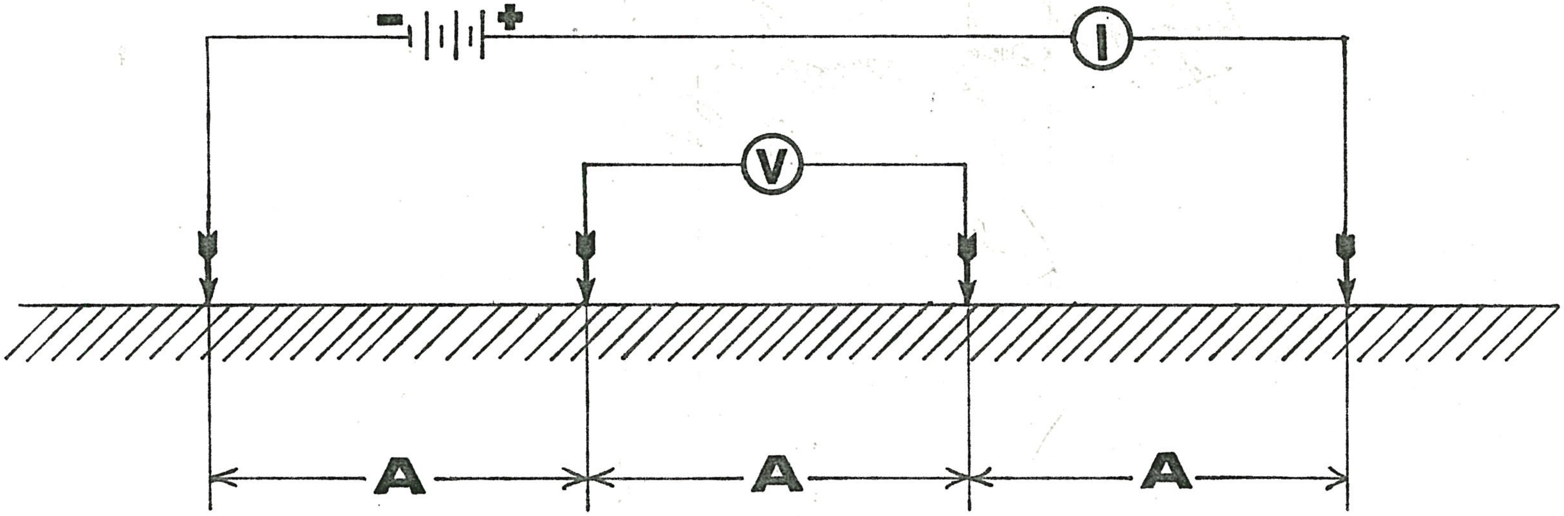
Equipotetial Surfaces

Electric Field Lines

After Earth Resistivity Manual, 1979.

There are several effective arrangements of the electrodes. Each arrangement is the most efficient at performing a different type of investigation. Some investigations are concerned with sounding (finding the depth to certain lithologic features). My investigation is concerned with profiling (constructing horizontal profiles of variations in earth resistivity). "For sounding, the recommended arrangement is Schlumberger, although Wenner is acceptable. For profiling, the recommended arrangement is Wenner" (Mooney, 1980, p. 30-4).

I used the Wenner method (Figure 4) in my field investigations. This method requires that all four electrodes be kept at an equal spacing along a straight line. This distance, the "A-spacing", can be determined by using the computer program <u>Resist</u> (Davis, 1979). Input for the program consists of the number of layers in the simulation (number of lithologic units), depths to the top of each layer, and the apparent resistivity of each layer. Apparent resistivity is determined by running several profiles across the field site at differing arbitrary A-spacings. The output of this program is a series of increasing A-spacings, and a list of decreasing resistivity values in ohm-meters (Davis, 1979). For each different layer boundary depth entered, a different set of data columns will be produced (Appendix A). By plotting these data values on logrithmic paper, (Figure 5) the optimal A-spacing can be determined by finding the point where one



Wenner Array

Figure 4

After Mooney, 1980

A-spacing will work best for varying depths to the second layer within a field site (Figure 5). From the Resist program, I determined that an A spacing of 20 m would give me the best results for the amount of time I had and the area I needed to cover with depth to bedrock between 3 and 10 meters (Figure 4).

FIELD METHODS

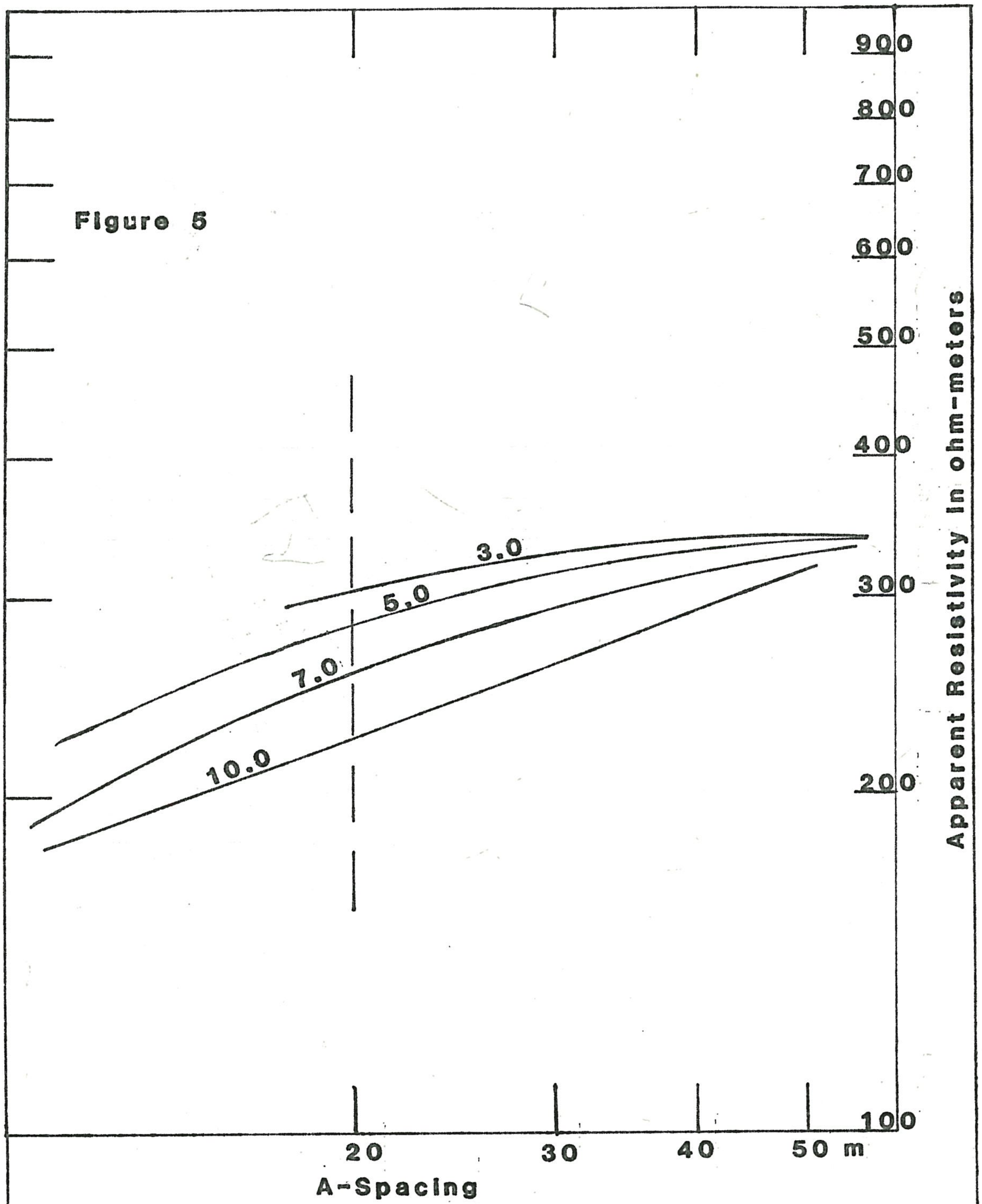
I made eight traverses at the Northfield site. A traverse is made by putting the four electrodes into the ground on a straight compass bearing. The electrodes are connected to the instrument by cable and a small current (usually 30 milliamps) is sent through the earth. The Bison instrument gives the reading:

$$2\pi \frac{V}{I}$$

For the Wenner array, this value is multiplied by the A-spacing distance to give the apparent resistivity (Instruction Manual, 1979).

The reading is recorded and the electrodes are disconnected from the instrument. The electrodes are positioned for the next reading by using a "leapfrog" procedure. The electrode at the tail of the traverse, I_1 in my work, is pulled out of the ground and repositioned at the head of the array, 20 m in front of I_2. Now the P_1 electrode from the first measurement becomes the I_1 electrode for this

Figure 5



A-spacing versus Apparent Resistivity

As Depth to second layer is varied

After Davis, 1979

measurement. P_2 becomes P_1, I_2 is now P_2, and the electrode moved to the fore is now I_2. This procedure is done after each measurement along the length of the traverse. A total of 80 data points were taken at the Northfield site in traverses ranging from 15 to 4 points each.

The composition of the shallow aquifer and depth to groundwater at the Aniwa site are very similar to those at the Northfield site. For this reason the A-spacing was kept at 20 m. I completed 6 traverses at the Aniwa site. Five of them included 4 resistivity measurements, and the sixth only 3 measurements, for a total of 23 data points.

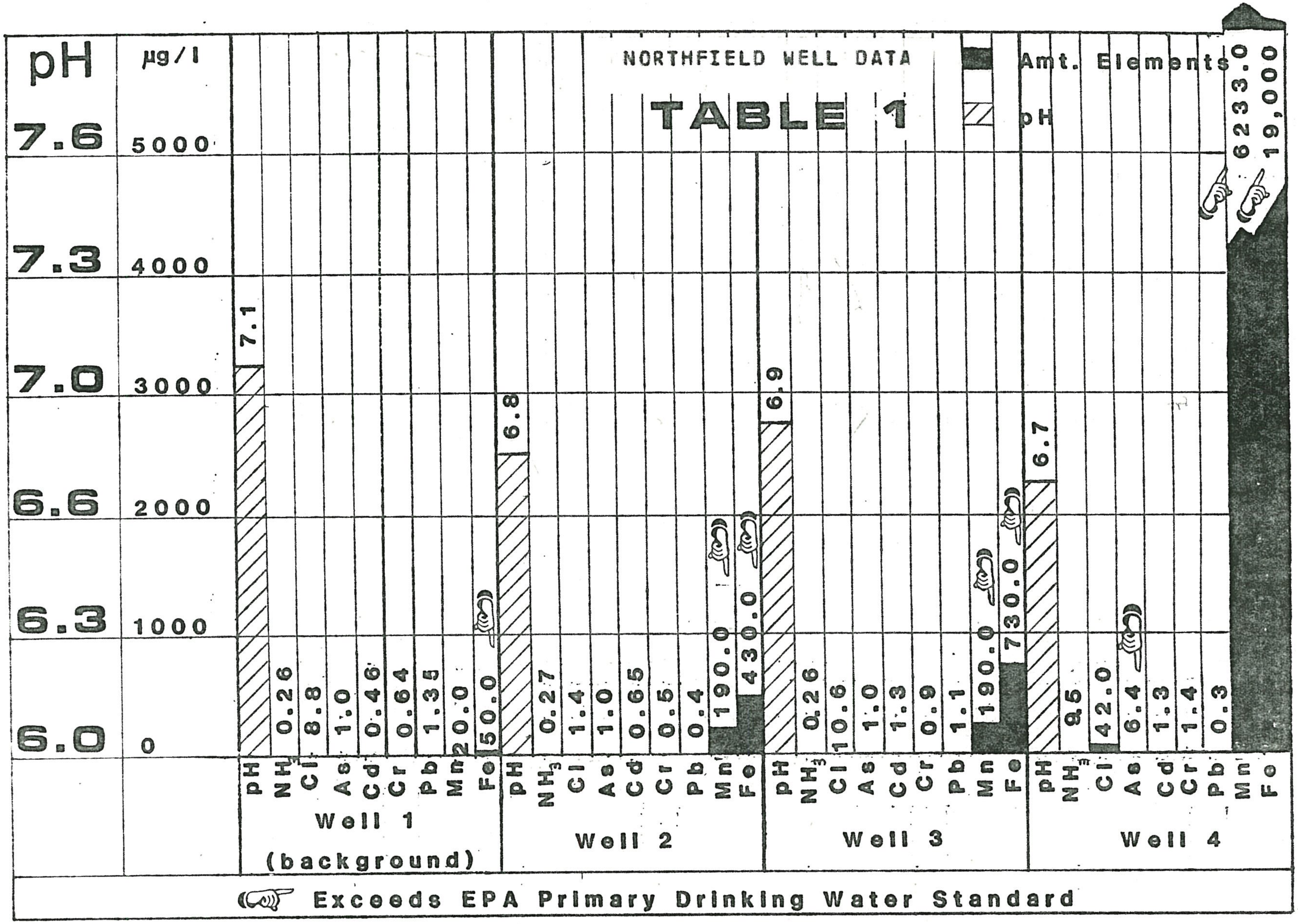
Water-sample data from the monitoring wells at each site were supplied by government agencies. The mean values of three sampling events at all four Northfield wells were supplied by the Minnesota PCA (Table 1). The actual values of four sampling events within a 21-month period at the Aniwa site are shown in Table 2. Only four of the wells were sampled all four times. The other four were sampled only in the two most recent events. These data were supplied by the EPA.

SITE DESCRIPTION: NORTHFIELD

The Northfield site is located approximately 1.2 km southwest of the city of Northfield on highway 78 . This site can be found on the Northfield, Minnesota topographic quadrangle in the SW 1/4 of the SE 1/4, section 2, Range 20 W, Township 111 N (Figure 6).

NORTHFIELD WELL DATA

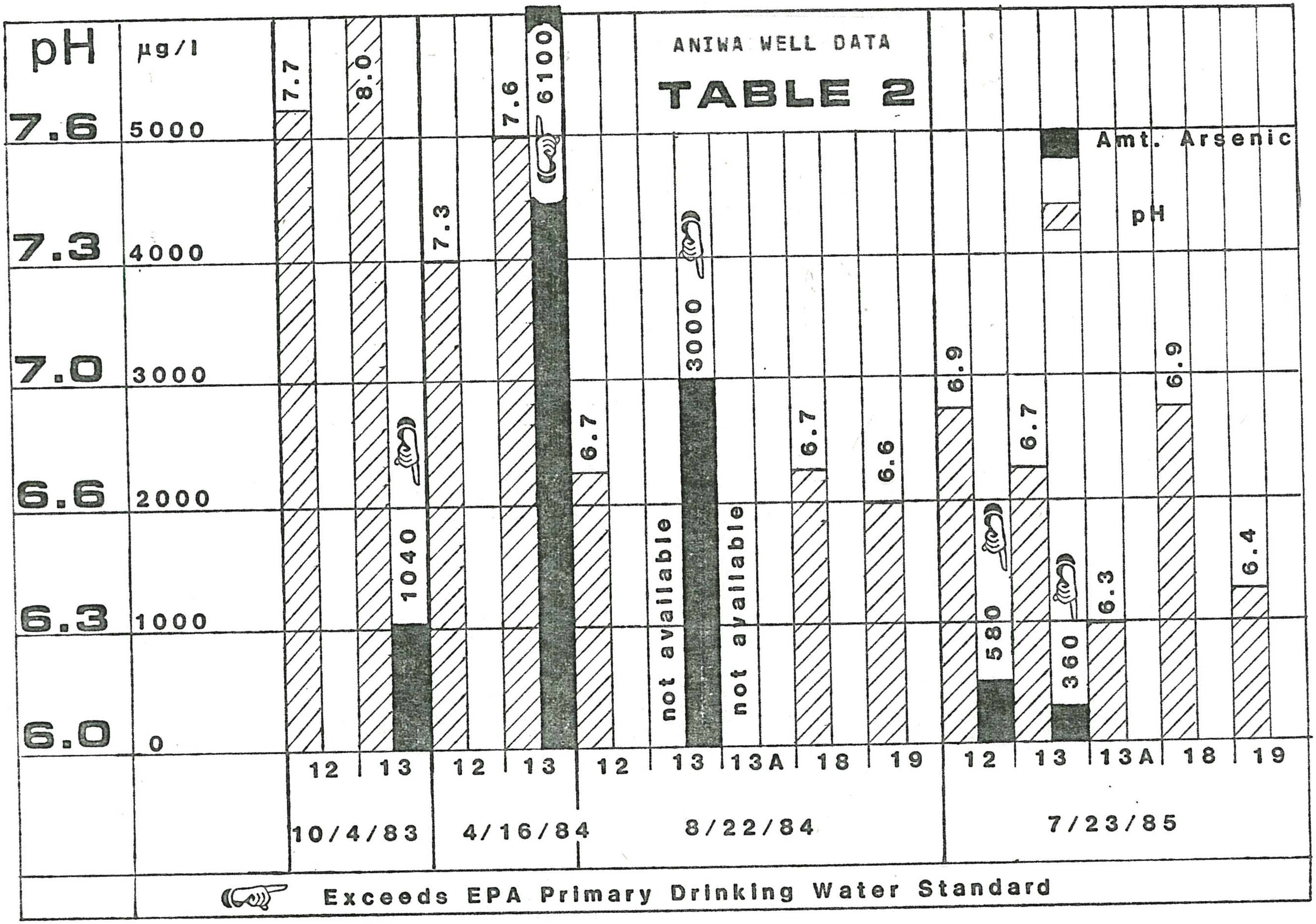
TABLE 1



☞ Exceeds EPA Primary Drinking Water Standard

ANIWA WELL DATA

TABLE 2



Exceeds EPA Primary Drinking Water Standard

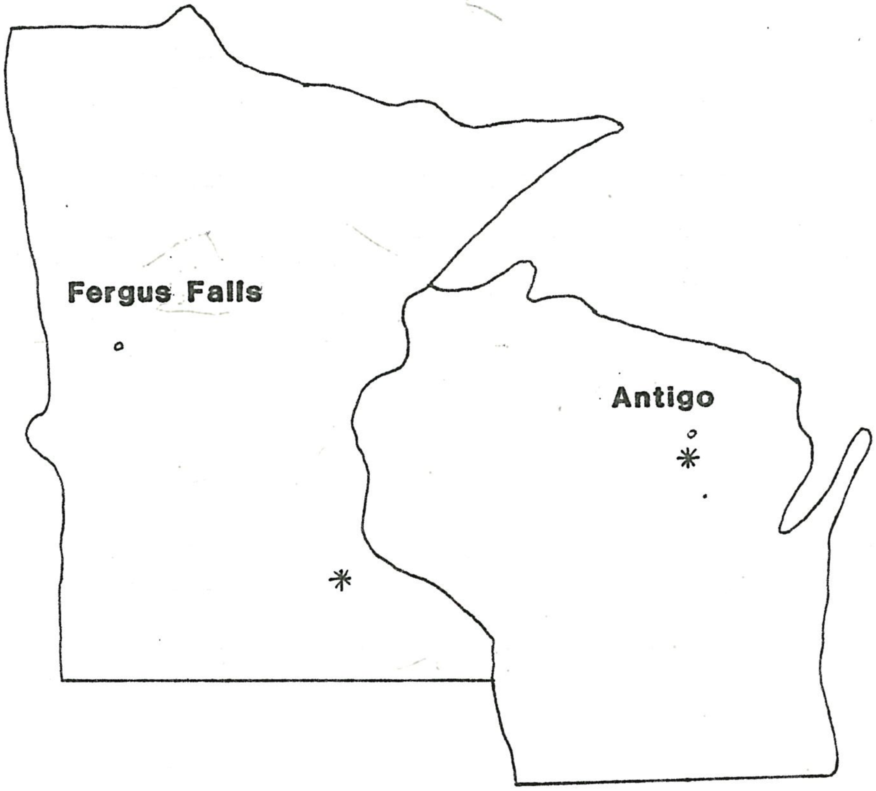


FIGURE 6

Maps of Minnesota and Wisconsin showing location of field sites and cities of note for orientation.

The contamination site is the old Northfield city landfill. "The six-acre dump is located in shallow alluvial soil (fine to coarse sand and gravel) over limestone bedrock" (Thompson, p.12 1985). It is not known if the wastes were deposited in contact with the limestone (Platteville Formation) or not. If not, there is not much more than 1 m of fill between the waste and the limestone. The site is approximately 20 m from the Cannon River. The limestone has been eroded to an unknown depth directly along the river and at least 3 to 4 m of floodplain sediments lie on top of it (Thompson, 1985).

The water table is approximately 3.5 m below the surface upslope of the dump, and 1 to 1.5 m below surface along the riverbank (Thompson, 1985). Shallow groundwater flow is in an easterly direction. Four monitoring wells have been drilled at the site by the Minnesota Pollution Control Agency (PCA). They range in depth from 6.5 to 4.0 m (Figure 7) (Thompson, 1985).

The site is bordered on the southeast by the Cannon River, on the northeast by Heath Creek, and on the southwest by "Spring Brook". The railroad lies to the northwest (Figure 7). Land usage in the vicinity is agricultural and recreational (Sechler Park).

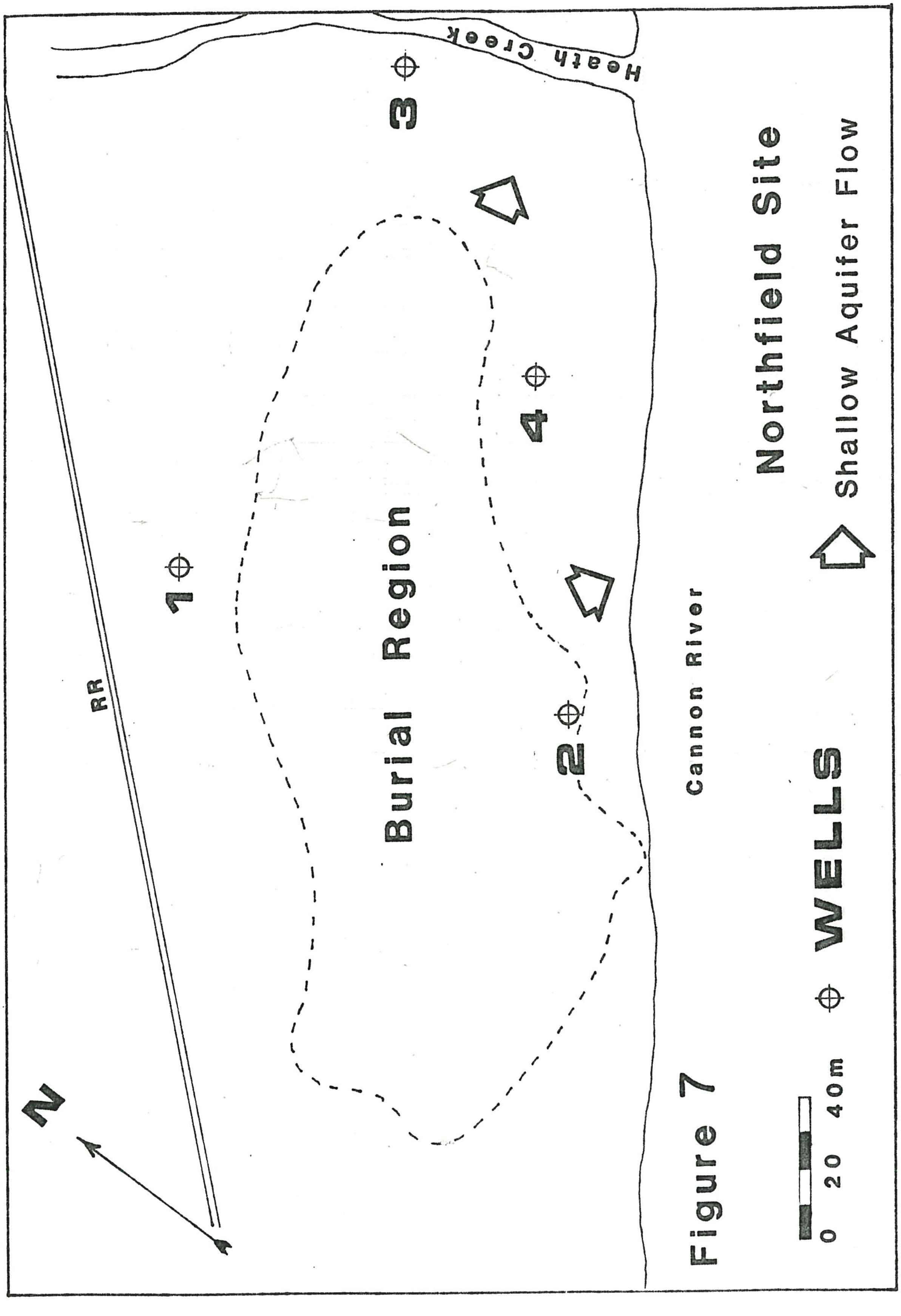


Figure 7

Northfield Site
Shallow Aquifer Flow
WELLS
Burial Region
Heath Creek
Cannon River
RR
N
1
2
3
4
0 20 40m

SITE HISTORY: NORTHFIELD

The Northfield site is commonly known as the old city dump. "The site opened in 1953, garbage was diverted to another site in 1969, and the site was finally closed in 1972" (Thompson, p.12 1985). Today the site is still used for the disposal of leaves, and the disposal and burning of diseased trees.

The dump received mainly mixed solid waste (MSW), as well as some industrial wastes and some demolition wastes (buildings and roads). During the earlier years of operation, wastes were dumped in trenches and burned, later the disposal method was switched to area-fill with gravel cover-material added once a week (Thompson, 1985).

SITE DESCRIPTION: ANIWA

The Aniwa site is located approximately 3.5 km south of the township of Aniwa, Wisconsin. It is accessible on Marsh road, 1.0 km west of state highway 45. This site is located on the Birnamwood quadrangle in the SE 1/4 of the NW 1/4 of section 19, range 11 E, township 29 N (Figure 6).

The contamination site has been a storage site for arsenic. The contamination has occurred in an aquifer consisting of glacial outwash deposits of indeterminate depth, 10 to perhaps 40 m. Soils in the area are mainly silty clayey sand with some gravel (Sanders, 1984).

Eight monitoring wells have been drilled on the site by the Environmental Protection Agency (EPA). These range in depth from 10.0 to 2.4 m, and the watertable in them varies from 2.2 m in well 10 to 4.3 m below the surface in well 11 (Figure 8). Groundwater flow is generally in a sotheasterly direction. There is a private well 400 m west of the site (Sanders, 1984).

The site is wooded and surrounded by farmlands and one residence to the west.

SITE HISTORY: ANIWA

The Aniwa contamination site differs from Northfield's in that it is an accidental contamination, and there is only one problematic metallic contaminant: arsenic. In the summer of 1933, a grasshopper plague moved across central Wisconsin. Sodium arsenate, $Na_2HAsO_4 \cdot 7H_2O$, was distributed to local governments. Farmers mixed it with sawdust and molasses to combat the plague. Arsenic left unused was collected by the state during the 1950's, but somehow the cache at Aniwa went unnoticed (Antigo Daily Journal, 1983).

The history of the site took on great importance in August of 1983 when the township of Aniwa was about to sell the approximately 2-acre piece of land. The potential buyer requested soil samples; samples of the dirt floor of an old shed on the property were found to contain 39,800 ppm of arsenic. The soil below the shed is contaminated to a depth of 2 meters (Antigo Daily Journal, 1983 and, Sanders, 1984).

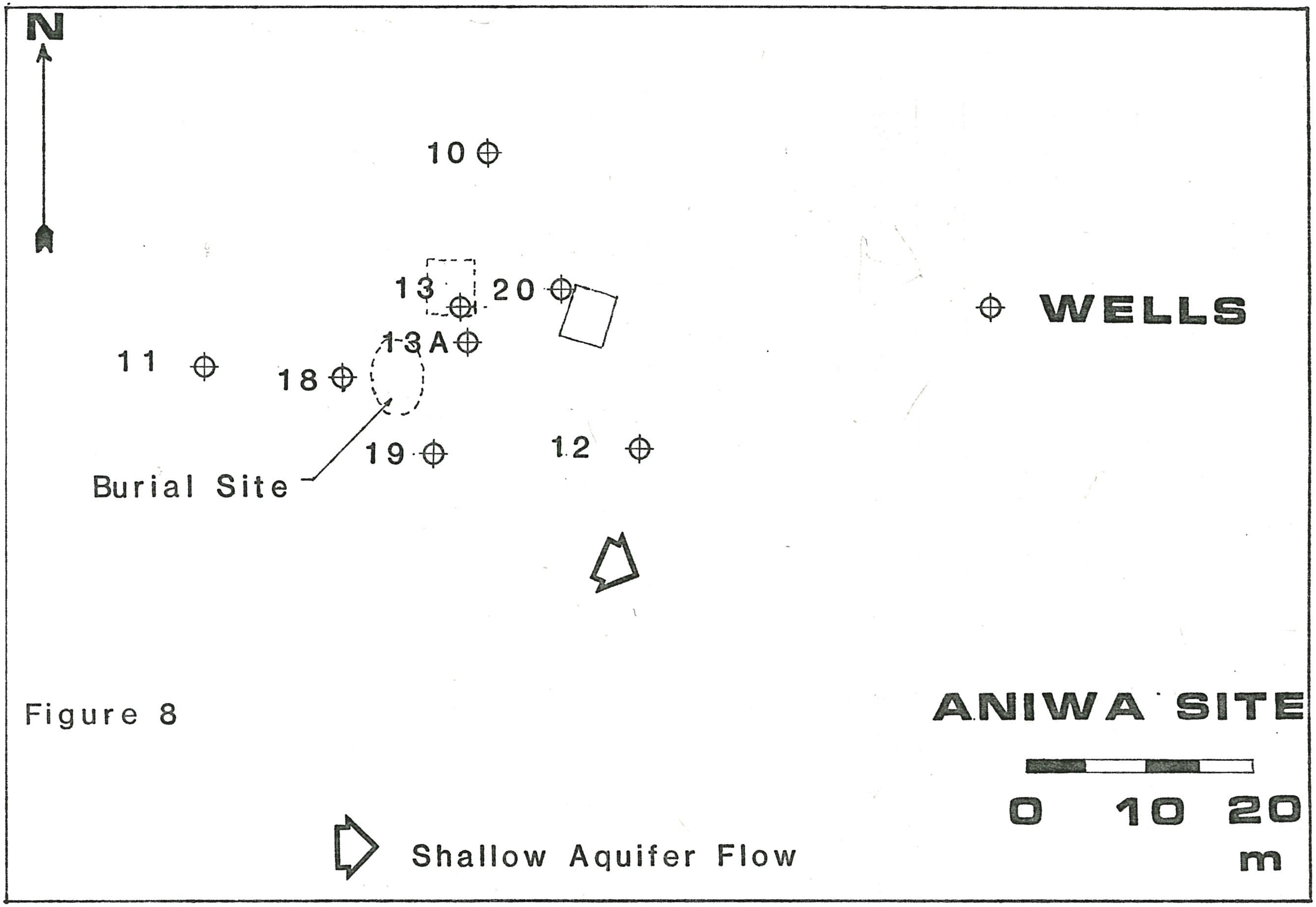

N
10
13
20
13A
11
18
19
12
Burial Site
WELLS
ANIWA SITE
0
10
20
m
Shallow Aquifer Flow

Figure 8

The arsenic had been stored in the shed from approximately 1933 to 1975. In 1975 the sodium arsenate, in 5 or 6 55-gallon (208.2 liter) steel drums and one wooden barrel, was buried near the shed at a depth of 2.5 to 4.0 meters (Figure 8) (Reyburn, 1984-5).

The shed was removed from its foundation and the barrels were located with metal detectors and several were uncovered with a backhoe. Finding them to be in poor shape and lacking funds for removal, the township left them there and had monitoring wells drilled on the site (Figure 8) (Reyburn, 1984-5).

RESULTS

The results of the resistivity mapping are displayed most vividly in the two, colored isoresistivity maps (Figures 9 and 10). These maps were constructed by plotting the resisitivity data points and then contouring them.

A three dimensional image of the apparent conductivity of each site was constructed by using the Fortran program Surface II (Sampson, 1975). Doing this causes areas of highest contamination, lowest resistivity, to appear as areas of highest relief (Figures 11 and 12). Both sites exhibit regions of relatively lower resistivity oriented roughly paralell to the direction of shallow groundwater flow.

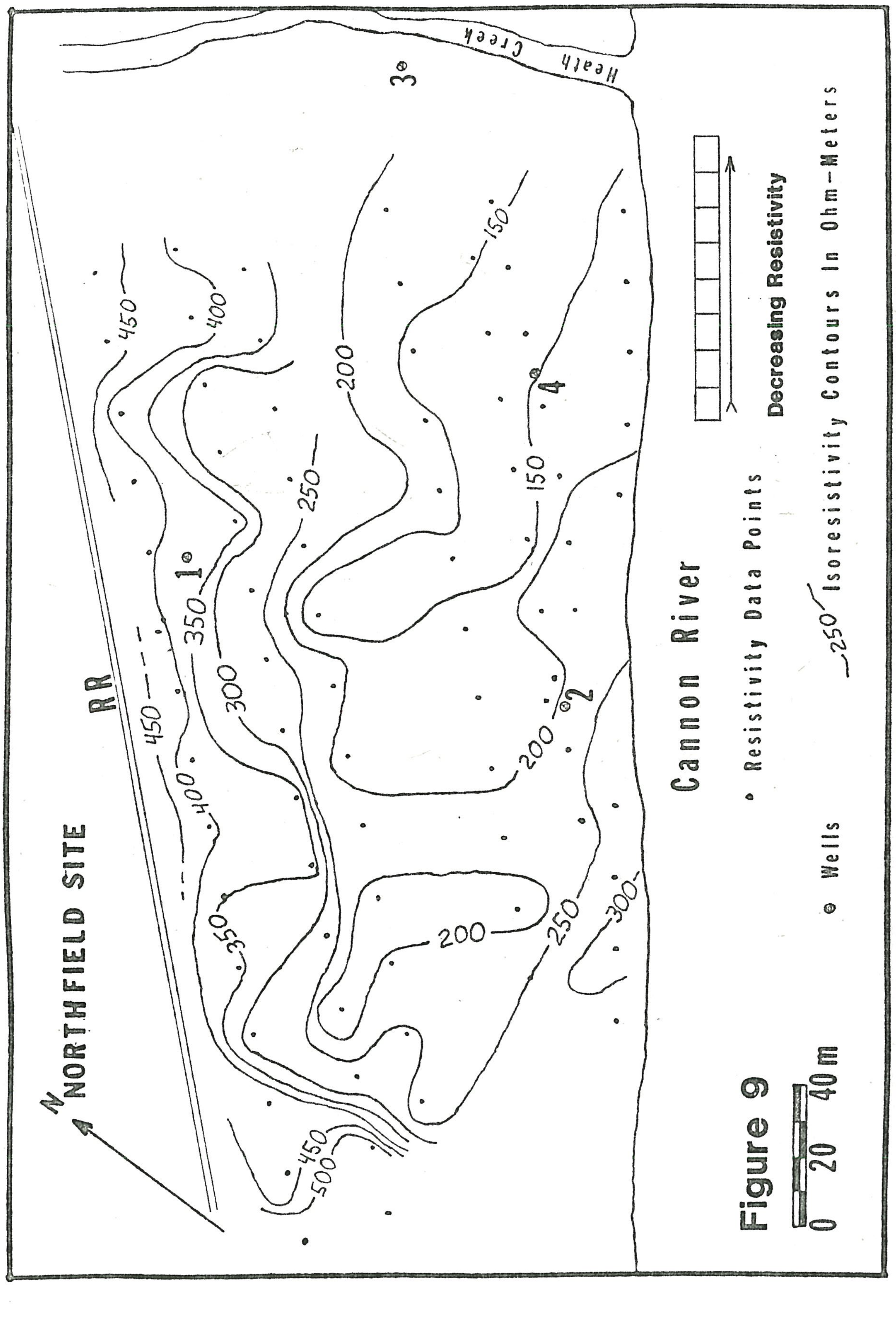

N
NORTHFIELD SITE
RR
Heath Creek
Cannon River
1
2
3
4
450
400
350
300
250
200
150
500
0 20 40 m
Decreasing Resistivity
Resistivity Data Points
Wells
250
Isoresistivity Contours In Ohm-Meters

Figure 9

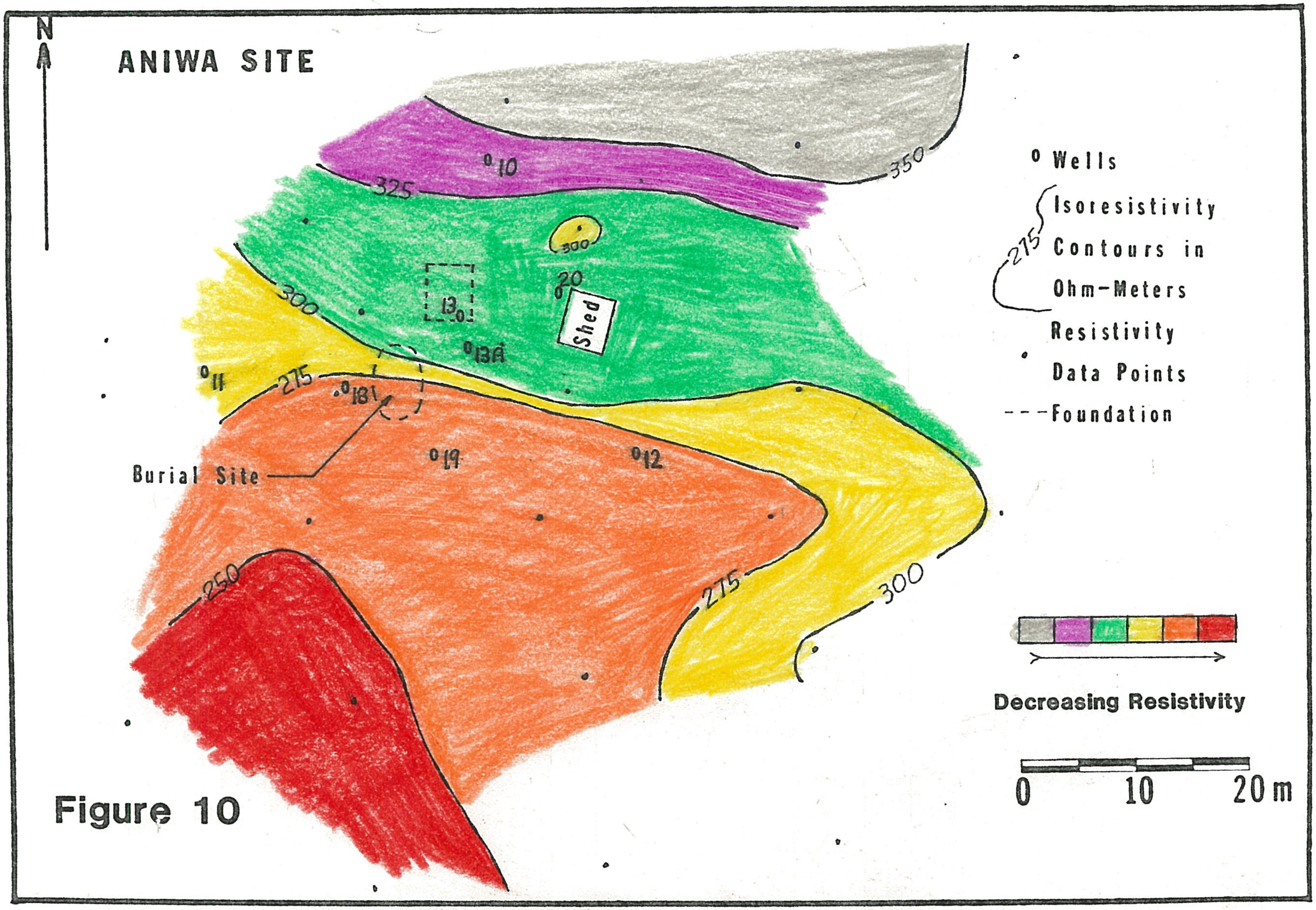

N
ANIWA SITE
350
325
300
275
250
300
275
10
300
20
Shed
13
13A
11
18
19
12
Burial Site
Wells
275
Isoresistivity
Contours in
Ohm-Meters
Resistivity
Data Points
Foundation
Decreasing Resistivity
0
10
20 m

Figure 10

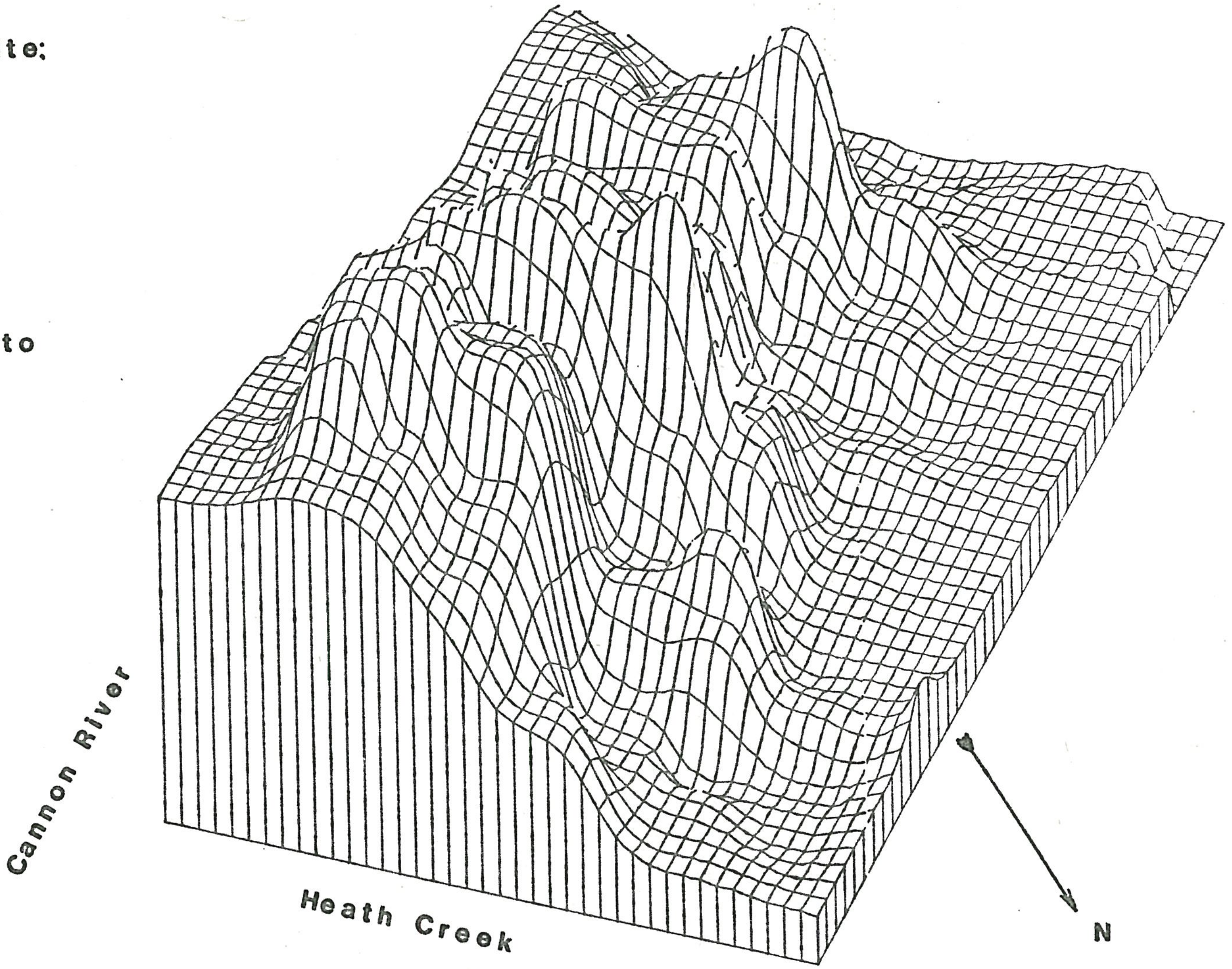
Northfield Site:

Conductivity

Proportional to

Relief

Figure 11



Aniwa Site:

Conductivity

Proportional

to Relief

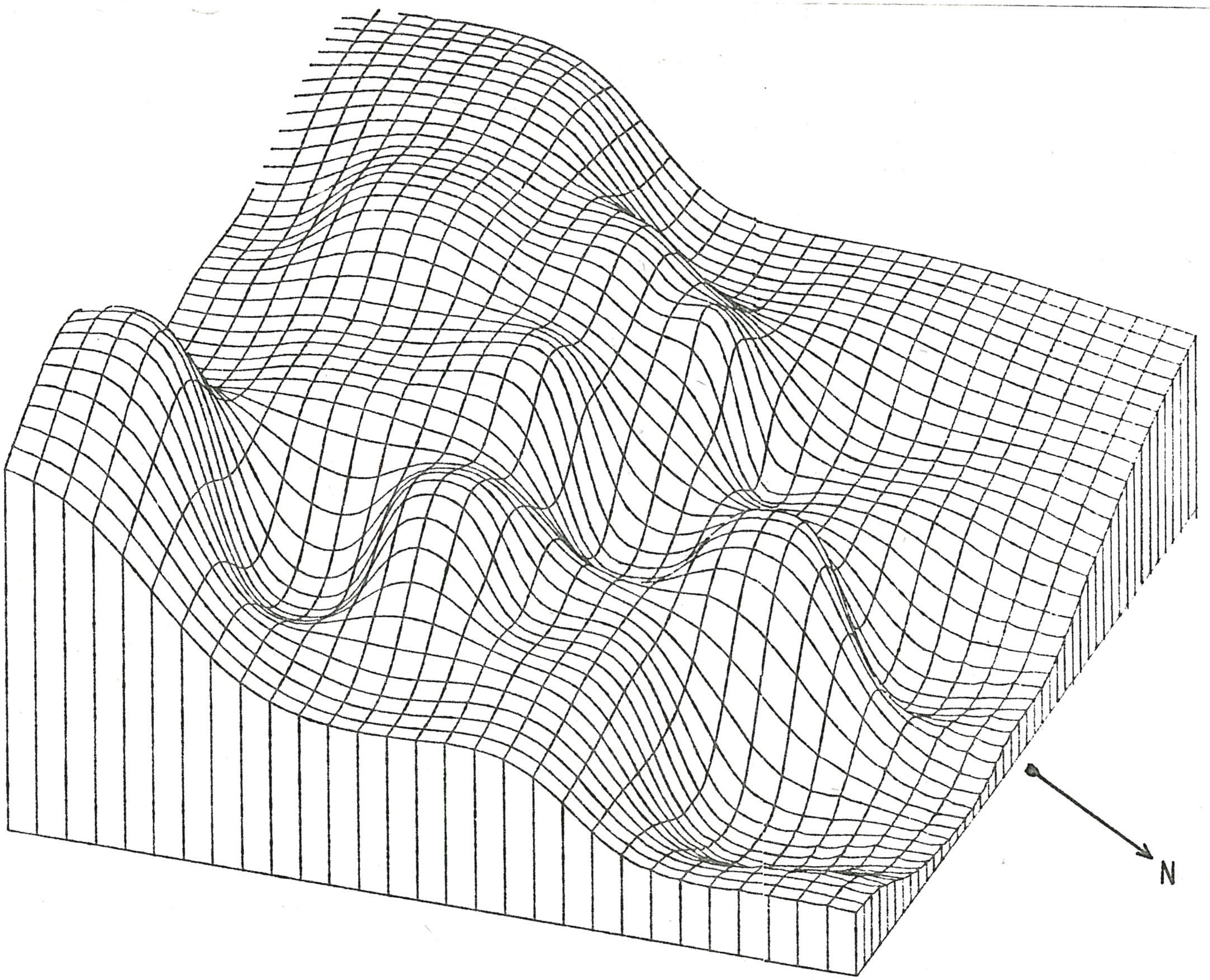


Figure 12

Results of the Northfield groundwater analyses show that the most contaminated well at the Northfield site is well #4. It is located in the region of lowest resistivity (Figure 9). Well #4 groundwater hosts a much larger number of transition metal and metallic ions than the other three wells (Table 1). This well also has significantly higher concentrations of nonmetallic ions with the exception of Na (Table 1).

At the Aniwa site, the well exhibiting the highest degree of contamination is #13. The level of arsenic in this well has been dropping since the 4/16/84 sampling event. Arsenic levels in well #12 have increased from below detection to 590 micrograms/liter between 8/22/84 and 7/28/85.

INTERPRETATION

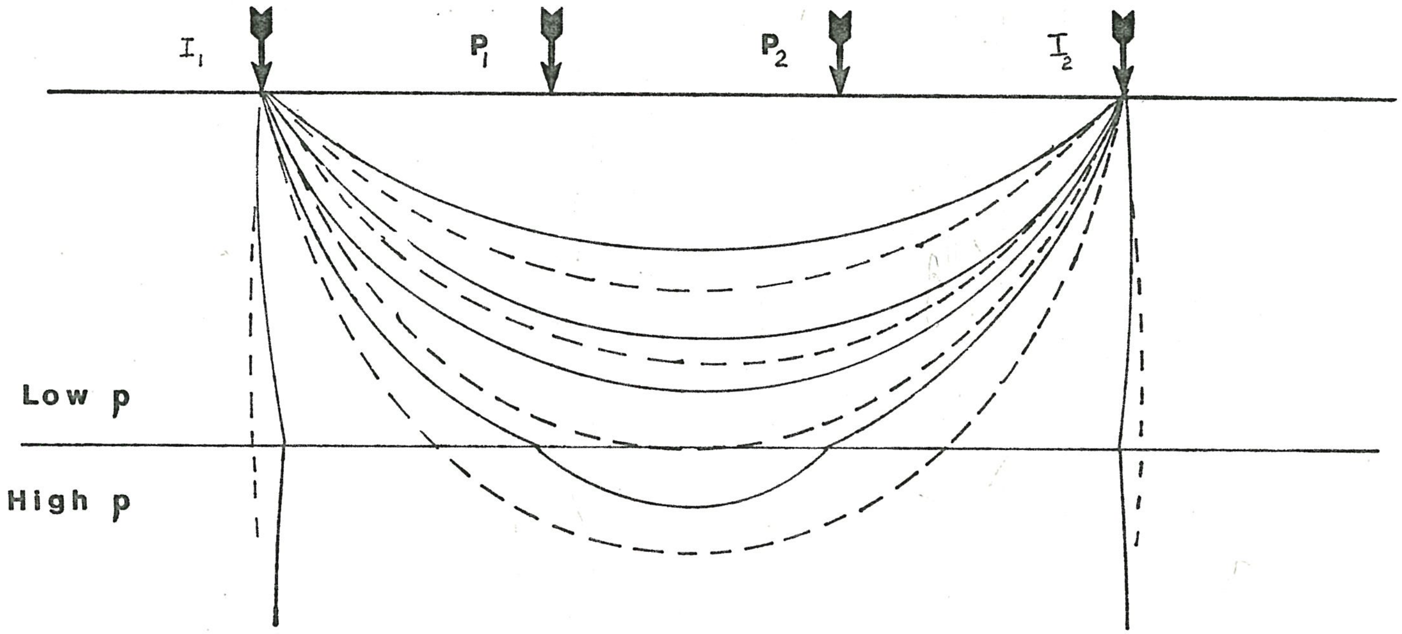
To begin with, it should be pointed out that the apparent-resistivity values in both studies are somewhat higher than they should be for groundwater located 3.0 to 5.0 m below the surface. The reason for this is the length of the A-spacing. For precise resistivity work with the Wenner array, the A-spacing should be approximately 1.5 to 2.0 times the desired depth of investigation (Mooney, 1980). The A-spacing I used is approximately 4.0 times the depth of investigation.

This lessens the resolution of the study by sending the current through more earth than required (Figure 13). With a smaller A-spacing, the current lines would travel along normal paths within the upper layer. Refraction of the current lines caused by the lower layer would be lessened. If I had more time to spend in the field it would have been possible to do a more focused survey in each of the areas of lower resistivity that I have determined.

Northfield Site

The limestone under the landfill and floodplain sediments exhibits an increased resistivity due to fewer pore spaces than the overlying material. If the limestone surface is eroded to dip towards the river, a general decrease of resistivity from the railroad tracks to the Cannon River could be expected. The decreasing depth to groundwater nearing the river would also cause a general decrease in apparent resistivity. The map shows a slight lessening of resistivity towards the river, but not in a uniform manner.

It is possible that a low-resistivity band could exist along the riverbank. This could be caused if the Cannon River were in an influent state dispersing its water, relatively high in Total Dissolved Solids (TDS), into the cleaner groundwater. I made two traverses within 5.0 m of the riverbank to determine if this was happening; it is not. Apparent resistivity values along these traverses range from



—— Actual Current Flow

– – – – Current Flow if it were not refracted by deeper higher resistivity layer

Figure 13 After Earth Resistivity Manual, 1979.

166 ohm-meters on the southeast end, near Heath Creek, to 310 ohm-meters on the southwest end.

The lowest apparent resistivities lie 30 to 40 m away from the river enclosed by the 150 ohm-meter contour (Figure 9). A possibility for this region of lower resistivity values could be a change in the topography of the underlying limestone. A previously eroded drainage gully that has been filled with gravel or sand would exhibit lower resistivity due to increased porosity compared to the surrounding limestone. This seems unlikely since there is a well developed drainage on each side of the lanfill.

Another factor weighing against this idea is the shape of the resistivity contours themselves. I would expect a subsurface gully to narrow gradually up slope. The resistivity contours flatten out abruptly in the 250 and 300 ohm-meter ranges.

This apparent-resistivity-low area really begins to take on the appearance of a contaminant plume when the preceding observations are coupled with the hydrologic knowledge of the area.

From the topography and the proximity and flow direction of the surface waters, it is fairly obvious that groundwater flow is in a easterly, direction. It is noted that the low resistivity region originates in the heart of the landfill and is oriented paralell with the groundwater flow.

Monitoring well number four is the only well located directly in the area of lowest resistivity. "Well four had the highest level of contamination at the site; concentrations averaged three to four times those observed in the other wells" (Thompson, 1985, p.16) (Table 1). The pH was the lowest, 6.7, in the number four sample. These observations are consistent with what is expected with leachate contamination (Thompson, 1985).

All of this leads me to believe that the area of lowest apparent resistivity I have mapped is due to a plume of contaminated water issuing forth from the landfill site. This ties in well with the conclusions Thompson made based solely on the groundwater data: "It is thought that well four was located in a major contamination plume from the dump. Wells two and three may have been on the fringe of the plume and/or had greater dilution from clean groundwater. . . " (Thompson, 1985, p. 17).

Aniwa Site

The Aniwa site does not offer such a straight forward interpretation as does the Northfield site. This site also demonstrates a region of low resistivity. Here again, this region is trending paralell to the shallow groundwater flow. The lowest resistivity on the map, however, is in the SW corner of the site, enclosed by the 250 ohm-meter contour (Figure 10). Knowing the exact location of the contaminants, it is highly improbable that this area was caused by an arsenic contamination plume.

It is possible that this low resistivity area is caused by a variation in subsurface geology. Perhaps a clay lens trending from the southwest corner to the east through the eastern most points of the 275 and 300 ohm-meter contours.

The question here is: has the introduction of arsenic into the groundwater had any effect on the apparent resistivity of the region? I think the answer to this question is yes, although the effect has been rather minimal especially when compared to the Northfield site. The best evidence of this on the isoresistivity map is the sharper points of the eastern most sections of the 275 and 300 ohm-meter contours. These peaks lie directly downflow of the burial site.

Movement of the arsenic in this direction is validated by the groundwater data. Especially that information collected at well ※12. From 10/04/83 through 08/22/84 the amount of arsenic in well ※12 was below detectable amounts. Within the next eleven months the amount of arsenic in well ※12 rose to 590 micrograms/liter. It seems resonable that this contamination has issued forth from the burial site rather than filtering down from the soil surface inside the shed foundation.

The only other well which showed detectable contamination was well #13, located in the foundation of the old shed. The amount of arsenic in this well has decreased over the last three sampling events (Table 2). The main source of contamination here is certainly arsenic filtering down to the watertable from the floor of the old shed. Now that the barrels have been removed from the shed and the residual sodium arsenate has been cleaned up, this spot is no longer a contamination source. This is reflected in the declining amounts of As in the water below the shed.

DISCUSSION:

Neither of the two sites that I investigated currently pose a serious threat to the health of local populations. The main contaminants at the Northfield site are Fe and Mn. Measured concentrations of both exceed EPA drinking water standards by several orders of magnitude (Table 1). Much of the contaminat plume issues forth into the Cannon River and is carried downstream. This movement helps to keep contaminants out of the local aquifers.

Arsenic contamination at the Aniwa site is also several orders of magnitude higher than the EPA drinking water standard (Table 2). Motion of the contaminants away from the source is retarded by the high attenuation of arsenic in clay soils (McLuckie, 1984). This and the sparse population in the site vicinity, lessen the chances of human contamination. At the time of the field studies neither contaminant source had contributed any ions to private or public wells.

CONCLUSION

This project is a demonstration of a practical application of a geophysical method to two fairly small scale groundwater contamination problems. The results obtained by earth resistivity correlate well with those results obtained by traditional well testing methods.

Although earth resistivity cannot give the quantitative data that well samples can, the extent of relative groundwater contamination at a site can be detected and mapped. It is extremely useful to map an area of relative contamination before drilling test wells. This safeguards against the loss of time and money by drilling in needless locations.

Earth resistivity can be used in the future at both of my field sites as a quick and inexpensive means of detecting growth and/or directional change of the contaminant plumes. It may also be interesting to do a more focused electrical survey at each site, concentrating on the areas of low apparent resistivity that I have already located.

ACKNOWLEDGEMENTS

I am most greatly indebted to Tim Vick for the inspiration behind this project, as well as help through the fall and winter with field methods and problems and finally getting the data to plot on the computer.

Secondly thanks go to Karen Ballentine for being my trusty field assistant through the rain, cold, and snow, and to Ed Buchwald for being my project advisor and giving timely advice during the writing.

Thirdly, thanks to my family for always being there and especially my Mom and brother Will who did some of the library research for this project.

Finally, thanks go out to Dale Thompson of the Minnesota PCA, Harold Allen of the United States EPA, and Jim Reyburn of the Wisconsin DNR for the information they gave.

APPENDIX A: Resist Program

```
ARRAY CHOICE:  INPUT --
         1 - FOR SCHLUMBERGER
         2 - FOR WENNER
         3 - FOR BIPOLE-BIPOLE.
2
CLOSEST A OR S SPACING?
(INCLUDE A DECIMAL POINT IN THE VALUE).
2.0
NUMBER OF LAYERS IN THE MODEL?
2
DESIRED NUMBER OF SIMULATED FIELD READINGS?
10

              ENTER LAYER PARAMETERS IN THE ORDER:
H(1), H(2),...H(N-1), R(1), R(2),...R(N), WHERE H(N)
IS THE THICKNESS OF EACH LAYER AND R(N) IS THE RESISTIVITY
OF EACH LAYER STARTING WITH THE UPPERMOST LAYER.
 INCLUDE A DECIMAL POINT IN EACH NUMBER.
3.0,150.0,400.0


APPARENT RESISTIVITY VALUES

WENNER ARRAY

 2 LAYER MODEL.

    LAYER NO.   THICKNESS   RESISTIVITY

        1         3.000        150.000
        2                      400.000


      SPACING       RHO

        2.00      161.519
        2.94      177.124
        4.31      204.126
        6.32      240.712
        9.28      280.625
       13.63      317.571
       20.00      347.622
       29.36      369.321
       43.09      383.302
       63.25      391.435
 WANT ANOTHER SIMULATION?  (1=YES, 0=NO)
1
```

```
 2 LAYER MODEL.

    LAYER NO.    THICKNESS   RESISTIVITY

        1          5.000         150.000
        2                        400.000


      SPACING         RHO

        2.00      153.050
        2.94      158.416
        4.31      170.775
        6.32      193.912
        9.28      227.879
       13.63      267.471
       20.00      305.961
       29.36      338.573
       43.09      363.058
       63.25      379.426
 WANT ANOTHER SIMULATION?  (1=YES, 0=NO)
1

 2 LAYER MODEL.

    LAYER NO.    THICKNESS   RESISTIVITY

        1          7.000         150.000
        2                        400.000


      SPACING         RHO

        2.00      151.183
        2.94      153.472
        4.31      159.474
        6.32      172.990
        9.28      197.575
       13.63      232.596
       20.00      272.395
       29.36      310.366
       43.09      342.049
       63.25      365.492
 WANT ANOTHER SIMULATION?  (1=YES, 0=NO)
1
```

```
2 LAYER MODEL.

    LAYER NO.    THICKNESS   RESISTIVITY

        1          10.000         150.000
        2                         400.000


       SPACING         RHO

         2.00       150.419
         2.94       151.279
         4.31       153.737
         6.32       160.130
         9.28       174.337
        13.63       199.749
        20.00       235.332
        29.36       275.202
        43.09       312.846
        63.25       343.983
 WANT ANOTHER SIMULATION?  (1=YES, 0=NO)
1
```

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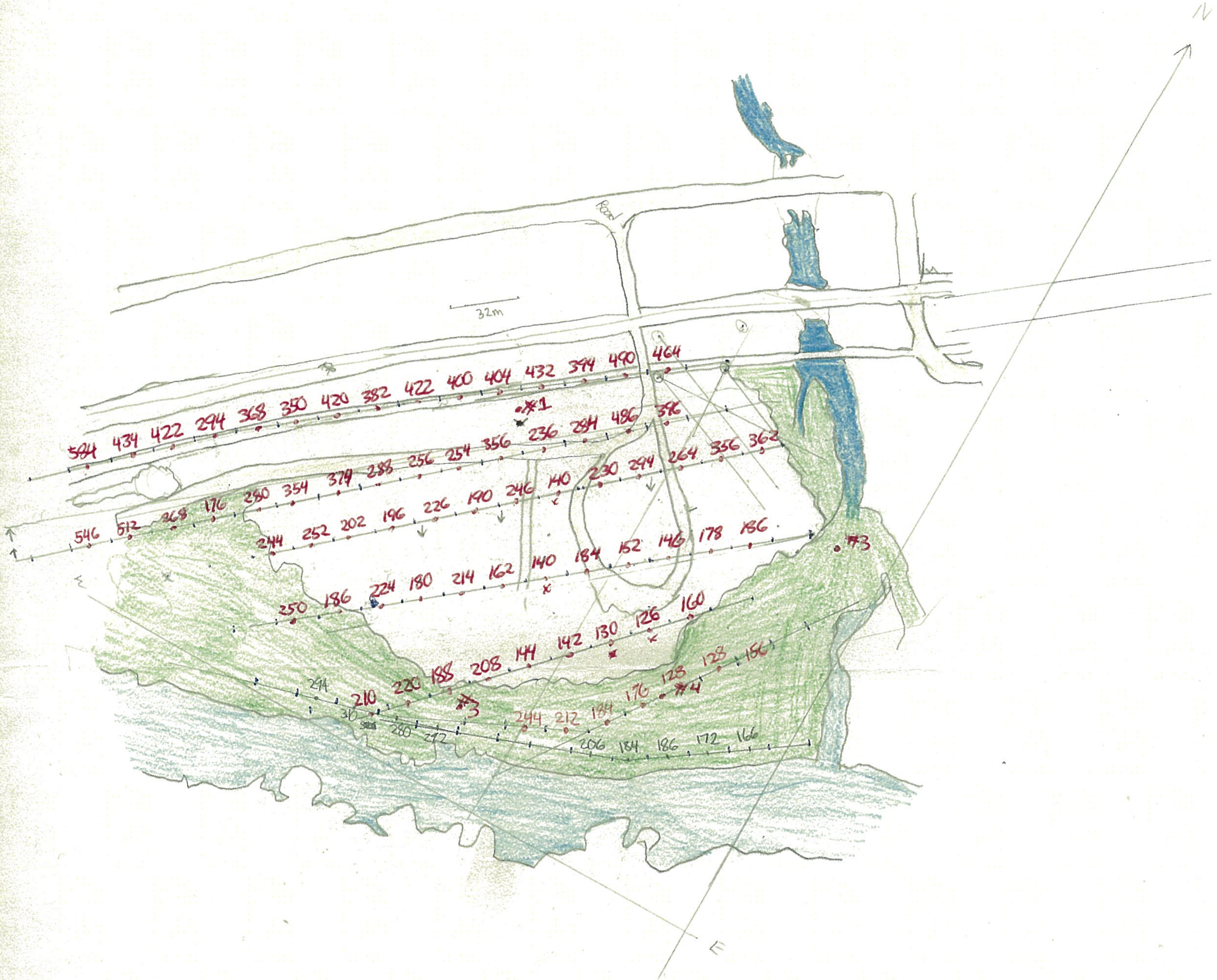

Air photo CQR-71
5/8/72
Magnified 3.4x

$\frac{1.1}{64} = \frac{2.25}{x}$

$1.1x = 128$

$=$

$\frac{1.1}{64}$