Variation of hydraulic conductivity in sandy glacial till : site variation versus methodology. [DNR-074] 1992

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VARIATION OF HYDRAULIC CONDUCTIVITY IN SANDY GLACIAL TILL: SITE VARIATION VERSUS METHODOLOGY

Abstract

The sandy till of the Green Bay Lobe in Wisconsin is mapped as the Horicon Formation, a lithostratigraphic term that implies that certain properties of the unit can be recognized everywhere it occurs. A compilation of a limited number of hydrogeological studies of the Horicon Formation by Rodenbeck (1988) showed that hydraulic conductivity varies over three orders of magnitude in a medium that appears texturally and lithologically homogeneous. The overall objectives of this study were: (1) to determine if this apparent heterogeneity is real or a result of different testing methods at different scales, and (2) to examine the effects of the scale of measurement on different methods of determining hydraulic conductivity in such materials.

Two field sites in till of the Horicon Formation were instrumented with piezometers. Each site is located in an area of thick, uniform till, away from drumlins and moraines. At Site 1, the aquifer is unconfined, with a saturated thickness of 8 m. At Site 2, the till aquifer is confined by locally occurring lake silt and clay. The saturated thickness at Site 2 is also about 8 m. The sites are instrumented with 26 and 27 piezometers, respectively. Each piezometer is 2 inches in diameter and has a screen length of 30 cm. The piezometer array is roughly square, with dimensions of about 10 m by 10 m.

The results of piezometer tests and pumping tests performed at the sites showed that hydraulic conductivity varies over nearly two orders of magnitude, from about $4x10^{-5}$ to about $2x10^{-3}$ cm/sec. In general, larger-scale tests yield larger values of hydraulic conductivity. However, results from a type of piezometer test at a larger scale indicate that testing a larger volume of aquifer results in a slightly lower hydraulic conductivity. Repeated tests of individual piezometers gave consistent values of hydraulic conductivity. Textural analyses of samples of the till from the screened intervals showed little variability, and there was no correlation between simple textural characteristics and hydraulic conductivity.

Introduction

The sandy till of the Green Bay Lobe is mapped as the Horicon Formation (Mickelson and others, 1984). This lithostratigraphic term implies that certain properties of the sediment can be recognized everywhere it occurs. A compilation of hydrogeological studies of the Horicon Formation in a six-county area from consulting reports by someone? in the present study and by Rodenbeck (1988) showed that there is a wide variation of hydrogeologic properties in material mapped as the Horicon Formation. The sandy till appears uniform in both outcrop and auger sampling. The till is not fractured and large inclusions of coarse sediments are not observed. Based on field observations and laboratory testing, there is little variation in texture. No structure or stratification is detected in outcrop and auger sampling, although this may be a function of sampling methods. Thus, the till appears to be lithologically and texturally homogeneous but hydrogeologically heterogeneous. This report summarizes a study which used a variety of methods to determine both vertical and horizontal variations of hydraulic conductivity in till of the Horicon Formation at a field scale of approximately 10 m by 10 m.

The results of this study include an evaluation of the various methods for determining hydraulic conductivity and a determination of the most accurate techniques for a given scale and objective. This information will benefit the Wisconsin Department of Natural Resources (DNR) and other regulatory agencies that require that hydraulic conductivity tests be made as part of any site investigation. This will allow these agencies to establish realistic and consistent requirements for initial site reports and feasibility studies.

The objectives of this project were to provide answers to and discussion of the following questions: (1) Is this sandy glacial till locally homogeneous? At what scale of measurement? (2) Is the observed variation in hydraulic conductivity due to the type of test used? (3) Is the variation caused solely by different testing techniques? (4) What is the vertical variation of horizontal hydraulic conductivity as tested at various scales? Is the variation systematic with the different scales of measurement? (5) What are the preferred methods of conductivity determination for different applications? (6) Is the till horizontally anisotropic? What glacial geologic conditions could account for the heterogeneity and anisotropy? Do assumptions of till genesis fit with hydrogeological results? This report provides responses to objectives 1 through 5. The remaining research objectives will be addressed in a future report.

Materials and Methods

Site selection and description

The criteria for site selection included (1) a large saturated thickness of till; (2) relatively shallow depth to water; and (3) accessibility and security for the drill rig and testing equipment. A relatively large saturated thickness was required in order to test a significant vertical section of the till. A shallow depth to water is important for ease of drilling, relatively lower cost of piezometers, and selection of pumping methods. Accessibility and openness of the site had to be balanced against the risk of vandalism to wells and equipment.

Based on the results of a number of exploratory borings, two sites in Dane County were selected for instrumentation. The sites are located near the western shore of Lake Waubesa in an area of thick, uniform basal till. Both sites are relatively flat and are not located on or near obvious moraines or drumlins. Two sites were chosen in order to make detailed studies of the hydraulic conductivity of the till under both unconfined and confined conditions. A fortuitous combination of location, access, and land owners resulted in the two sites being in relatively close proximity to each other.

Site 1 is located in the corner of a corn field near Gannon Road (Figure 1). At this site the aquifer is unconfined. Depth to water is approximately 5 m and depth to sandstone bedrock is 13 m, giving a saturated thickness of about 8 m. A general geologic description of the site is shown in Figure 2.

Site 2 is located about 100 m southwest of Site 1 (Figure 1). The site is located down a gentle slope from the first site and is close enough to the level of Lake Waubesa to have been covered by Glacial Lake Yahara near the end of the most recent glaciation. The result of this is a layer of about 3 m of silty-clay lake sediment over the sandy till. The lake sediment acts as a confining bed at the site, but pinches out about 20 m north of the site. Depth to till at this site is about 3 m, and with the artesian conditions the water level in the wells is 1 m below the land surface. Depth to bedrock is about 11 m, giving a saturated thickness (of till) of about 8 m. Generalized stratigraphic columns are shown in Figure 2.

The sites were studied and characterized by sampling from drilling. During installation of the piezometers the boring was sampled frequently, generally at five to ten foot intervals. Occasionally the drill string rotation had to be reversed in order to withdraw it from the hole; when this occurred sampling frequency was less due to the loss of sample. However, every borehole was sampled at least twice, and always in the screened interval. At each site one or more borings were sampled by continuous split spoon sampling using hollow stem augers. This method of sampling gives a continuous core from the surface to bedrock, which could be sampled for grain size analysis or taken back to the laboratory in large pieces for testing in a permeameter. At Site 1 one vibracore was taken of the upper 2 m. The core was split open and photographed but not tested.

Sediment textural analysis was done at the UW-Geology Quaternary Laboratory. Normal methods such as wet sieving, hydrometer analysis, and dry sieving are being used. The dry sieving of the sand fraction (2.00 mm - 0.0625 mm) was at quarter phi intervals to look for characteristics of the cumulative distribution curves that may not be apparent using the normal 1 phi mesh size intervals.

Site Instrumentation

Sites 1 and 2 were instrumented with 25 and 26 piezometers respectively. At each site, the piezometers were arranged in a roughly square array of approximately 10 m by 10 m. Each piezometer is 5 cm (2 in) in diameter and is screened at a 30 cm (12 in) interval in the saturated zone. Each 30 cm zone was covered by at least two piezometers, although not all 30 cm intervals of the saturated zone were screened. Figures 3(a) and 3(b) show the distribution of piezometers with depth at the two sites. The screen length of 30 cm was chosen in order to test a small vertical segment of the medium. Screen slot size is 10-slot (0.004 cm) which was chosen to retain 40-50% of the aquifer material. The piezometers were installed and backfilled with only native material emplaced around the screen; no sand or gravel filter pack was used. Each piezometer had a bentonite cap placed in the annulus near the surface. At each site a 10 cm (4 in) pumping well was installed in the center of the array. These wells were screened over most of the aquifer (6.1 m) to conform to assumptions in the Theis and Jacob methods of pump test analysis and to allow pumping at a rate that would stress the aquifer without pumping the well dry.

After the piezometers were installed they were developed using a surge block and a suction pump. The development stage was a crucial part of this study; if the wells are overdeveloped the conductivity testing methods will partially test an artificially high conductivity zone around the screen instead of the true till medium. If the wells were underdeveloped the screened area may be clogged with silt and clay smeared on the borehole from the augers. The objective of development in this study was to ensure that the well screen was hydraulically connected to the aquifer. Each piezometer was developed identically by alternating gentle surging and pumping three times. At this point the water still contained some silt but the well appeared to react instantly to an applied stress. Development of the 10 cm pumping well was more extensive and included air lifting, surging, and overpumping.

The most important part of the instrumentation phase of the project was the necessity of holding constant all variables we could control. These variables include drilling procedure, well construction, screen size and type, well installation, development, and testing procedures.

Laboratory and Field Testing Methods

There are a variety of tests of hydraulic conductivity that are used in this study. Laboratory methods constitute a minor part of this investigation but are being performed for comparison purposes.

Laboratory methods include flexible wall and rigid wall permeameter tests. These will be performed on approximately five sections of core taken from the borings for the central pumping well. The results of these tests will be compared to laboratory values determined by consultants on till samples from the nearby proposed Libby landfill site. These tests are being performed during the spring of 1992.

Piezometer tests of two different scales (i.e. tests that test different volumes of aquifer) have been performed on each piezometer. In this type of test, the aquifer is stressed by creating an instantaneous increase or decrease of the head in the piezometer and monitoring the response of the water level over time. These tests are commonly called slug tests and bail tests, and they are the most common method of measuring K in the field. Several methods of analyzing the piezometer tests were compared, but the chief method used in this study was the Bouwer and Rice (1976) and Bouwer (1989) method which seems to be favored by most consulting firms. Analyses of piezometer tests was done using a software package developed by Geraghty and Miller called AQTESOLV.

Borehole dilution tests, sometimes called point dilution tests, are single well tracer tests used to calculate groundwater velocity. A tracer is introduced into the screened interval of the well and allowed to dissipate through time by natural flow through the aquifer. Hydraulic conductivity can be calculated from a variation of Darcy's law by measuring the gradient in the vicinity of the well screen and the effective porosity (n_e) of the aquifer (or by assuming n_e to be equal to the specific yield). This type of test avoids the problems of conventional tracer test such as uncertain flow paths and the large number of monitoring wells needed to detect the tracer. Borehole dilution tests have been performed on selected wells to determine groundwater velocity in the vicinity of the screened interval and hence the hydraulic conductivity. The scale of measurement of this test is somewhat larger than the scale of the piezometer tests.

Pumping tests are tests in which the aquifer is stressed by pumping water from one well for a period of time and recording the change in water levels in the pumping well and nearby observation wells with time. Pumping tests can last from several hours to several weeks, depending on the aquifer type and aquifer parameters. Several pumping tests were performed during the summer of 1991 at each site using a electric submersible pump. Results were analyzed using the Hantush (1964) method for leaky confined aquifers and the Neuman (1974) delayed yield method for unconfined aquifers. These analyses were performed using AQTESOLV. Pumping tests determine hydraulic conductivity in the volume of aquifer between the pumping well and the observation well. The scale of measurement of this type of test is thus the largest of any type of field test of hydraulic conductivity.

Results and Discussion

Compilation of DNR information

This section presents data on the hydraulic conductivity of till of the Horicon Formation in Wisconsin from Department of Natural Resources (DNR) files. The objective of this part of the study is to update the work of Rodenbeck (1988), who compiled and analyzed hydrogeologic and engineering data submitted to the DNR from private consulting firms. Rodenbeck's thesis included data from all of the Pleistocene formations in eastern Wisconsin. This report is limited to till of the Horicon Formation, the sandy till deposited by ice of the Green Bay Lobe.

Figure 4 shows the distribution of the Horicon Formation in Wisconsin. The unit is widespread, covering all or parts of eighteen counties. In this study, only data from the southern part of the Green Bay Lobe were used. The area is composed of all or parts of Dane, Jefferson, Sauk, Dodge, Columbia, and Green Lake counties. This restrictive sampling eliminates wide textural variations that may occur near the Green Bay lowland and the Lake Winnebago basin. This textural variability affects the hydraulic conductivity, making comparison between finer-grained till influenced by finer-grained lacustrine sediment in the northern part of the lobe and sandier till from the southern part of the lobe meaningless.

Differentiation of till from other glacigenic sediments is not easy; this is especially true for till of the Horicon Formation. The till is sandy (about 65%-80% sand) and is easily mistaken for glaciofluvial and other types of sandy glacigenic or fluvial sediment. This problem is compounded by the common layering of till over sandy outwash at many sites. In addition, the DNR has required consulting firms to identify the sediments at a site by a genetic name only recently. Therefore, many of the boring logs from sites in Horicon till either misidentify the till or don't identify it at all. This complicates the compilation of a summary of values from a particular stratigraphic unit. Restrictive sampling from the six counties helps to minimize this problem, but there is some subjectivity in interpreting boring logs from some of the sites. Hydraulic conductivity values from questionable genetic interpretations were eliminated from the present study.

The main source of the data was landfill initial site reports and feasibility studies. Wisconsin law requires that both field and laboratory measurements of hydraulic conductivity be performed at multiple locations at a prospective landfill or landfill expansion site. In this study only field measurements of hydraulic conductivity were used. Additional field measurements of conductivity from hazardous waste sites and Superfund sites in the sampling area is included here.

Figure 5(a) is a histogram of Rodenbeck's (1988) compilation of hydraulic conductivity data for Horicon Formation till from consulting reports. Figure 5(b) is a histogram of hydraulic conductivities compiled from more recent consulting reports. All data are field tests from landfill feasibility studies and hazardous waste site investigations on file at the Wisconsin Department of Natural Resources. Note that the two histograms show a similar range of hydraulic conductivities and that reported conductivities range from $10^{-5.5}$ to 10^{-2} cm/sec, a range of 3 1/2 orders of magnitude.

Figure 6 is a summary of hydraulic conductivity from piezometer tests at the smallest scale from this study plotted at the same scale. In contrast to Figures 5(a) and 5(b), note that the range of measured hydraulic conductivity values is slightly greater than one order of magnitude. These results are also shown in Figure 8 in a boxplot, and are discussed later in this report.

Results of textural analysis and piezometer tests

Over 100 textural analyses of the till were performed by the UW-Madison Quaternary Laboratory. Results of these tests are summarized in Figure 7. These ternary plots show that the average sand/silt/clay percentages from the two sites are 69/22/9 and 67/22/11 respectively. The analysis shows that the till at both sites is very uniform in texture, with a very low variance from the mean. Based on the results of regression analysis, there is no relationship between sand, silt, or clay percentages and hydraulic conductivity. More complex relationships, such as the relationship between hydraulic conductivity and sorting, have not been tested.

The results of over 140 small-scale (30-cm head change) piezometer tests are summarized in Figure 8 and Table 1. Figures 8a and 8b are boxplots, a simple graphical plot of the 10th, 25th, 50th, 75th, and 90th percentiles of a data set. Note that the variability is slightly greater at Site 1, and that variability at both sites is much less than shown by Rodenbeck (1988). This could be due to the scale of the test (i.e. the volume of aquifer stressed) or the small site area tested. There appears to be no correlation between hydraulic conductivity and simple grain size (e.g. K vs. % sand, etc.)

A summary of over 60 larger scale (3-m head change) piezometer tests is shown in Figure 9 and Table 2. The data are presented graphically in the form of boxplots. Note that the variability of hydraulic conductivity is similar to that from small-scale piezometer tests, and that the mean conductivity is lower. We are uncertain of the reasons for this lower mean hydraulic conductivity. A possible explanation is that the larger-scale piezometer test stresses a larger volume of aquifer outside of the disturbed zone of the boring. Thus the hydraulic conductivity determined by this larger-scale test may be more representative of the true properties of the aquifer at the piezometer-test scale.

Figure 10 and Table 3 summarizes the results of pump tests from the test sites. Again, the data are presented in the form of boxplots and associated statistics. Variability of hydraulic conductivity is somewhat greater than for the other, smaller-scale tests, which may be an indicator of heterogeneities in the till.

Borehole dilution tests were performed on twenty piezometers at the two field sites. Results from the borehole dilution testing show a groundwater velocity of approximately 2 cm/day. Attempts to verify this value from calculations of velocity based on Darcy's Law showed that the average borehole dilution velocity is approximately one to one and one half orders of magnitude higher than the calculated velocity. We believe that the calculated velocity is more accurate than the borehole dilution velocity. Therefore, the borehole dilution method is inappropriate for determining velocity (and hence hydraulic conductivity) at these sites, due to the combination of relatively low hydraulic conductiviy, hydraulic gradient, and effective porosity. The borehole dilution method probably gives a higher velocity because of molecular diffusion of the tracer out of the borehole.

Spatial correlation of hydraulic conductivity

Geostatistics can be used to examine spatial correlation of hydraulic conductivity. A semivariogram is a plot describing the spatial dependence of some property between samples (the semivariance) at different distances. In general, the spatial dependence between samples is high (i.e. the semivariance is low) at small distances. At some greater distance the points being compared are far enough apart so they are not related to each other, and their semivariance is equal to the variance around the average value. At this point the semivariance no longer increases and the semivariogram plots as a flat region called a sill.

Examples of semivariograms are shown in Figures 11a and 11b, which are semivariograms for small-scale (30 cm initial water level displacement) hydraulic conductivity values for sites 1 and 2. Note that the semivariograms are calculated for both 0 degrees and 90 degrees on a north-south coordinate system to test for any directional relationships. The semivariograms of both sites show a sill at a distance less than the smallest sampling interval (2 m). This indicates that the variable (hydraulic conductivity) has no spatial correlation at this distance. This lack of spatial correlation agrees with the highly uniform textural properties and lack of sorting and bedding in the till. This result also agrees with visual observations of boring and outcrop samples. The lack of spatial correlation, the narrow range of hydraulic conductivity values from different testing methods, and the uniform textural properties of the till indicate a homogeneous medium, at this size of field site.

Conclusions

1. Most of the reported variability (from DNR files) of field-measured values of hydraulic conductivity in till of the Horicon Formation is due to different testing methods (e.g. slug tests versus pumping tests), different scales of the same testing method (e.g. different slug sizes) that test different volumes of aquifer, or misidentification of the material.

It is likely that significant changes in texture and other properties of the till occur in the six-county area of interest. These changes, at the scale of kilometers, have not been observed in this small-scale study, but could account for some variability of hydraulic conductivity from site to site. When surficial deposits in the area are mapped in more detail it is likely that subunits of the

Horicon Formation will be delineated (John Attig, personal communication, 1992).

2. The till can be considered homogeneous at a site scale (15 m x 15 m). There is no spatial correlation of hydraulic conductivity at the smallest sampling interval (2 m) when determined by a slug test. However, tests of this type (initial water level displacement of about 30 cm) may not adequately determine the hydraulic conductivity outside of the disturbed zone of the borehole.

3. Results of bail tests (a type of piezometer test with an initial water level displacement of about 3 m) also show the till to be relatively homogeneous at a site scale (15 m x 15 m), but with a slightly lower mean hydraulic conductivity than the slug tests from (2).

4. The results from (2) and (3) indicate that if slug tests are used to determine hydraulic conductivity in piezometers, they should be performed at several scales (for example using slug lengths of 1 m and 2 m in a 2-in well). A significant difference in hydraulic conductivity may indicate that smaller-scale slug tests do not adequately test the aquifer outside of the disturbed zone of the boring or the sand pack of the well.

5. Results of the different testing methods show that in this medium, the different types of tests yield different mean values of hydraulic conductivity. The difference between the lowest mean value (bail test) and the highest (pumping test) is nearly a factor of 3. This scale effect occurs even at the small-scale field sites used in this study.

6. Piezometer (slug or bail) tests performed at several scales are adequate for determining the hydraulic conductivity of the till where it is not of major hydrogeologic importance. However, if the till has a significant saturated thickness or is highly involved in the migration of contaminants, it is recommended that a pumping test be performed to determine the hydraulic conductivity for a larger volume of material. For silty-sandy tills such as till of the Horicon Formation a maximum distance of about 10 m from the pumping well to the farthest observation well will test an appropriate larger volume.

7. Genetic classification of glacial sediment is difficult for consultants. However, if unfractured basal till is identified based on its highly uniform textural properties, then fewer tests of the hydraulic conductivity of the till should be required than in mixed sediments. This is due to the apparent homogeneity of the till within a field-scale study.

8. **Determination of hydraulic conductivity should always be performed using a test scale that matches the scale of the field problem as closely as possible.**

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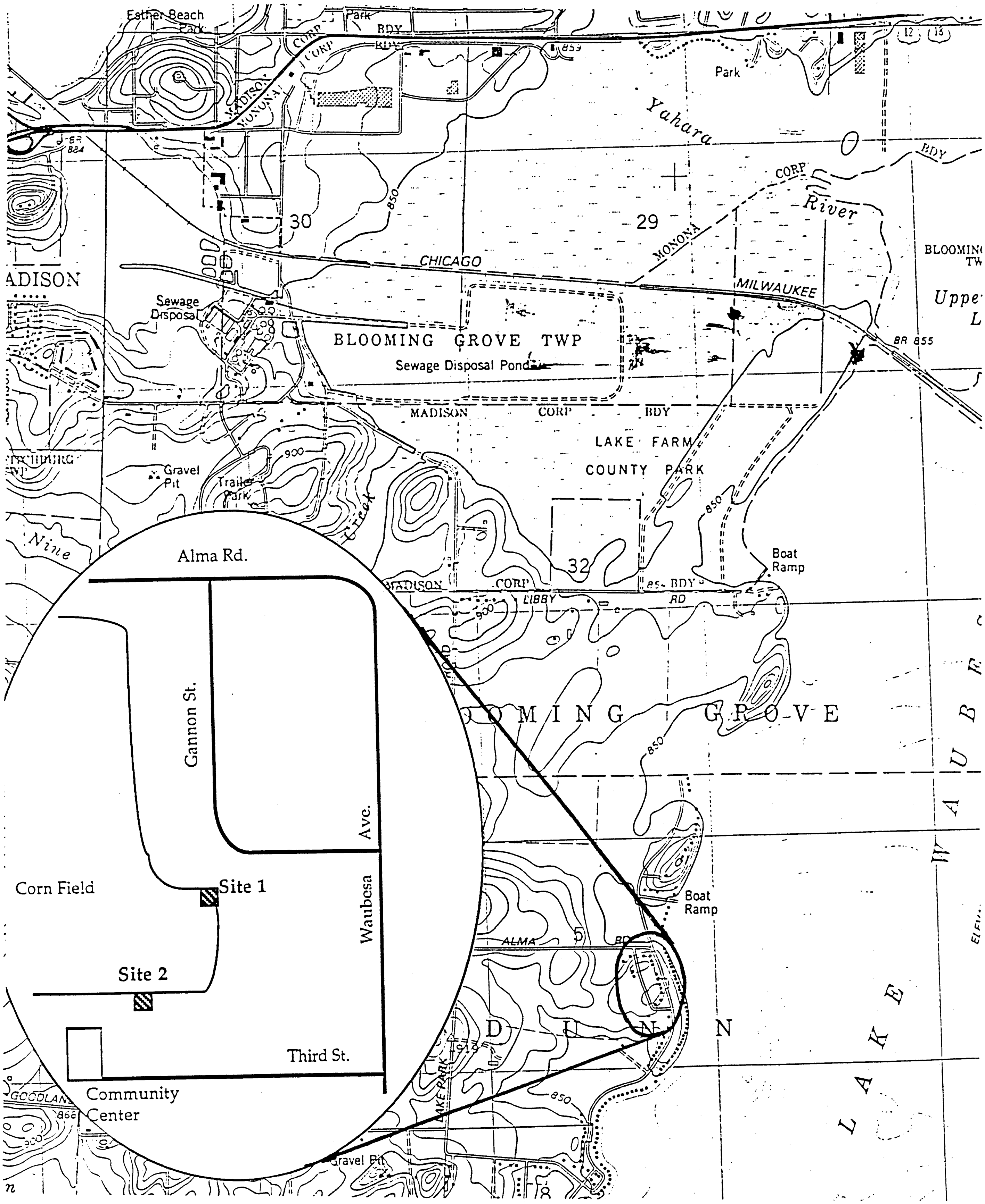


Figure 1. Location map of Sites 1 and 2 from USGS 1:24000 Madison East Quadrangle. Enlargement showing sites is schematic.

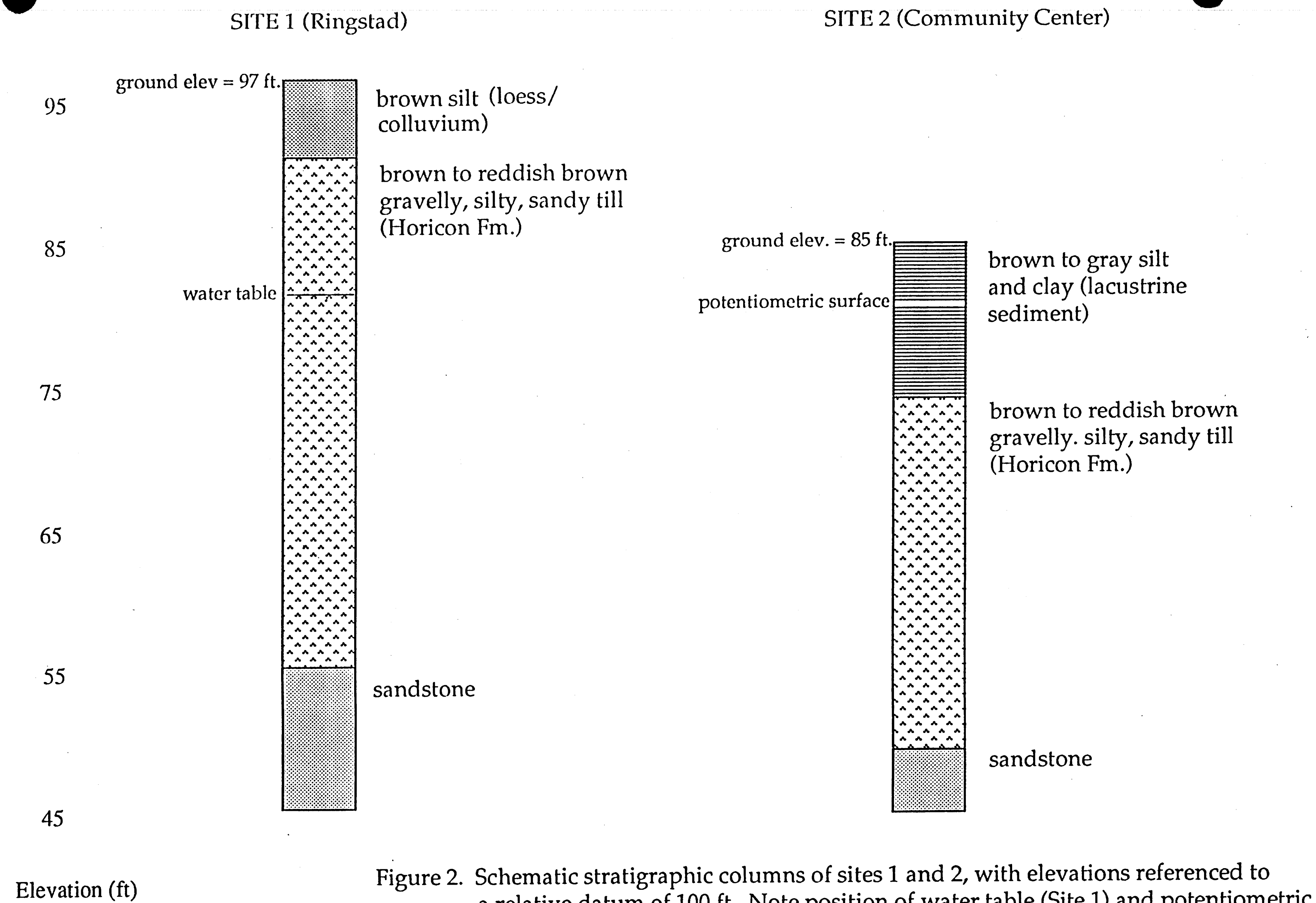
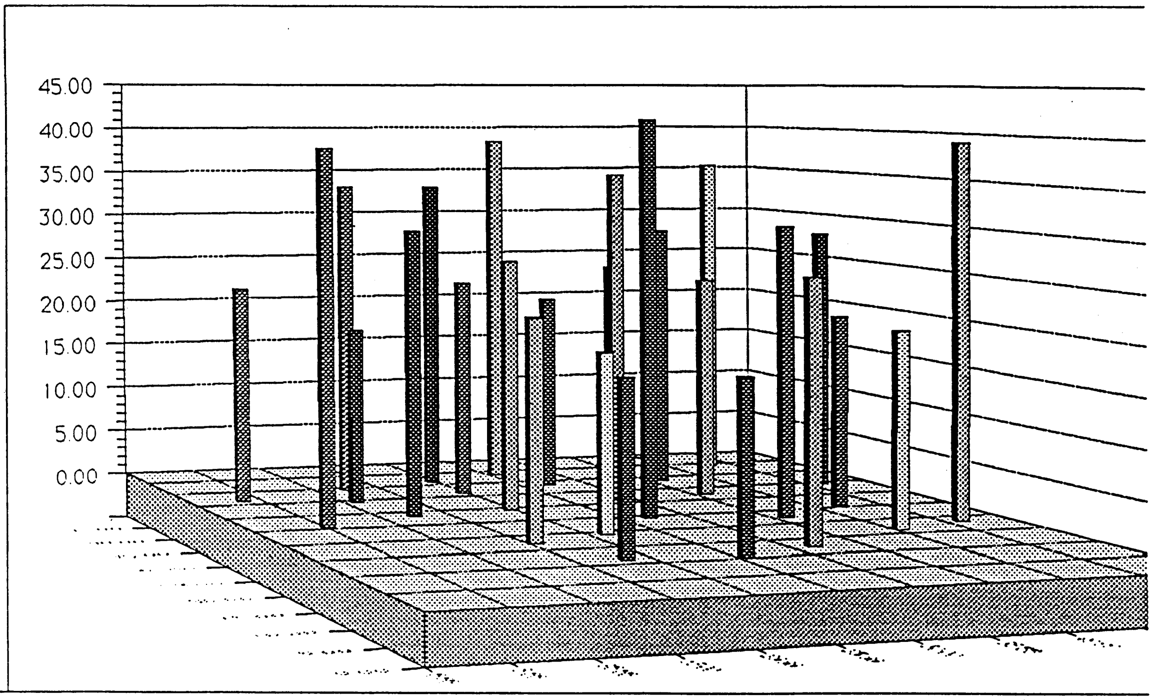


Figure 2. Schematic stratigraphic columns of sites 1 and 2, with elevations referenced to a relative datum of 100 ft. Note position of water table (Site 1) and potentiometric surface (Site 2) result in an equivalent saturated thickness of till for the two sites.



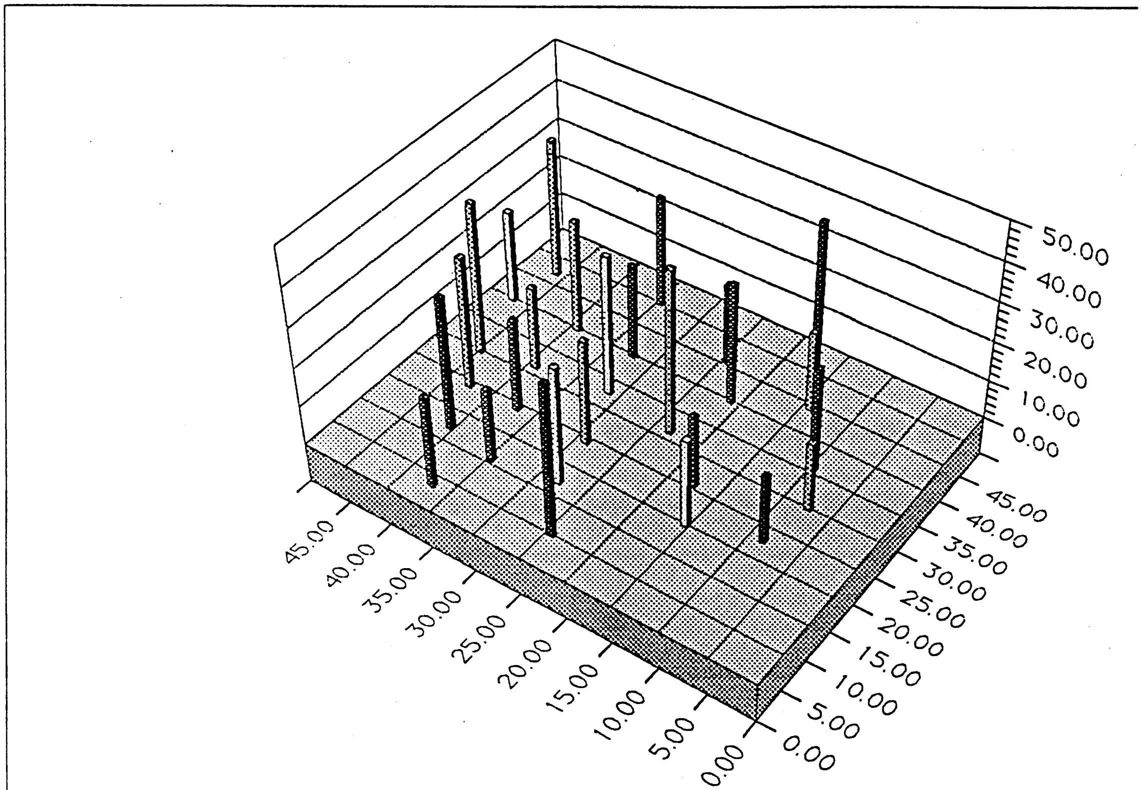
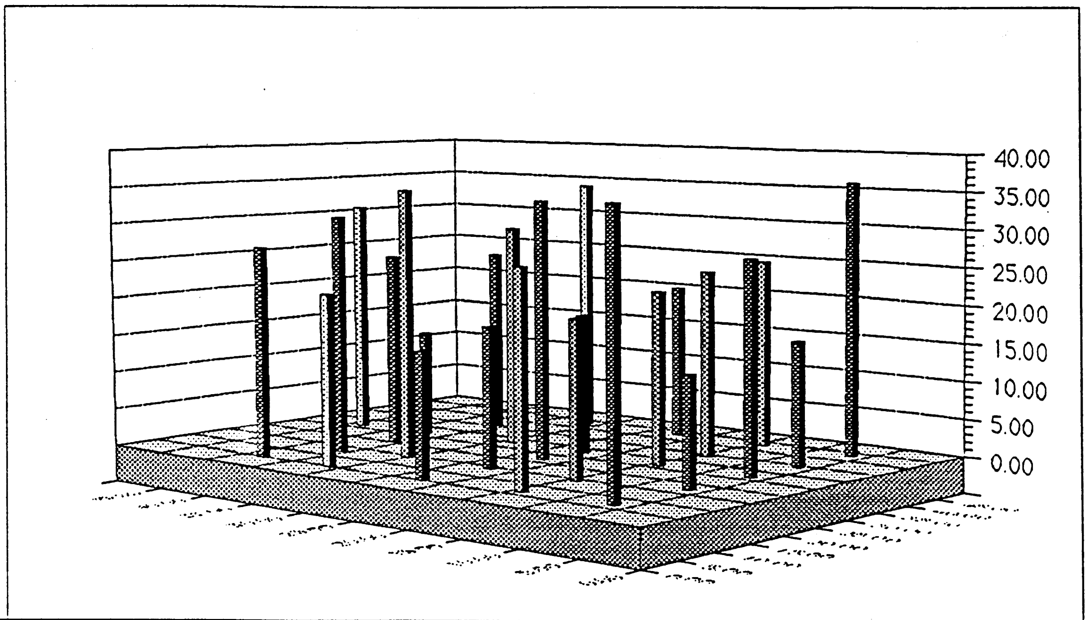


Figure 3a. Distribution of piezometers at Site 1, with positive Z axis indicating depth of piezometer from ground surface. All scales are in feet.



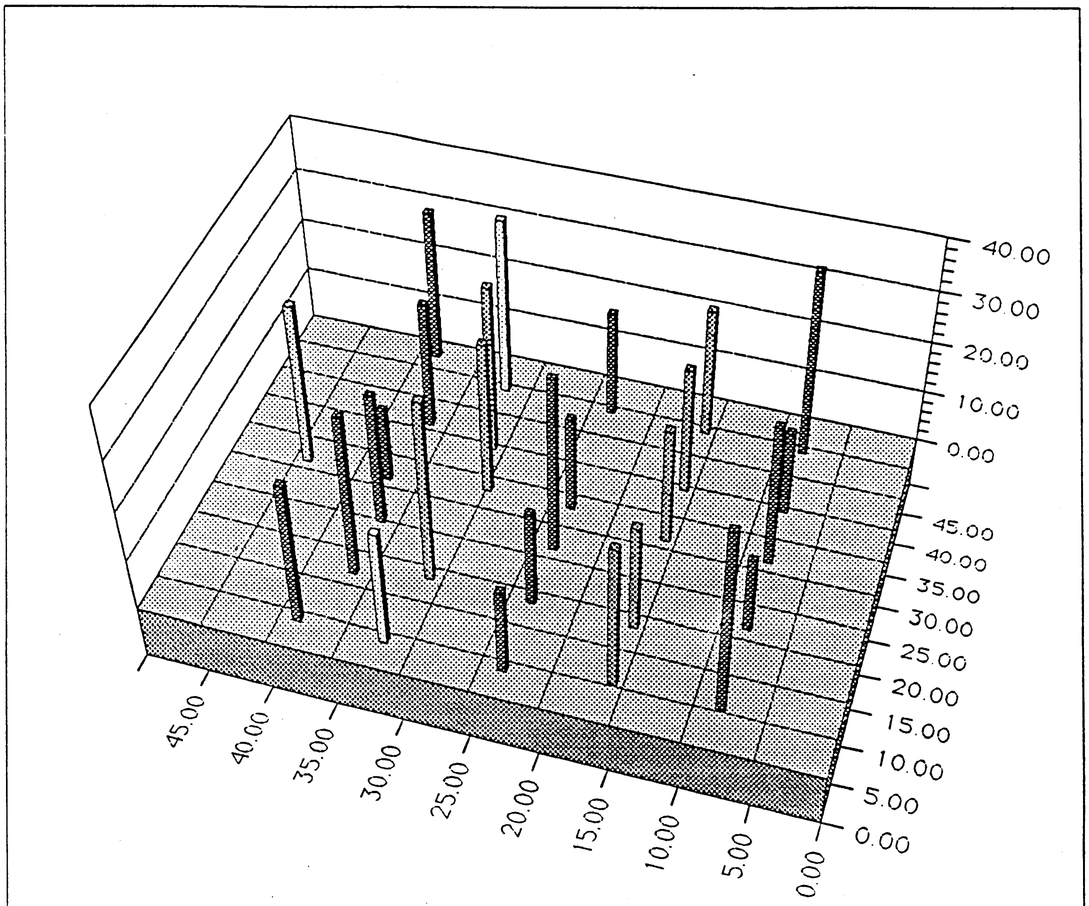


Figure 3b. Distribution of piezometers at Site 2. Positive Z axis indicates depth of piezometer from ground surface. All scales are in feet. Depth to bedrock is approximately 10 m (34 feet).

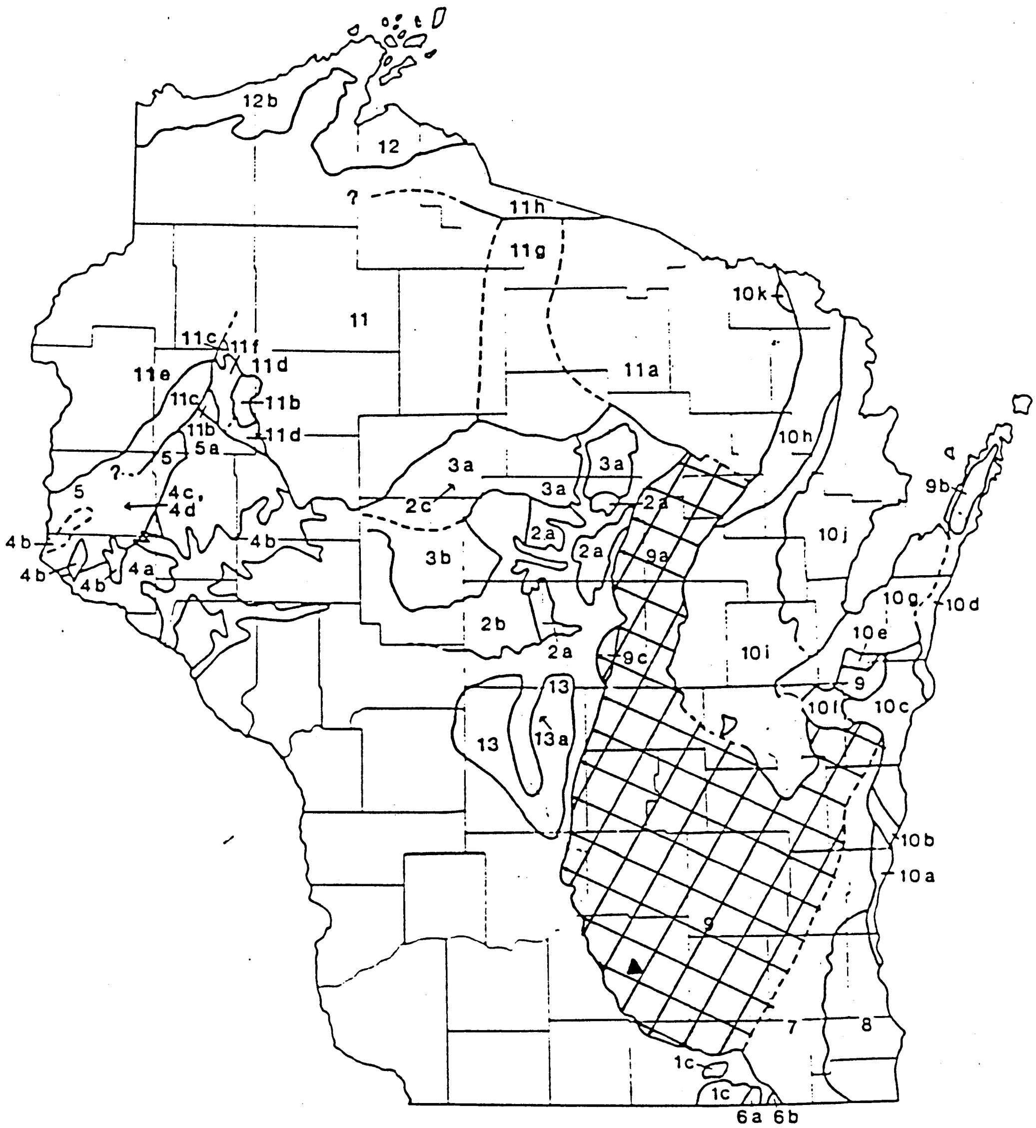
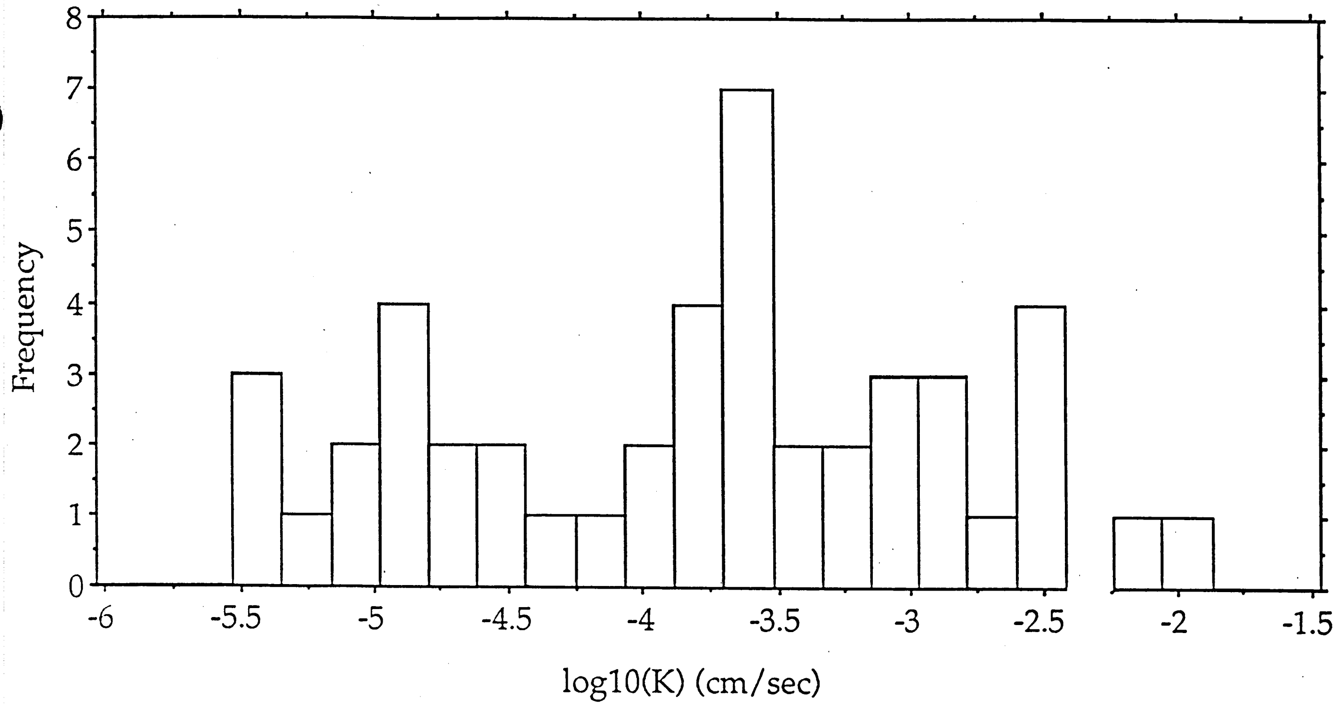


Figure 4. Map of Wisconsin showing the distribution of Horicon Formation (cross-hatched) from Attig and others (1988). Triangle indicates location of study area.



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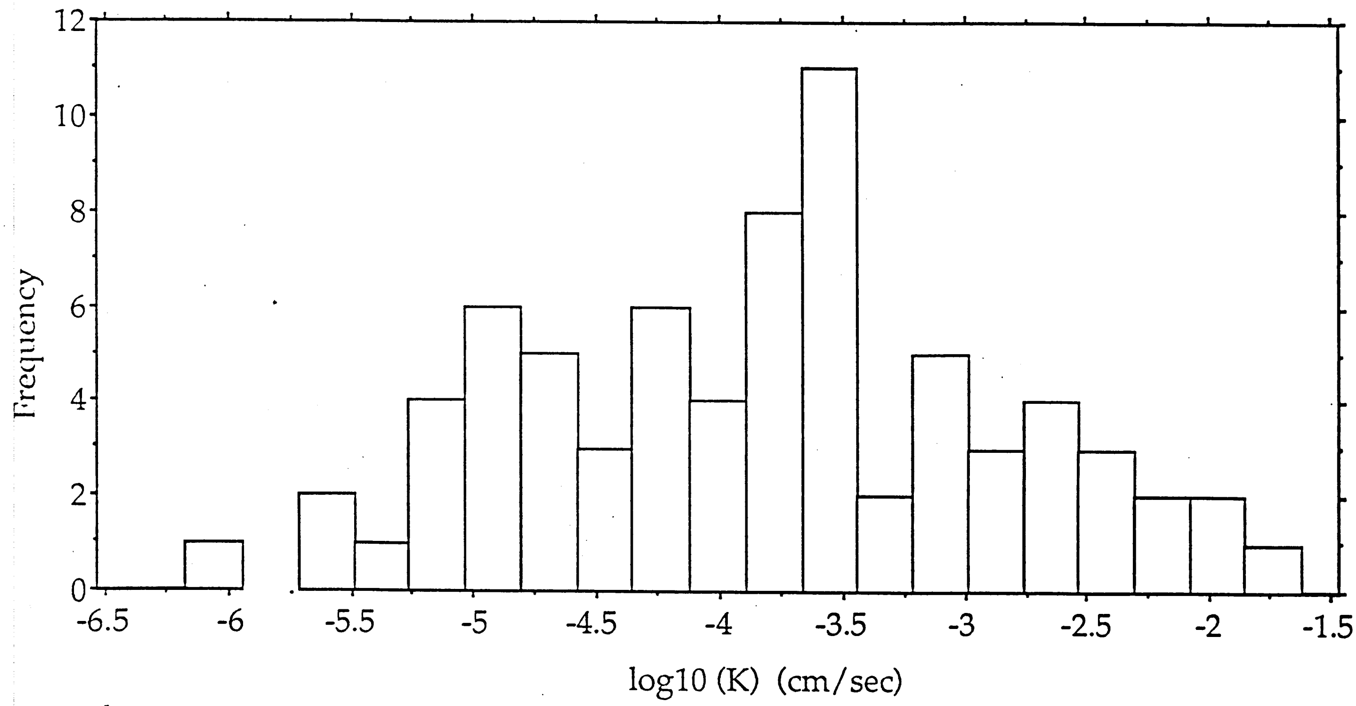


b.

Figure 5. (a) Histogram of log10 hydraulic conductivity values (cm/sec) of Horicon Formation till compiled from DNR files prior to 1988 by Rodenbeck (1988).
(b) Histogram of log10 hydraulic conductivity values (cm/sec) of Horicon Formation till compiled from DNR files from 1988 to 1991 for this report. Note the similar shape and range of the two histograms.

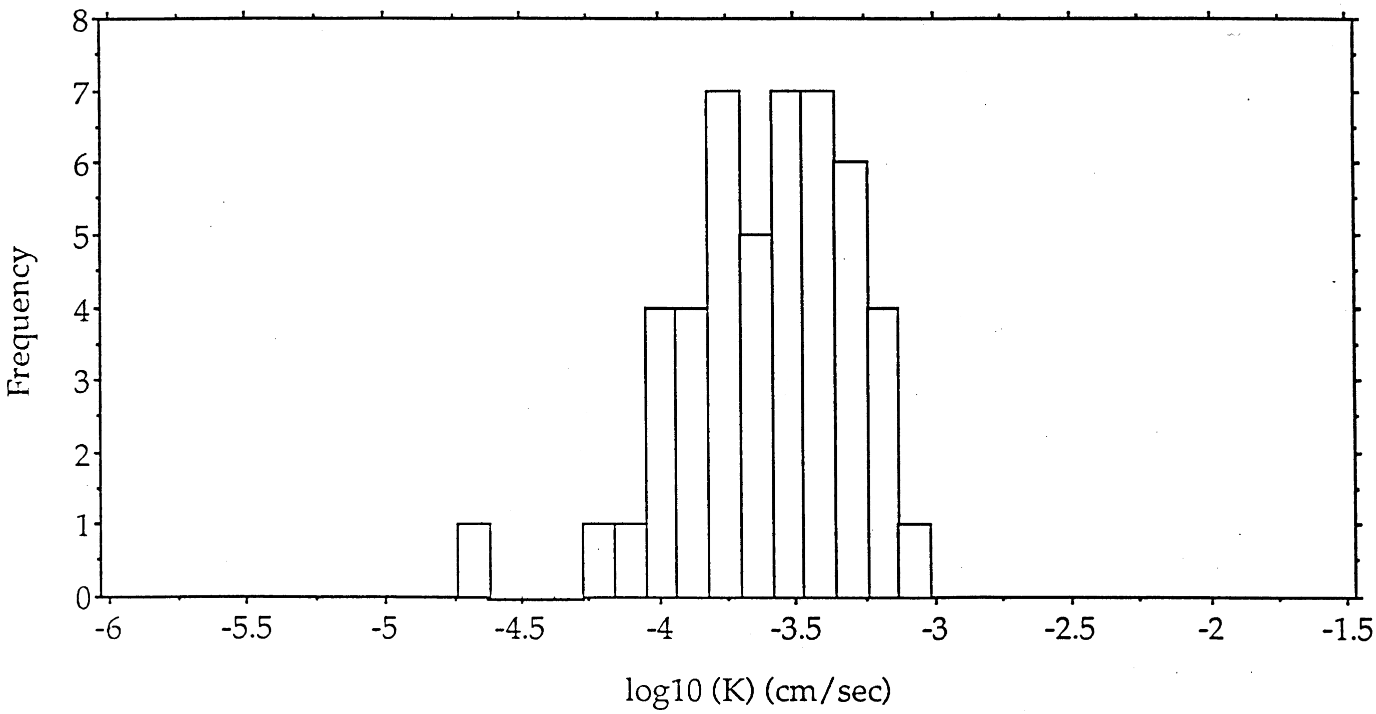
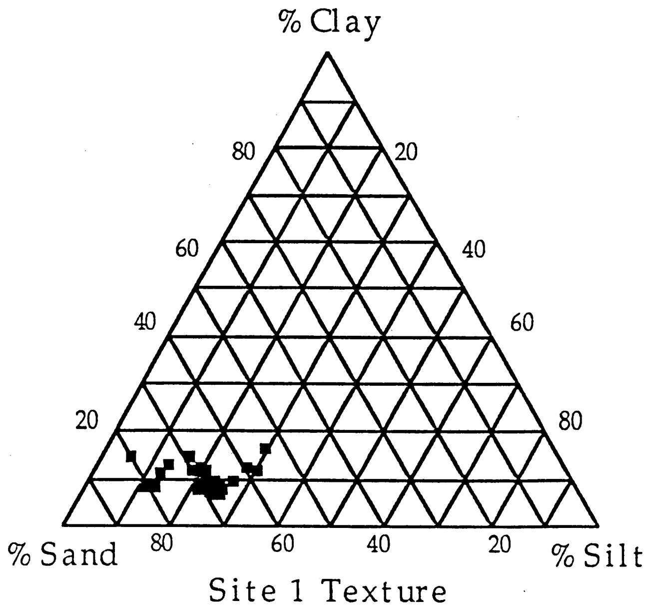


Figure 6. Histogram of log10 hydraulic conductivity values (cm/sec) from small-scale (1 foot head change) from sites 1 and 2. Note that this histogram, plotted at the same scale as Figures 5(a) and 5(b), shows a similar shape but a much smaller range.



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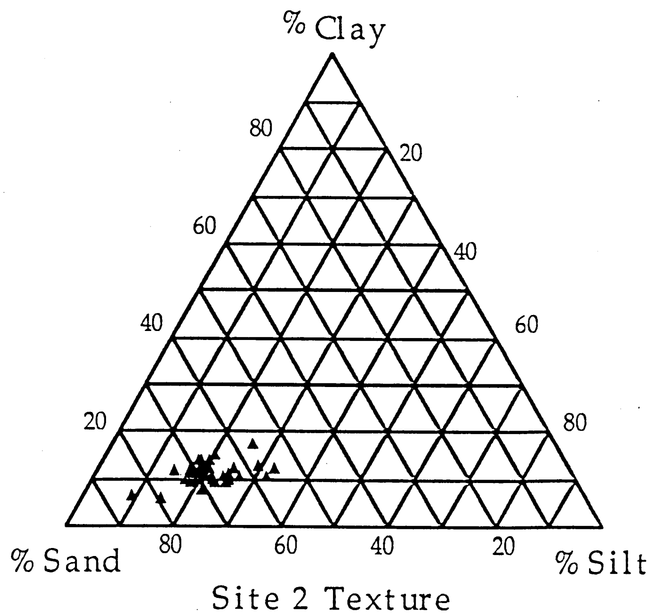
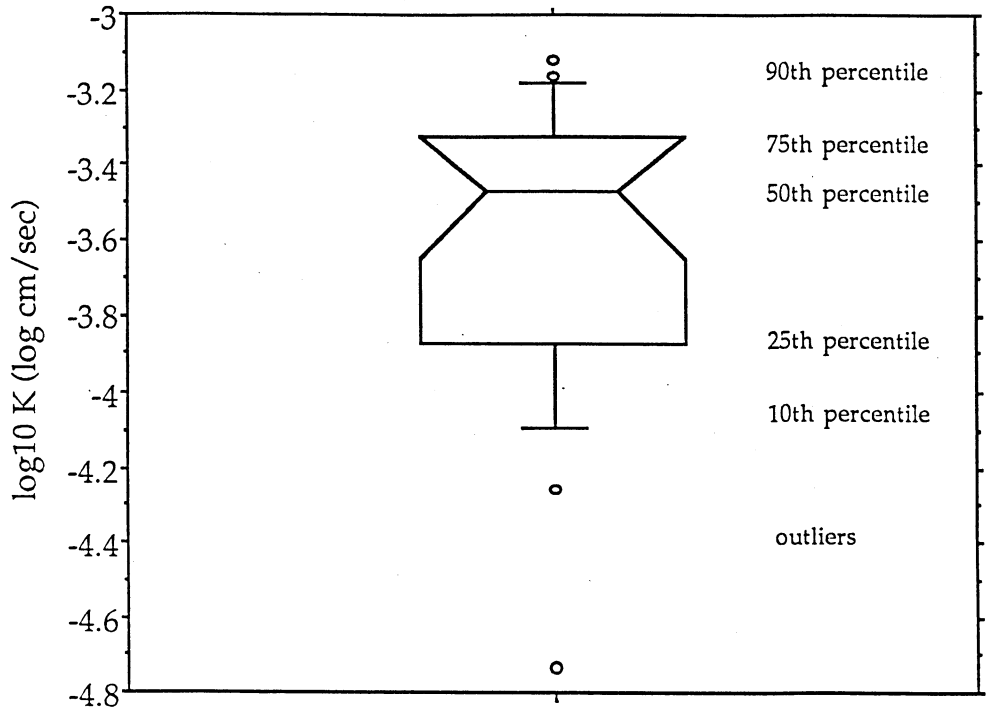


b.

Figure 7. (a) Ternary diagram of sand-silt-clay percentage of till from Site 1. (b) Ternary diagram from Site 2.



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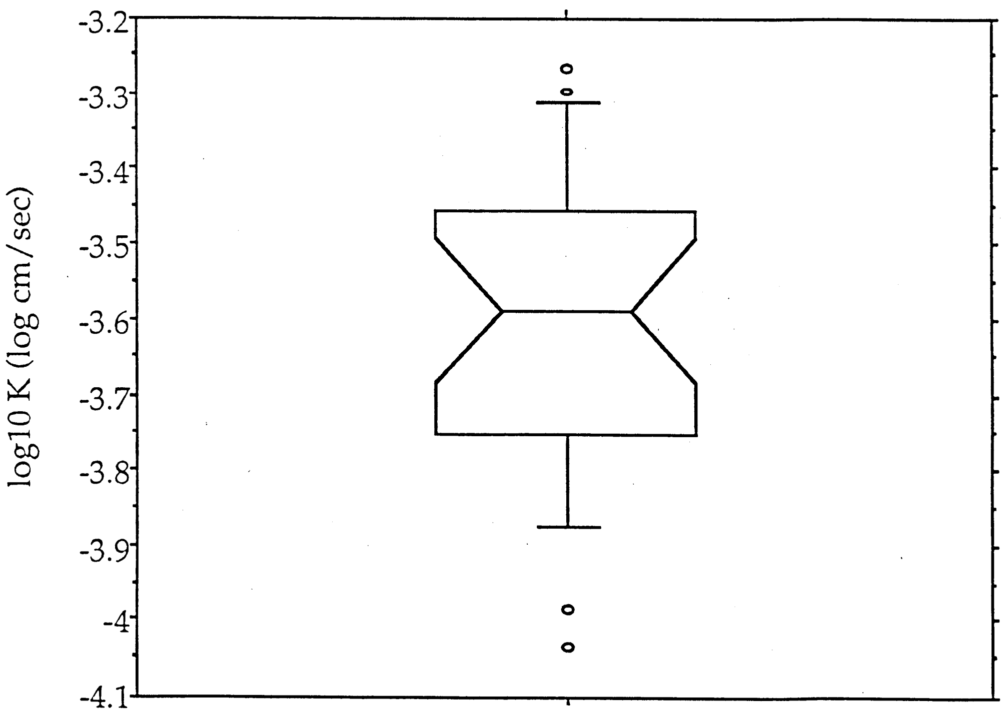


b.

Figure 8. Boxplots of log10 hydraulic conductivity (cm/sec) of slug test data from Site 1 (a) and Site 2 (b). See Table 1 for summary of means, etc.

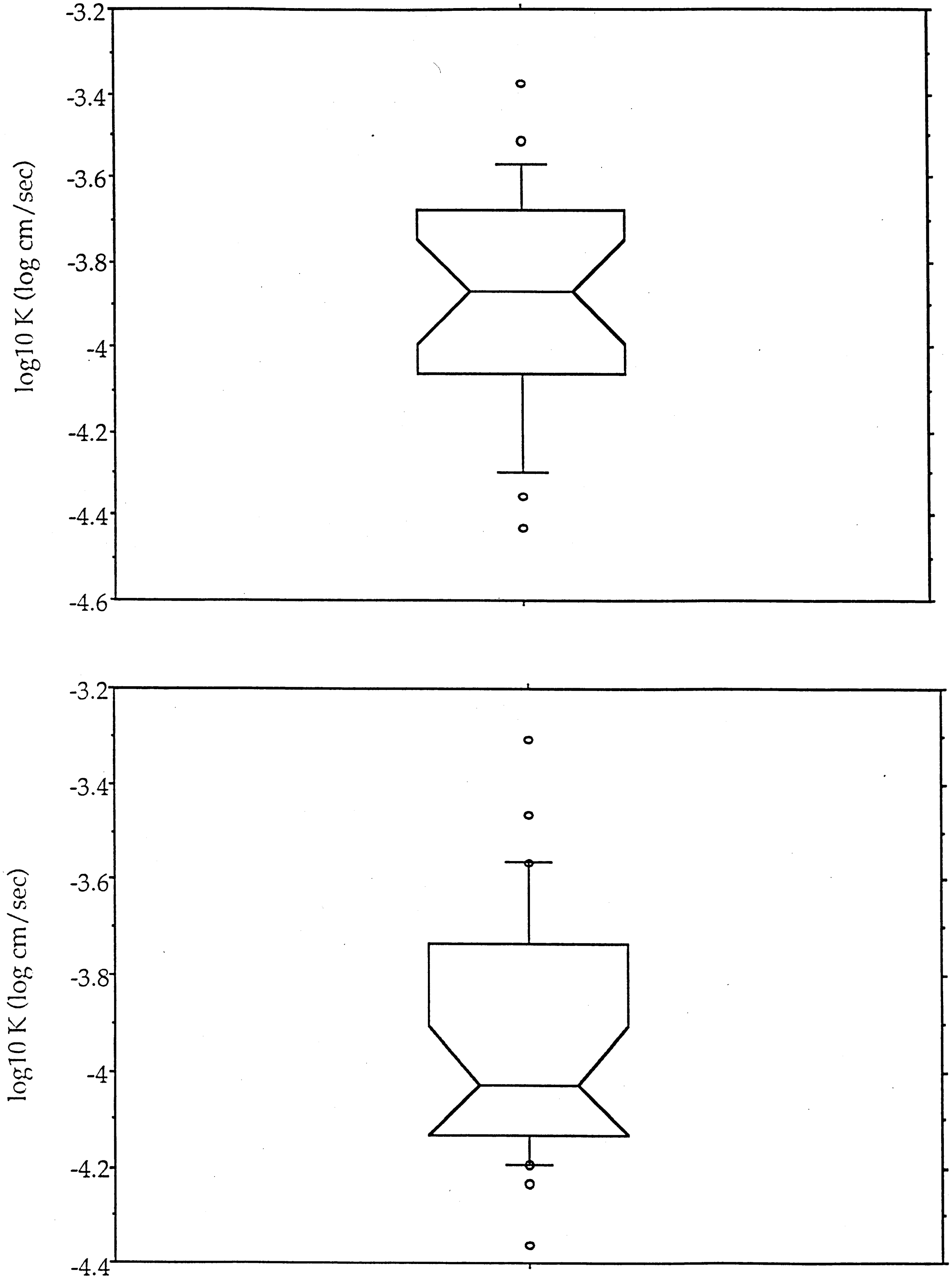
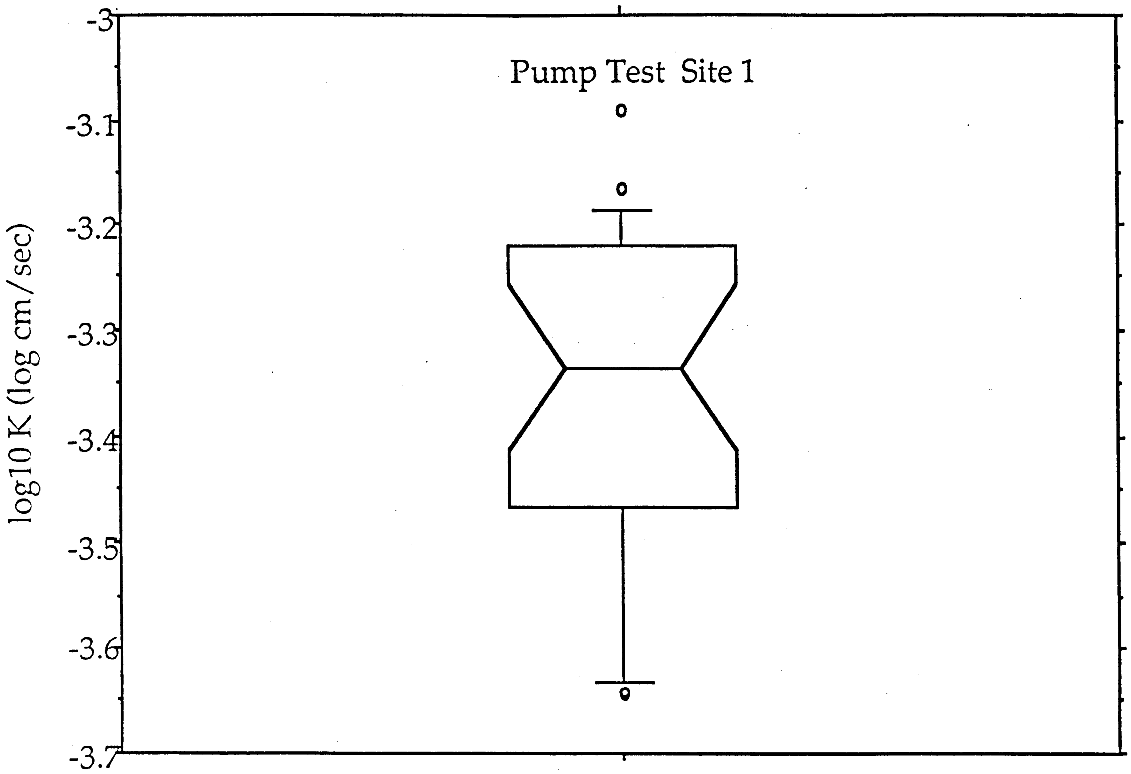


Figure 9. Boxplots of log10 hydraulic conductivity (log cm/sec) of bail test data from Site 1 (a.) and Site 2 (b.). See Table 1 for a statistical summary.



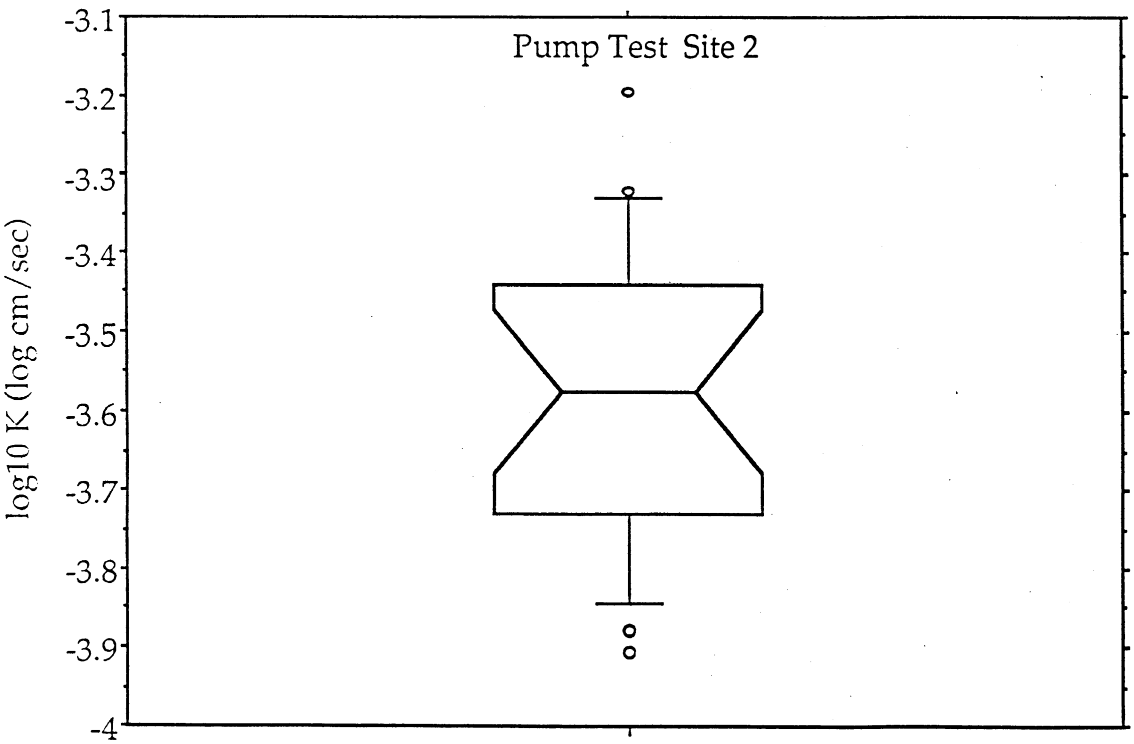


Figure 10. Boxplots of log10 hydraulic conductivity (log cm/sec) of pumping test data from Site 1 (a.) and Site 2 (b.). See Table 3 for a statistical summary of values.

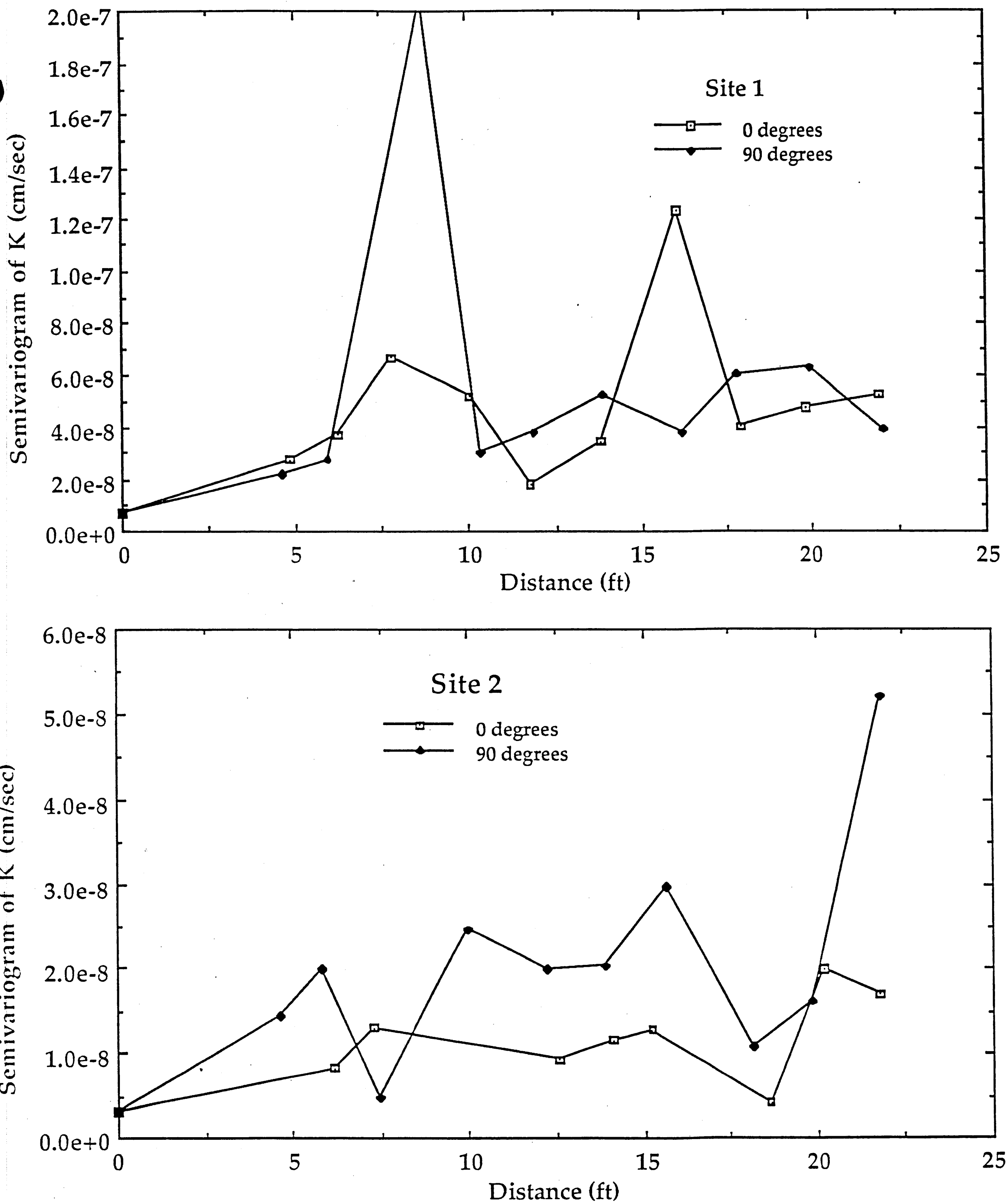


Figure 11. (a.) Semivariograms of hydraulic conductivity measurements from small scale (30 cm displacement) piezometer tests at Site 1. (b.) Semivariograms with the same parameters at Site 2. Semivariograms were determined for both 0 degrees and 90 degrees on an N-S coordinate system at both sites to test for any directional properties.

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.000325	.000224	.0000457	.0000001	68.9443853	24
Minimum:	Maximum:	Range:	Sum:	Sum Squared:	# Missing:
.0000186	.0007643	.0007457	.007799	.0000037	24
# < 10th %:	10th %:	25th %:	50th %:	75th %:	90th %:
2	.0000812	.0001335	.0003402	.0004719	.0006621
# > 90th %:	Mode:	Geo. Mean:	Har. Mean:		
2	•	.0002365	.0001407		

a.

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.0002783	.0001296	.0000264	1.6785525E-8	46.5619983	24
Minimum:	Maximum:	Range:	Sum:	Sum Squared:	# Missing:
.0000924	.0005397	.0004474	.006678	.0000022	24
# < 10th %:	10th %:	25th %:	50th %:	75th %:	90th %:
2	.0001337	.000176	.0002577	.0003505	.0004876
# > 90th %:	Mode:	Geo. Mean:	Har. Mean:		
2	•	.00025	.0002231		

b.

Table 1. These tables summarize the small-scale (30-cm displacement) piezometer tests at Site 1 (a.) and Site 2 (b.) (all hydraulic conductivity values in cm/sec). Note the small variance, shown graphically on Figures 8a and 8b, and the difference between the arithmetic and geometric means. Extra digits on hydraulic conductivity values are not significant; for example, mean hydraulic conductivity at Site 2 is 2.8 x 10 -4 cm/sec.

X1: Bail Test 1 (cm/sec)

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.000152	.0000919	.0000184	8.4526137E-9	60.4788062	25
Minimum:	Maximum:	Range:	Sum:	Sum Squared:	# Missing:
.0000374	.0004223	.0003849	.0038004	.0000008	34
# < 10th %:	10th %:	25th %:	50th %:	75th %:	90th %:
2	.0000501	.0000858	.0001354	.0002095	.0002703
# > 90th %:	Mode:	Geo. Mean:	Har. Mean:		
2	•	.0001272	.0001047		

a.

X1: Bail test 2 (cm/sec)

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.0001429	.0001067	.0000209	1.1383714E-8	74.6454671	26
Minimum:	Maximum:	Range:	Sum:	Sum Squared:	# Missing:
.000043	.0004954	.0004524	.0037163	.0000008	33
# < 10th %:	10th %:	25th %:	50th %:	75th %:	90th %:
3	.0000637	.0000726	.0000936	.0001849	.0002716
# > 90th %:	Mode:	Geo. Mean:	Har. Mean:		
3	•	.0001161	.0000986		

b.

Table 2. These tables summarize the large-scale (3-m displacement) piezometer tests at Site 1 (a.) and Site 2 (b.). All values of hydraulic conductivity are in cm/sec. Note the relatively small variance, shown graphically in Figures 9a and 9b. Extra digits on conductivity values are not significant; for example, mean hydraulic conductivity at Site 2 is 1.4 x 10 -4 cm/sec.

X1: Pump test 1 (cm/sec)

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.0004606	.0001592	.0000318	2.5337513E-8	34.557884	25
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum Squared:**	**# Missing:**
.0002274	.0008128	.0005855	.0115153	.0000059	34
# < 10th %:	**10th %:**	**25th %:**	**50th %:**	**75th %:**	**90th %:**
2	.0002324	.0003432	.0004634	.0006058	.0006503
# > 90th %:	**Mode:**	**Geo. Mean:**	**Har. Mean:**		
2	•	.0004325	.0004035		

a.

X1: Pump test 2 (cm/sec)

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
.0002895	.0001353	.0000303	1.8305561E-8	46.7379941	20
Minimum:	**Maximum:**	**Range:**	**Sum:**	**Sum Squared:**	**# Missing:**
.0001239	.0006391	.0005152	.0057896	.000002	39
# < 10th %:	**10th %:**	**25th %:**	**50th %:**	**75th %:**	**90th %:**
2	.0001443	.0001852	.0002673	.0003634	.0004674
# > 90th %:	**Mode:**	**Geo. Mean:**	**Har. Mean:**		
2	•	.000262	.0002378		

b.

Table 3. These tables summarize the pumping tests at Site 1 (a.) and Site 2 (b.). All values of hydraulic conductivity are in cm/sec. Note that the mean hydraulic conductivity is larger at Site 1. Extra digits on conductivity values are not signigicant; for example, mean hydraulic conductivity at Site 2 is 2.9 x 10 -4 cm/sec.