EVALUATION OF THREE SAMPLING METHODS USED IN GRAVEL DEPOSITS

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ABSTRACT

EVALUATION OF THREE SAMPLING METHODS
USED IN GRAVEL DEPOSITS

by Thomas A. Herbert

Three sampling methods, auger boring, channeling and grab sampling are compared on the basis of their ability to detect natural variations within a gravel deposit. Auger boring has often been used for sampling when too little information has been known about the bias imparted by the method. This has led to errors in commercial evaluations by some gravel pit operators. Channeling is the accepted method for commercial sampling and grab sampling is often used by geologists for sediment sampling.

Samples from one gravel pit were examined on the basis of the size-frequency distributions for each sample to compare the three methods and assign confidence levels to each method. An analysis of variance statistical treatment of the median grain size and sorting coefficient data established that auger boring is sufficiently representative where sizes below one inch are considered. Grab samples provide a representative sample where bank exposures are available and all particle sizes are considered. Channel samples were found to be less reliable and subject to more sample error due to inconsistent sample size than either auger boring or grab sampling.

EVALUATION OF THREE SAMPLING METHODS USED IN GRAVEL DEPOSITS

By

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CHAPTER I

INTRODUCTION

Purpose

This investigation examines the variables that effect a sample of unconsolidated sand and gravel obtained by uncased auger boring, channeling, and grab sampling. The truck-mounted auger drill has been used in the past to evaluate gravel deposits but often the samples obtained were biased by unknown geological and mechanical factors. The specific problem is, therefore, to examine and compare results from several different sampling methods so that the most representative sample can be obtained and degrees of confidence assigned to other methods.

Reason for Study

The size distribution or grading and the total reserves with the boundary of a deposit are the two most important factors in a gravel deposit evaluation. Accurate reserves of a property can only be calculated after information about the natural variability among samples is determined. To do this, representative samples must be taken from the deposit, the samples analyzed by sieving, and the size distribution calculated. In order to be reasonably sure that a representative sample is being obtained, sampling along the face of a deposit should provide statistically significant differences between sample sites which, by observation, are known to be slightly different. Geological factors such as changes in stratigraphy, grading, pellicular water, and position of ground water table are a few of the more obvious factors that could reasonably be expected to influence samples from the same deposit. An understanding of comparisons and relations between samples which do detect natural variations will allow more confidence to be placed upon these sampling methods and correspondingly a better estimate of the grading and total reserves will be made.

Cased test holes provide the necessary information for an evaluation but their use is often limited because of high cost. Vertical channeling of a pit face is the accepted method but several problems occur when sampling in this manner that may affect the final evaluation to some degree. Caving of bank material, and inability to maintain a constant width and depth of channel, cause the size-frequency distribution of several adjacent samples to have a wide range in values.

Small gravel pit operators in Michigan have indicated a need for a rapid, inexpensive method of property evaluation. Uncased auger boring can be used for such evaluations if its limitations are known. This study examines the uncased auger boring method of sampling with regard to the factors that bias an auger sample and the ability of the method to detect small scale variations within a deposit.

CHAPTER II

METHOD OF PROCEDURE

General Statement

The factor thought to contribute most to bias when sampling with the uncased auger is material selectively introduced by the drilling equipment or technique. It was thought that by studying one gravel pit with uniform overall stratigraphy and using a uniform drilling procedure, an evaluation of selectivity could be made. Channel and grab samples were taken from the pit face for comparison with the auger data to determine stratigraphic variation.

A site for the sampling study was selected at the American Aggregates Corporation gravel pit in Kalamazoo County, Michigan (Figures 1, 4 and 9). The site has essentially uniform stratigraphy and ground water conditions along the working face where the samples were obtained. Samples were obtained by auger boring; four holes at each of eight sample sites adjacent to the working face. A standardized drilling technique was used for all test holes. Two channel samples were dug from the face opposite the four bore holes at seven of the eight bore hole sites. Grab samples from a gridded sample pattern were taken in the same position as the channel (Figure 3).

Figure 1. Location of the area.

The data from three hundred mechanical analyses were used to plot cumulative size-frequency distribution curves. Statistical moments determined from the graphical data were then used to determine the between-site variability and the reliability of the three sampling methods. The percentage of fine aggregate or material passing the 3/8-inch sieve for each sample site was used in an attempt to relate the stratigraphic variability as indicated by the three sampling methods.

Support

This project was supported by the Michigan Department of State Highways, Research Laboratory Division, under Research Project number 63 A-21(2).

Location

The sample sites were located at the north end of the American Aggregates Corporation gravel pit in Cooper Township, Kalamazoo County, Michigan (Figure 1). The pit is located on the west bluff of the Kalamazoo River, T1S, R11W, Sections 9, 10, 15, and 16. This deposit was chosen because the large size of the pit provided excellent vertical exposure near the working area and approximately 1/4 mile of horizontal exposure (Figures 2 and 4).

Geology of the Deposit

The American Aggregates pit is located on an upper level fluvial terrace of the Kalamazoo River and the site

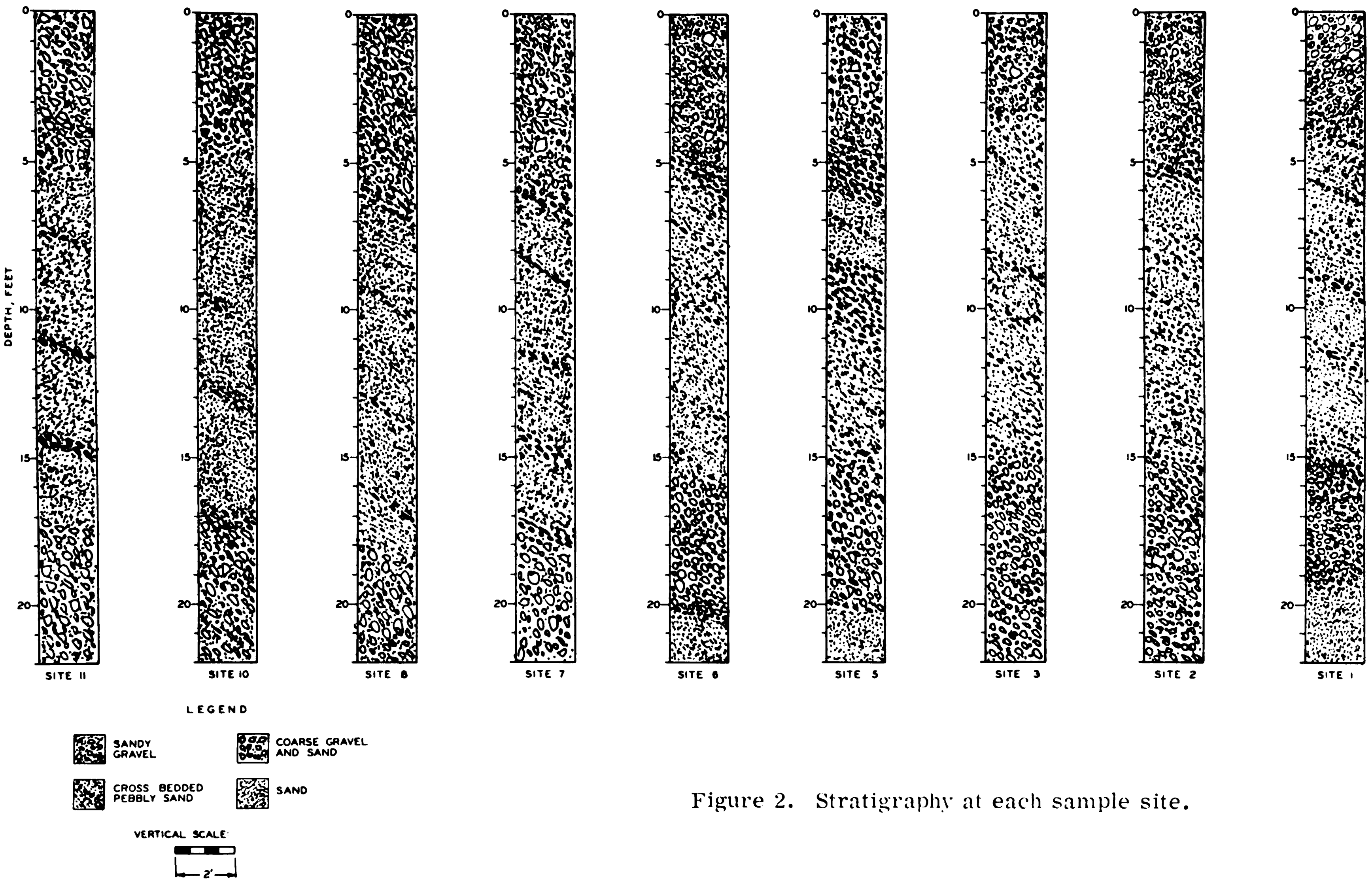

Figure 2. Stratigraphy at each sample site.

is well drained, with the water table well below the bottom of the pit. The level of the Kalamazoo River is approximately 100 feet below the bottom of the pit. Approximately eighty feet of vertical exposure is found along the 1/4 mile of pit face and below the sandy clay loam soil horizon which has been stripped off as overburden because of its high clay content. There are four strata exposed in the working area where the sample sites were located; they are, from top to bottom:

Bed 1--4 feet to 6 feet of cobbles, pebbles, and sand, cross-bedded at the bottom, transitional into Bed 2.

Bed 2--10 feet to 16 feet of cross-bedded coarse sand, with a few pebbles and cobbles.

Bed 3--4 feet to 6 feet of cross-bedded cobbles and pebbles, well sorted.

Bed 4--40 feet to 60 feet of well sorted, medium to fine sand extending to bottom of pit (not included in samples) (See Figures 2, 9, Appendix 1 and 2).
All textural terms are based on the Wentworth grade scale.

Sampling Methods Used in Property Evaluation

The most common sampling methods for property evaluation or commercial sampling are vertical channeling and test holes. The test holes and channeling methods may be used together or separately to obtain a sample. Two engineering oriented publications, the Concrete Manual and the Am. Soc. for Testing Materials (ASTM) Standards could be considered the "handbooks" for commercial sampling. Neither publication, however, makes reference to the geological, mechanical, and statistical problems involved in commercial sampling.

The ASTM Standard states, for example, with regard to the channeling methods: ". . . the sample shall be taken by channeling the face vertically, bottom to top, so that it will be representative of the material proposed to be used." The ASTM Standard states further that test holes, presumably cased or uncased, "shall be drilled or excavated to determine the quality and extent of the material." And with regard to correlation between test holes and bank face samples, the ASTM Standard states:

> Separate samples shall be obtained from the face of the bank and from test holes, in the manner described above, and if visual inspection* indicates that there is considerable variation in the material, individual samples shall be selected to represent the material in each well-defined stratum. If the deposit being investigated does not have an open face, samples shall be obtained entirely from test holes.

The statement "visual inspection" is indefinite and is an unreliable method of estimating size gradation where, for example, rigid aggregate specifications are to be met.

For the past 40 years geologists have studied sediment sampling techniques. The most troublesome and most frequently encountered problem is how to take a representative sample. Cochran (1963, p. 1) in his introduction expresses

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*Writer's underline.

the problem simply,

> . . . when the material is far from uniform, as is often the case, the method by which the sample is obtained is critical, and the study of techniques that ensure a trustworthy sample becomes important.

Otto (1938) considers the aim of the engineering (commercial) sample to be that of obtaining a representative or average sample. He further states that a regular sampling pattern must be established to eliminate personal bias. "Visual inspection" as prescribed by the ASTM Standards has a high degree of personal bias and for commercial evaluation this method is not sufficiently reliable.

Several authors have used rigorous statistical methods to compare various sampling techniques. Kurk (1941) compared the use of the spot sample to that of a channel sample in the mechanical analysis of a series of glacio-fluvial deposits. He concluded for the spot sampling method that the unweighted average of the mean particle sizes of individual beds did not give a representative sample of the entire series and should not be used for commercial sampling.

Steinmetz (1957, 1962), compared three methods of sampling, sedimentation unit samples, grid-spot samples, and channel samples, in a study of quartzose pebbles from unstratified, poorly stratified and well stratified deposits. After rigorous statistical treatment of the data Steinmetz (1957, pp. 84-85), concluded that "well-bedded deposits are most effectively sampled by sedimentational unit, unbedded deposits by channel or grid samples, and poorly-bedded gravel deposits by grid samples."

Two sampling methods were used to determine an approximation of the size frequency distribution in the deposit. Channel samples taken according to ASTM procedures, and grab samples taken on a modified grid pattern, as suggested by Steinmetz (1957, 1962), were used for comparison to determine the size distribution and the sedimentational trends within the deposit. Auger samples were then compared to both the channel and grab sample methods in an attempt to determine how well the auger method detects natural variations within the deposit.

Channel Method

Channel samples were obtained at seven sites along the near vertical face at the American Aggregates deposit. Sites number 1, 2, 3, 5, 6, 7, and 8 were sampled by the channel method, sites 10 and 11 were not sampled by the channel method because of frozen ground conditions. Two channels were excavated at each sample site with a separation between them of from four feet to eight feet (Figures 3 and 9). Samples were not obtained at sites 4 and 9 because caving removed vertical exposures.

The ASTM method of bottom to top vertical channeling was used. The sampler was supported on the steep face by a canvas sling attached by steel cable to a truck-mounted

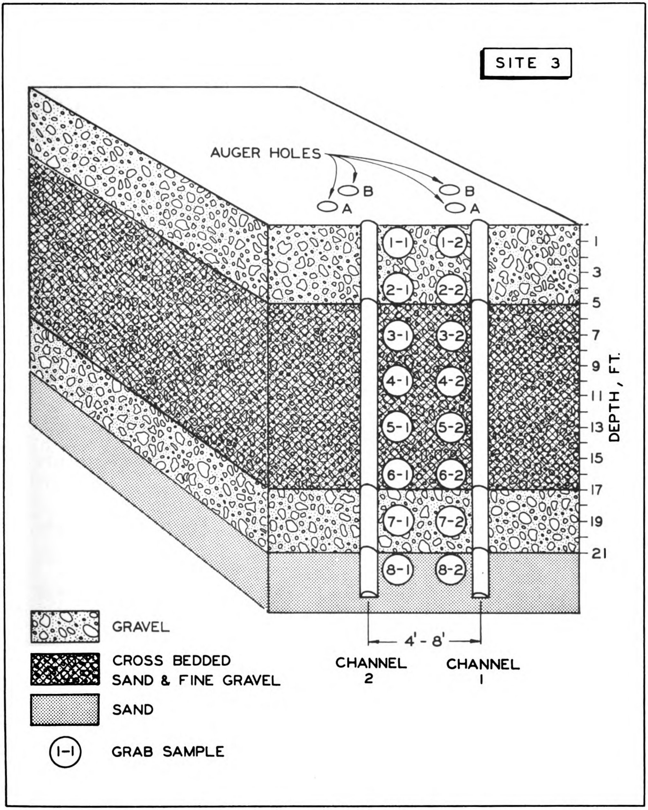


Figure 3. Sampling positions for each method.

winch. The pit face was divided into three foot vertical increments by positioning a measuring tape against the face. Each three foot increment was sampled by digging an eight-inch wide by four-inch deep channel or strip. The material from each three foot interval was placed in a 16- by 26-inch canvas bag. Approximately 50 to 60 lbs. of material was obtained for each three feet of vertical slope distance.

Since stratigraphic variation was apparent over the short distance between the two channels at one site, the "sample" was considered to be the entire amount of material removed from one 8-inch by 4-inch by 21-feet excavation. However, the samples were analyzed on the basis of the individual bags, seven for each channel, and then combined arithmetically.

The problems encountered in field sampling by the channel method were numerous, and the wide range in the final size-frequency distributions is probably due, to a great extent, to these factors, since the other sampling methods detected no measurable variation between samples at one site. The most difficult problem is to properly weight the sample both by bulk weight and volume so that the sedimentary units are sampled proportional to their thickness. To do this a uniform depth and width of channel must be maintained. However, the sampler can estimate the volume of material by filling identical sample bags to the same depth each time. Uniform channel width and depth can be maintained fairly well as long as the bank does not cave, but when caving occurs, the reference channel is usually destroyed. If the channel is destroyed due to caving sampling can be resumed if careful note is kept of the reference measuring tape.

Grab Method

Krumbein and Graybill (1966) define a grab sample as a relatively small fixed volume of material. Grab samples are usually taken from a grid in either a regular or random pattern and may be either single or nested samples. The selection of the sampling plan is usually determined by the complexity of the deposit and the information desired.

Grab samples, in this study, were obtained from a regular, nested grid sampling plan. The sampling plan is illustrated in Figure 3. Two samples were taken at eight vertical positions at each of eight sample sites, a total of 128 individual samples were obtained from the eight sites. Site 1 was not sampled because caving caused the lower portions of the face to be covered with talus material.

The regular grid pattern was used so that the grab samples would be adjacent to the channels in order to compare grab and channel samples. The nested, two-sample design was used to check the small-scale variations between two samples taken from the same vertical position.

The position of the eight vertical samples was determined by the thickness of the sedimentation unit at the sample site. In order to weight the samples correctly as to the thickness of each sedimentation unit, a steel measuring tape measure was positioned normal to the beds. The 22 foot mark was positioned at the pit edge and the samples were taken at the 21, 18, 15, 12, 9, 6, 3, and 0 marks on the tape. This happened to coincide with at least two sample positions for each stratigraphic unit, both samples were of approximately the same bulk weight. The samples were placed in 8- by 16-inch canvas bags and the bags marked as to site, position and sample number (Figure 3).

Sampling by sedimentation unit allowed the data to be used in two ways. First, the nested samples allowed the small scale variations to be assessed. In other words two samples taken from a small unit volume, repeated 64 times, gave sufficient data for statistical analysis. Secondly, the sedimentation unit data were combined arithmetically for comparison with the channel and auger results.

Two problems were apparent when sampling by this method. The proper weighting of material for each unit was again a problem as it was in the channel method. However, close attention to the positioning of the tape measure and the uniformity in bulk sample weight reduced this problem. The sampling phase of the study was done in late December and frozen ground conditions affected the sampling program. Sample error was probably increased where it was difficult to obtain samples at the correct vertical position due to frozen ground conditions.

Auger Method

Opposite each channel position two auger holes were bored and a portion of the material brought to the surface was taken as the sample. A total of 36 bore holes were drilled to a depth of 21 feet. Site 7 was drilled, but an error in the marking of the individual bags made the sample unusable. Figure 3 illustrates the relation between auger holes and the grab samples and channels.

The auger boring equipment and operator were furnished by the Department of State Highways, Soils Division, District 7. The drilling rig, a Mobile Drill Model B-52 (Figure 8) was mounted on a four-wheel drive truck which gave the unit a high degree of mobility. Standard 6-inch diameter construction augers were used. Each auger section has an actual diameter of 5-1/2 inches, a pitch of 5 inches, and a length of 5 feet.

Two different methods of auger boring may be used with the same drilling equipment. The lift recovery method* which was used in this study enables loose material to be brought to the surface on the continuous flutes or "twist" of the auger tool by lifting the auger string from

*Names used by this writer to differentiate two drilling techniques that may be used with the same equipment.

the hole. The sample can be removed as material is brought to the surface. The spin recovery method* uses the spinning or augering action of the auger tool to bring material to the surface. This method is commonly used where qualitative subsurface information is required.

The drilling started when the drilling rig was positioned over a predetermined drilling site and the first section of auger was connected to the spindle. The auger sections were drilled into the ground by a combination of spindle rotation and hydraulic ram feed supplied by two cylinders mounted on the mast. Five sections of auger were advanced into the ground to a depth of 21 feet at the slowest possible feed rate. The normal, slow hydraulic feed rate is 14 feet-per-minute, but this was reduced even more by frequent disengagement of the clutch mechanism. The slow feed rate was used to minimize disruption of the material (Figure 5). When a depth of 21 feet was reached, the auger string was lifted slowly from the hole and the material adhering to the auger flutes was removed. A sample was removed from this material and put into canvas sample bags (Figure 6).

Because the sample was mixed to some degree by the augering action and no clear-cut sedimentation unit boundaries were observed, no attempt was made to separate the sedimentation units.

An additional sampling technique was attempted in the beginning of the study. This involved advancing the auger five feet at a time and then removing the auger string and obtaining the sample. This technique proved to be too slow and caused enlargement and caving of the hole.

It was expected that most of the errors using the auger method would be due to size selectivity caused by the physical dimensions of the auger tool. For example, the larger diameter particles would either be pushed aside by the drilling action or simply left in the ground because their diameters were greater than the flute width of the auger tool. No doubt this is a factor but, unfortunately, these effects were masked by another factor which was somewhat expected. Each auger hole had at least three to five feet of auger penetration into Bed 3, a well-sorted coarse gravel. As the auger was being lifted from the hole mechanical vibrations, caused by the lifting operation, dislodged a portion of this coarse material (Figure 7).

The loss of this portion of the sample was probably the main source of error among the four auger holes at any one site. It was observed that the amount of material lost from the bottom of the auger string was not the same each time. At two adjacent auger holes, where there was a small amount of material dislodged, size-frequency distributions were remarkably similar. Sample Site 1 was unusual in that little material was lost by dislodgement; correspondingly the percentage of fine aggregate values (the statistic used for comparison among the sampling methods) had a range of only 0.4 per cent. At sites where sample loss was not uniform, the range was as much as 7.0 per cent.

Cased test holes, as a matter of reference, are excavated by first driving a steel casing into the ground and then either augering or bailing the material from within the casing.

Figure 4. View of the gravel pit face.

Figure 5. Drilling first auger section into the ground.

Figure 6. Sampling from the auger tool.

Figure 7. Sample loss from the bottom auger section.

Figure 8. Auger boring next to the pit face.

Figure 9. Pit face stratigraphy and two channels.

CHAPTER III

LABORATORY ANALYSIS

The laboratory phase of this project involved a total of 600 sieve analyses; 300 each for material larger and smaller than 3/8 inch diameter. The samples were brought in from the field and allowed to air dry for three weeks. At the end of this time, the moisture content was checked against the oven dry weights and was less than 2 per cent by weight. The field moisture content was from eight to twelve per cent.

Analysis of the Channel and Auger Samples

Both the channel and auger samples were 300-400 lbs. in size. A composite sample this large cannot be sieved at one time. In order to avoid splitting the sample and introducing possible errors in the large size fraction (the ASTM Standard suggests 300 lbs. of sample for 3-inch diameter maximum size) each bag was sieved separately and the results combined arithmetically.

Each bag, representing three feet of vertical exposure, was first sieved through the 2-, 1 1/2-, 1-, 3/4-, 1/2-, and 3/8-inch screens. The material passing the 3/8-inch screen (the fine aggregate) was then split to from 400 to 800 grams (1 to 2 lbs.) for fine sieve analysis (Figure 10). The fine screens included the U. S. Standard Numbers 5, 10, 18, 35, 60 and 120 which correspond to -2, -1, 1, 2, and 3 units on the Phi Scale. This allowed the cumulative size-frequency distributions to be plotted on rectangular coordinate paper. The statistical moments were then taken from the frequency curves directly in phi units.

Analysis of the Grab Samples

The grab samples ranged in weight from 3000-4000 grams (6 to 10 lbs.). A slightly different mechanical analysis procedure was used due to the smaller sample size. The coarse fraction was separated by hand sieving through 10-inch diameter sieves. Then the fine fraction was split to 400-800 grams (1 to 2 lbs.) and sieved in the same manner as the channel and auger samples (Figure 10).

CHAPTER IV

DATA REDUCTION

Mechanical analysis data provides quantitative information about the size distributions or grading within a sample. In order to proceed from raw data to refined data which could be used in statistical comparisons, weight percentages were calculated. The Michigan Department of State Highways (MDSH) computer facilities were used in all calculations except for the analysis of variance routine which was run at Michigan State University.

In order to examine the selectivity factors of size and mechanical dislodgement in the auger boring method; the mechanical analysis data were treated by calculating weight percentages for the samples in the following five ways:

1. A complete distribution for the twelve sieve sizes from 2 inches to .0049 inches with the plus 3/8 inch and minus 3/8 inch percentages adjusted to plot on the same frequency curve.

2. A size-frequency distribution for the minus 3/8 inch sizes only to eliminate bias due to oversize material not included in the auger samples.

3. Complete adjusted distributions with 2 inch size deleted from calculations.

4. Complete adjusted distributions with 2 inch and 1-1/2 inch sizes deleted.

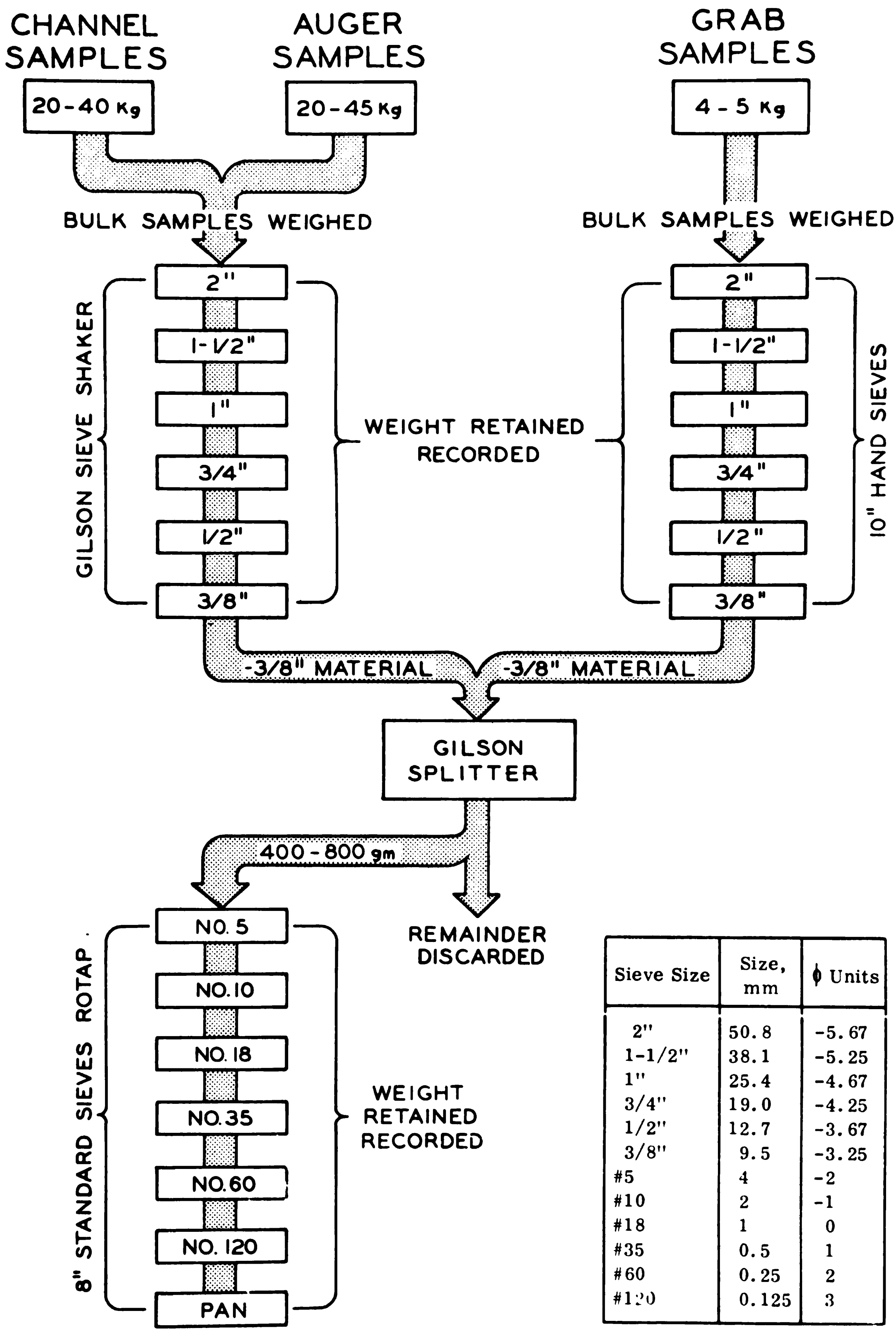
5. Complete adjusted distributions with 2 inch, 1-1/2 inch and 1 inch sizes deleted.

According to Krumbein and Pettijohn (1938) perhaps the most important statistical measure is that of central tendency. Measures of central tendency would include such diverse measures as the arithmetic mean size, median size, modal size, and the geometric mean size. The most readily available of these, at least from the cumulative frequency curves, is the median size.

The first step in data reduction and analysis was to plot size-frequency distribution curves for the minus 3/8 inch data from the three sampling methods. An inspection of the complete distributions from 2 inches to .0049 inches indicated that the minus 3/8 inch data were the most readily used sizes for statistical comparisons. The minus 3/8 inch fraction was used for convenience because the two stage sieving procedure gave a natural division point. Inspection of the data indicates that sizes up to 1 inch could have been used without increasing sample error.

Quartile moments which correspond to the Y intercepts at the 25 per cent (Q_1), 50 per cent (Q_2), and 75 per cent (Q_3) levels were obtained from the minus 3/8 inch cumulative size-frequency curves. Figure 11 depicts the size-frequency distributions for four auger holes at Site 1 (selected as being a representative example).

The median grain size in phi units are expressed. The arithmetic mean of the four median size values (Q_2) is 0.42 phi while the standard deviation is 0.07 phi units. Figure 11 shows the two channel samples from site at site 1. The median grain sizes are 0.18 phi and 0.43 phi, respectively, while the mean is 0.30 phi. This compares well with the 0.42 mean value of the auger samples at the same site. In general the three sample methods gave similar distribution curves at any one site. But the statistical treatment of the data as discussed later indicates that, while similar at one site, the three methods of sampling have a wide range in the confidence levels when natural sedimentary differences between sites are considered. The size-frequency curves at each site for the three sampling methods are included in Appendix 3.



Sieve Size	Size, mm	ϕ Units
2"	50.8	-5.67
1-1/2"	38.1	-5.25
1"	25.4	-4.67
3/4"	19.0	-4.25
1/2"	12.7	-3.67
3/8"	9.5	-3.25
#5	4	-2
#10	2	-1
#18	1	0
#35	0.5	1
#60	0.25	2
#120	0.125	3

Figure 10. Flow scheme for laboratory analysis.

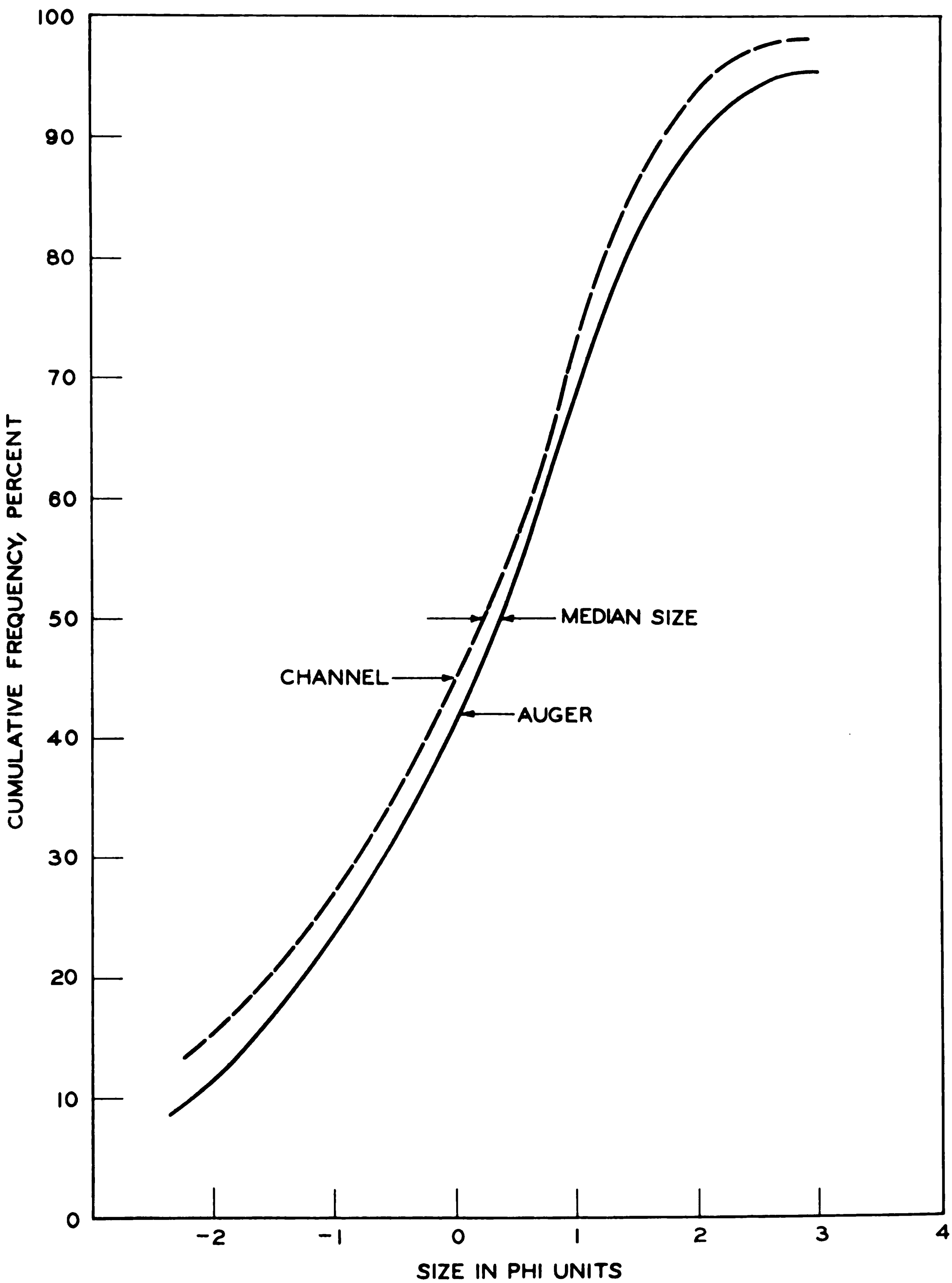


Figure 11. Two size-frequency distribution curves for the channel and auger methods at site 1, minus 3/8-in. fraction.

CHAPTER V

STATISTICAL TREATMENT OF THE DATA

Perhaps the most important and possibly the most overlooked factor in the commercial evaluation of a gravel deposit is that of stratigraphic variability. The channel method of sampling as outlined by the ASTM Standards does not give sufficient small-scale information to estimate the horizontal nor the vertical variability within the deposit. Sedimentologists often restrict the use of channeling to search sampling only, for example, when searching for a specific lithologic or fossiliferous zone in an outcrop. Combining all segments of a channel into a bulk sample for analysis as suggested by the ASTM Standards eliminates almost all the information about the vertical variation with the deposit. Individual analysis may help to locate the economic strata more easily and reliably.

In order to determine which sampling method is most reliable in detecting the stratigraphic variation within the deposit, the sample data was analyzed using an analysis of variance (AOV) computer routine. The grab sample median size data of the minus 3/8 inch fraction for vertical position at each site were fed into the computer to calculate the significance of; (1) repetition of sample, (2) vertical position, and (3) site. Both median grain size and sorting coefficient were used in the analysis of the channel and auger data. The sorting coefficient as introduced by Trask (1932) is:

$$\text{Sort Coeff} = \sqrt{\frac{Q_3}{Q_1}}$$

This was used for the auger and channel samples where less data were available and it was felt that the addition of the sorting coefficient data would provide more specific information about the shape of the frequency curves.

Analyses of Variance (AOV) of Grab Sample Data

Table 1 presents the array of grab sample median grain size data as to site, vertical position, and repetition of sample. The AOV routine was used to test the variance of position, site, and repetition of samples.

The variability among vertical positions, as would be expected from the observed stratigraphy, is highly significant at the 0.99 level (Table 2). The high significance of the interaction between site and vertical position was due to the fact that the strata were not uniform in thickness among the sampling sites.

AOV of Auger Data

The median grain size and the sorting coefficient data were used in an attempt to determine the effects of sample repetition within site and the ability of the auger and channel methods to detect between site variations (Tables 1, 2, and 3).

The analysis determined that there was no significant difference between the four auger holes within a site (Table 3). Neither the median size nor the sorting coefficient data showed significant differences between paired auger holes at any one site at the 0.95 level. The auger method, however, was effective in determining between site variability. Both the median grain size and sorting coefficient data indicated significant difference at the 0.99 level of confidence.

AOV of Channel Data

The channel method proved less reliable in detecting between site variation. Neither the median grain size data or the sorting coefficient data indicated a significant difference between sites at the 0.99 level of significance. The difference between two channels at one site was not significant. The F ratio was tested at the 0.95 level for both the median grain size data and the sorting coefficient data. The sorting coefficient data proved significant at the 0.95 level but the median grain size values were not, which indicates that the median grain size, while helpful in detecting differences among samples, provides no information about the shape of the size-distribution curve, which in turn would be related to the uniformity of the deposit. The sorting coefficient, however, gives some information about the shape of the frequency curve and thus would give additional information about the sample. The median grain size for the fourteen channels probably did not provide sufficient data to detect differences between sites. The increase in information about the sample sites using the sorting coefficient showed significant difference between sites at the 0.95 level.

Examination of the Factors Which Bias Auger Samples

In order to evaluate the auger boring method of sampling, the factors that contribute to bias must be examined. Two factors were thought to influence the sample: size selectivity due to the physical dimensions of the auger tool and sample loss due to mechanical vibrations during recovery of the sample. These two factors were examined by comparing the percentage of fine aggregate in the auger samples with the percentage of fine aggregate for the channel and grab samples.

In order to study the effects of size selectivity and sample loss the original weight percentages were recalculated deleting the larger sizes of material (2 inch and 1-1/2 inch) from the channel samples and the calculated composite grab samples. Positions 7 and 8 used in the calculation of the composite grab sample were deleted and the weight percentages were recalculated. Table 4 lists the comparisons between methods of sampling.

It was thought that if the average percentages for the recalculated channel and composite grab samples approached the values obtained for the auger samples, there would be an indication of the degree of bias imparted to the auger samples by the two factors of sample loss and size selectivity. The thirty-two auger holes had an average value of 88.5 per cent fine aggregate (minus 3/8 inch) while the fourteen channel samples averaged 77.6 per cent and the calculated composite of the grab samples averaged 80.6 per cent. The minus 3/8 inch percentage was calculated from the cased test hole data supplied by the American Aggregates Corporation and was found to be 80.6 per cent fine aggregate for five test holes located in and around the sample area for this study.

The recalculated average values for the channel method with the 2 inch and the combined 2 inch and 1-1/2 inch sizes deleted increased to 82.7 per cent and 84.0 per cent, respectively (Table 4). The channel samples included the lower three to four feet of coarse gravel which was lost in part with auger boring. The 1 inch size pebbles were not included in the deletion and recalculation procedure. It is possible that a portion of the 1 inch size was also selectively "missed" by the auger tool so that the 84.0 per cent value for 2 inch and 1-1/2 inch deleted would be increased even more, approaching the 88.5 per cent value of the auger samples.

The calculated composite grab samples were also used to reconstruct and examine the selectivity of the auger method. The average composite grab sample fine aggregate percentage, was 80.6 per cent, which is in agreement with the 77.6 per cent value of the channel method and the 80.6 per cent value of the cased test hole samples. Deletion of vertical positions 7 and 8, which were from the coarse gravel horizon, increased the percentage of fine aggregate to 83.1 per cent. The additional deletion of the 2 inch size and 2 inch and 1-1/2 sizes combined produced values of 84.5 per cent and 85.4 per cent, respectively (Table 4).

The fine aggregate percentages for the channel and grab sample methods approach the auger value to within four per cent which is still a significant value. The four per cent difference possibly can be explained by the fact that the horizontal distance between the samples taken from the bank-face and the channels were only approximately eight feet apart at the edge of the pit, but due to the slope of the pit face, the bottom of the channel and the bottom of the auger holes were up to 20 feet apart. It was shown from the analysis of variance that sites were significantly different while the between sample differences at one site were insignificant. However, when considering the four per cent difference in fine aggregate between the auger samples and the channel and composite grab samples, it must be noted that the separation between the auger holes and the channel was often as great as between sample sites. If there is a significant difference between sample sites 25 to 30 feet apart, it would be reasonable to assume that there might be significant difference between the auger and channel samples separated by 10 to 20 feet.

While the normal pit variation explains the differences to some degree there are no doubt additional variables which cannot be attributed to any one factor. The sample error among all the samples is dependent not only on the natural variation but also on the personal bias involved when sampling by either of the three methods.

TABLE 1
MEDIAN GRAIN SIZE DATA FOR GRAB SAMPLES
AT EACH SITE AND POSITION, MINUS 3/8-IN. FRACTION,
EXPRESSED IN PHI UNITS

Position No.	Sample Site							
	11	10	8	7	6	5	3	2
1	-0.71 -0.87	-1.27 -1.08	-1.57 -1.43	-0.28 -0.40	-0.85 -1.04	-0.81 -0.69	-0.98 -0.94	-0.7 -1.0
2	0.08 0.34	-0.19 -0.38	0.42 0.38	-1.82 -1.77	-1.11 -1.40	-1.76 -1.77	0.76 0.53	0.00 0.18
3	-0.44 -0.32	-0.01 0.07	-1.63 -1.51	-0.14 -0.05	-0.58 -0.59	1.62 1.63	0.77 0.92	0.90 0.92
4	0.14 0.16	0.06 0.09	0.51 0.46	-0.13 -0.19	0.08 0.07	0.30 0.39	-0.03 0.03	0.82 0.66
5	0.23 0.21	0.84 0.90	-0.10 -0.32	-0.27 -0.57	-0.14 0.02	-0.72 -0.62	0.78 0.82	0.90 0.95
6	0.30 0.78	0.93 1.00	0.26 0.57	0.59 0.19	0.78 0.66	1.03 1.51	0.61 0.58	0.32 0.53
7	-0.83 -0.63	-1.32 -1.23	0.59 0.60	-1.14 -1.14	-0.33 -0.27	0.36 -0.20	-1.97 -1.99	-1.80 -1.88
8	-1.78 -1.90	-0.68 -0.76	-1.14 -0.96	-0.48 -0.21	0.60 0.74	1.87 1.83	-1.92 -1.94	-1.50 -1.60

TABLE 2
AOV RESULTS FOR THE GRAB SAMPLE MEDIAN
GRAIN SIZE DATA, MINUS 3/8-IN. FRACTION

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Position	33.71503393	6	5.61917232	320.9 (2)
Site	3.63913929	7	0.51987704	29.7 (2)
Position x Site	45.32912321	42	1.07926484	61.6 (2)
Repetition of Samples (1)	0.00965714	1		
Position x Repetition (1)	0.08910536	6		
Site x Repetition (1)	0.13517143	7	0.01751 (3)	
Position x Site x Repetition (1)	0.74696607	42		
Remaining Error	0.00000001	0		

(1) Effects pooled for error estimate

(2) Significant at 0.99 level

(3) Mean square error

TABLE 3
AOV RESULTS FOR THE SORTING COEFFICIENTS AND MEDIAN GRAIN SIZE DATA FOR THE CHANNEL AND AUGER METHODS, MINUS 3/8-IN. FRACTION

		Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio
Median Grain Size	Auger Method	Hole	0.08623	3	0.02874	1.9314(1)
		Site	2.22480	7	0.31783	21.3595(2)
		Hole x Site	0.31253	21	0.01488	----
		TOTAL	2.62355	31		
	Channel Method	Channel	0.02161	1	0.02161	0.8511(1)
		Site	0.37337	6	0.06223	2.4510(1)
		Channel x Site	0.15234	6	0.02539	----
		TOTAL	0.54732	13		
Sorting Coefficient	Auger Method	Hole	0.05294	3	0.01765	1.6016(1)
		Site	1.25954	7	0.17993	16.3276(2)
		Hole x Site	0.23151	21	0.01102	----
		TOTAL	1.54399	31		
	Channel Method	Channel	0.01086	1	0.01086	0.3731(1)
		Site	0.90869	6	0.15145	5.2027(3)
		Channel x Site	0.17469	6	0.02911	----
		TOTAL	1.09424	13		

(1) Not significant at 0.95 level

(2) Significant at 0.99 level

(3) Significant at 0.95 level

TABLE 4

COMPARISONS BETWEEN THE THREE SAMPLING METHODS ON THE BASIS OF THE MINUS 3/8-IN. FRACTION, VALUES ARE PERCENT PASSING THE 3/8-IN. SIEVE

Sample Site	Position No. of Channels	Channel Samples	Channel Samples		Paired Auger Holes	Auger Test Holes	Position of Paired Grab Samples	Calculated Composite of Grab Samples	Calculated Composite of Grab Samples		
			2 inch Dia Deleted	1-1/2 and 2 inch Dia Deleted					7 & 8 Deleted	7 & 8 plus 2 inch Dia Deleted	7 & 8 plus 1-1/2 & 2 inch Dia Deleted
1	1	81.0	84.1	85.9	1	90.0	1	N. S.	N. S.	N. S.	N. S.
					2	89.7					
	2	81.0	86.4	88.1	1	89.6	2	N. S.	N. S.	N. S.	N. S.
					2	89.6					
2	1	83.8	89.6	90.4	1	87.6	1	86.3	86.5	87.8	88.4
					2	92.8					
	2	78.5	84.5	86.0	1	89.1	2	87.5	88.3	88.3	89.6
					2	86.5					
3	1	79.6	83.9	85.2	1	88.4	1	79.5	79.5	82.3	84.5
					2	92.9					
	2	76.1	83.4	84.0	1	89.9	2	81.2	83.0	83.7	85.1
					2	91.0					
5	1	74.2	80.3	81.3	1	87.6	1	83.2	87.4	87.4	87.8
					2	88.6					
	2	77.8	82.2	83.9	1	84.4	2	84.1	86.9	88.4	88.4
					2	91.4					
6	1	76.2	83.0	84.2	1	86.4	1	75.6	77.5	77.8	80.7
					2	87.7					
	2	81.9	85.5	86.4	1	85.4	2	79.3	80.3	81.5	82.6
					2	86.1					
7	1	74.7	80.6	81.5	1	N. S.	1	72.3	81.0	81.0	82.3
					2	N. S.					
	2	70.8	72.9	74.9	1	N. S.	2	74.5	81.0	81.9	81.9
					2	N. S.					
8	1	74.4	80.7	82.5	1	90.1	1	84.3	86.2	87.2	87.5
					2	89.5					
	2	77.0	81.0	82.3	1	89.8	2	84.3	87.3	88.2	88.2
					2	89.1					
10	1	N. S.	N. S.	N. S.	1	90.0	1	84.1	83.5	85.4	85.4
					2	88.8					
	2	N. S.	N. S.	N. S.	1	88.8	2	78.0	79.9	82.1	84.1
					2	83.2					
11	1	N. S.	N. S.	N. S.	1	87.3	1	78.3	80.9	84.2	85.4
					2	86.5					
	2	N. S.	N. S.	N. S.	1	85.4	2	76.8	80.5	84.5	84.5
					2	88.1					
Average Values		77.6	82.7	84.0		88.5		80.6	83.1	84.5	85.4

CHAPTER VI

CONCLUSIONS

Auger Method

Where visual inspection of a deposit is not possible, auger samples are shown to be sufficiently representative provided sizes below one inch are considered. To augment information determined from cased test holes so that the number of cased holes may be reduced the auger may be used, but again with consideration of the selective loss of the larger sizes.

Where visual inspection of the deposit is possible, auger boring provides a more representative sample for evaluating variations than the channel method and one comparable to grab sampling.

Near-surface ground water conditions, while not a factor in this study, may also limit the usefulness of the uncased auger. Saturated material from below the water table may be dislodged more easily than less moist material from above the water table. Dry conditions also may disrupt auger sampling. The best time of the year for auger boring is probably in the spring or fall when pellicular water is at a maximum.

From the results of this study it can be concluded that the lift-recovery auger boring method of sampling can be used effectively in situations where the stratigraphy is simple and the ground water table is below the sampling level. It should be realized that the uncased auger method of sampling is limited in the depth from which the auger can lift material. The Mobile Drill, Model B-52, with the 6-inch diameter auger was effective in drilling to a depth of only approximately 25 feet through the four strata found at the sample site. The maximum depth to which the lift-recovery method is effective is limited by the diameter of the auger and the lifting capacity of the drilling rig. At this time no information is available with regards to other combinations of auger diameters and lifting capacities, and the effective drilling depth.

Channel Method

The channel method of sampling provides useful information about the grading or size distribution within a deposit. However, the difficulties involved in excavating the actual channels tend to bias the small size sample to a greater degree than with other sampling methods. Bank caving and inconsistent sample volume lead to greater sample error.

Grab Method

The sedimentation unit method of sampling (the grab sample method as it happened in this study) is as reliable as the auger method in the ability to detect variation within the deposit. The total amount of time involved in any economic evaluation would be important not only for the recipient of the study in terms of cost but also in terms of efficiency of the method. The grab sample method provides a sample much smaller in size, eliminating extra handling while providing more valuable information about the deposit with correspondingly reduced sample error as shown by Steinmetz (1957, 1961).

Future Study

On the basis of previous work done in the field of sediment sampling, and the results of this study, an alternate method of commercial sampling from pit face exposures is suggested. The sedimentation unit method of sampling is not new as it was first stated by both Otto (1938) and Apfel (1938).

The sedimentation unit composite sample would be made up of equal spot or grab samples from each sedimentary unit which would contain the specific information about the unit; equally weighted samples, when combined proportionally to thickness of the units would give deposit grade and total reserves.

The sedimentation unit method requires more initial preparation before sampling than does the channel method but the total time involved is less. The first step is to correctly measure the thickness of each sedimentary unit at the exposure. Next, determine the ratio of the unit thicknesses. Then, take a number of samples from each unit equal to the ratio number. For example, if a three unit exposure had strata five feet, six feet, and seven feet thick, than the ratio would be 5:6:7 and five, siz, and seven equal volume sample would be taken, respectively. Each sample would be small in size, 8 to 10 lbs. and the composite would weigh approximately half as much as a channel sample at the same location. Combined samples from one unit would be analyzed separately for the within unit information and the data from several units combined into a composite.

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APPENDIX 1

AUGER HOLE LOGS

Hole Number	Depth (Ft.)	Description
A 1-1a	0-7	Cobbles, pebbles, coarse sand with some clay
	7-12	Sand with some pebbles
	12-19	Pebbly sand
	19-21	No sample
A 1-1b	0-7	Cobbles, pebbles, coarse sand with some clay
	7-13	Sand, few pebbles
	13-19	Pebbly sand
	19-21	No sample
A 1-2a	0-4	Cobbles, pebbles, coarse sand clay
	4-12	Pebbles, coarse sand
	12-17	Coarse sand, few cobbles, pebbles
	17-22	Coarse sand, few cobbles, pebbles
A 1-2b	0-4	Cobbles, pebbles, coarse sand clay
	4-12	Pebbly coarse sand
	12-22	Coarse sand, cobbles, pebbles
A 2-1a	0-2	Pebbles, sand, clay
	2-7	Pebbly sand
	7-12	Pebbly sand
	12-17	Sand, few pebbles
	17-22	Pebbles, sand
A 2-1b	0-4	Cobbles, Pebbles, sand, clay
	4-12	Sand, pebbles
	12-17	Coarse sand, few pebbles
	17-22	Coarse sand, cobbles

Hole Number	Depth (Ft.)	Description
A 2-2a	0-2	Pebbles, sand, some clay
	2-7	Pebbly sand, grading to coarse sand
	7-12	Sand, grading to coarse sand
	12-17	Coarse sand, pebbles
	17-22	Coarse gravel, sand
A 2-2b	0-2	Cobbles, pebbles, coarse sand clay
	2-7	Pebbles, grading to coarse sand
	7-12	Med. sand, grading to coarse sand
	12-17	Coarse sand, pebbles
	17-22	Coarse pebbly sand
A 3-1a	0-2	Cobbles, pebbles, sand and clay
	2-8	Pebbly sand, grading to coarse sand
	9-16	Coarse sand and pebbles
	17-22	Coarse pebbly sand
A 3-1b	0-2	Cobbles, pebbles, sand and clay
	2-8	Pebbly sand, grading to coarse sand
	9-16	Coarse sand and pebbles
	17-22	Coarse pebbly sand
A 3-2a	0-3	Cobbles, pebbles, sand, clay
	4-10	Pebbly sand, coarse sand
	11-16	Coarse sand and pebbles
	17-21	Coarse pebbly sand
A 3-2b	0-3	Cobbles, pebbles, sand, clay
	4-10	Pebbly sand, coarse sand
	11-16	Pebbles, coarse sand
	17-21	Coarse pebbly sand, cobbles
A 5-1a	0-5	Cobbles, sand
	5-13	Coarse sand to ten feet, then fine sand
	13-18	Fine sand
	18-20	Cobbles, pebbles, sand
	20-21	No sample

Hole Number	Depth (Ft.)	Description
A 5-1b	0-5	Pebbles, sand, clay, few cobbles
	5-13	Coarse sand to ten feet
	13-18	Pebbly sand
	18-20	Cobbles, pebbles, coarse sand
	20-21	No sample
A 5-2a	0-2	Pebbles, sand, few cobbles
	2-12	Pebbly sand
	12-14	Pebbly sand
	14-20	Coarse pebbles and sand
	20-21	No sample
A 5-2b	0-4	Pebbles, sand and clay
	4-8	Pebbly sand
	8-10	Pebbly sand
	10-13	Pebbly sand
	13-16	Coarse sand
	16-20	Pebbly sand with cobbles
	20-21	No sample
A 6-1a	0-5	Cobbles, pebbles, sand and clay
	5-6	Block clay
	6-10	Pebbly sand, grading to coarse sand at eight feet
	10-13	Coarse sand, grading to pebbly sand
	13-18	Coarse sand, some cobbles after sixteen feet
	18-21	No sample
A 6-1b	0-4	Cobbles, pebbles, coarse sand and clay
	4-5	Block clay
	6-8	Six inch sand at eight feet, sand
	8-12	Pebbly sand
	12-18	Pebbly sand
	18-21	Pebbly sand, cobbles
A 6-2a	0-4	Cobbles, pebbles, coarse sand clay
	4-5	Block clay
	5-9	Pebbly sand, grading to fine
	9-13	Pebbly sand, few cobbles at thirteen feet
	13-18	Pebbly sand, cobbles some large
	18-21	No sample

Hole Number	Depth (Ft.)	Description
A 6-2b	0-4	Cobbles, pebbles, coarse sand clay
	4-5	Block clay
	5-9	Sandy gravel, grading to fine
	9-13	Pebbly sand, few cobbles at thirteen feet
	13-18	Coarse sand and pebbles, cobbles after sixteen feet
	18-21	No sample
A 7-1a	0-4	Pebbles, sand, clay
	4-12	Coarse sand, pebbles
	12-14	Coarse sand, pebbles
	14-20	Cobbles, pebbles, sand
	20-21	No sample
A 7-1b	0-3	Pebbles, sand, and clay
	3-13	Sand and fine gravel
	13-16	Grading to coarse sand
	16-20	Cobbles, gravel
	20-21	No sample
A 7-2a	0-3	Pebbles, sand, clay
	3-12	Pebbly sand
	12-16	Coarse sand and pebbles
	16-18	Pebbly sand
	18-20	Cobbles, pebbles, sand
	20-21	No sample
A 7-2b	0-3	Pebbles, sand, clay
	3-14	Pebbly sand
	14-17	Coarse sand
	17-20	Cobbles, gravel, sand
	20-21	No sample
A 8-1a	0-8	Cobbles, pebbles, coarse sand clay
	8-11	Pebbly sand
	11-12	Sand, some coal pebbles
	12-18	Pebbly sand, grading to coarse sand
	18-20	Gravel, cobbles
	20-21	No sample

Hole Number	Depth (Ft.)	Description
A 8-1b	0-5	Cobbles, pebbles, sand, clay
	5-15	Sand, grading to coarse sand and pebbly sand
	15-18	Pebbly sand
	18-20	Cobbles and pebbles
	20-21	No sample
A 8-2a	0-6	Pebbles, sand, grading to coarse sand, pebbly sand
	6-15	Pebbly sand
	15-20	Cobbles and pebbles
	20-21	No sample
A 8-2b	0-5	Cobbles, pebbles, sand, clay
	5-15	Med. sand, grading to coarse sand and pebbly sand
	15-20	Pebbly sand, cobbles
	20-21	No sample
A 10-1a	0-4	Pebbles, sand, some clay
	4-8	Coarse sand, grading to med. sand and pebbly sand
	8-14	Pebbly sand
	14-20	Pebbles, cobbles, sand
	20-21	No sample
A 10-1b	0-3	Pebbles, sand, clay
	3-8	Coarse sand grading to med. sand and pebbly sand
	8-15	Pebbly sand
	15-20	Gravel, cobbles, sand
	20-21	No sample
A 10-2a	0-5	Pebbles, cobbles, sand
	5-15	Pebbly sand
	15-21	No sample, hole caved
A 10-2b	0-5	Pebbles, cobbles, sand
	5-10	Pebbly sand
	10-18	Pebbly sand
	18-21	No sample, caved
A 11-1a	0-3	Pebbles, cobbles, sand
	3-4	Coal pebbles, sand
	4-10	Pebbly sand
	10-15	Pebbly sand, cobbles
	15-21	No sample, caved

Hole Number	Depth (Ft.)	Description
A 11-1b	0-4	Pebbles, cobbles, sand
	6-14	Pebbly sand, cobbles
	14-20	Pebbly sand, cobbles
	20-21	No sample
A 11-2a	0-3	Cobbles, pebbles, coarse sand
	3-4	Coal pebbles, pebbly sand
	4-15	Pebbly sand
	15-20	Cobbles, Pebbles
	20-21	No sample
A 11-2b	0-4	Cobbles, pebbles, sand
	4-5	Coal pebbles, pebbly sand
	5-15	Pebbly sand
	15-21	Sample lost

APPENDIX 2

SITE STRATIGRAPHY

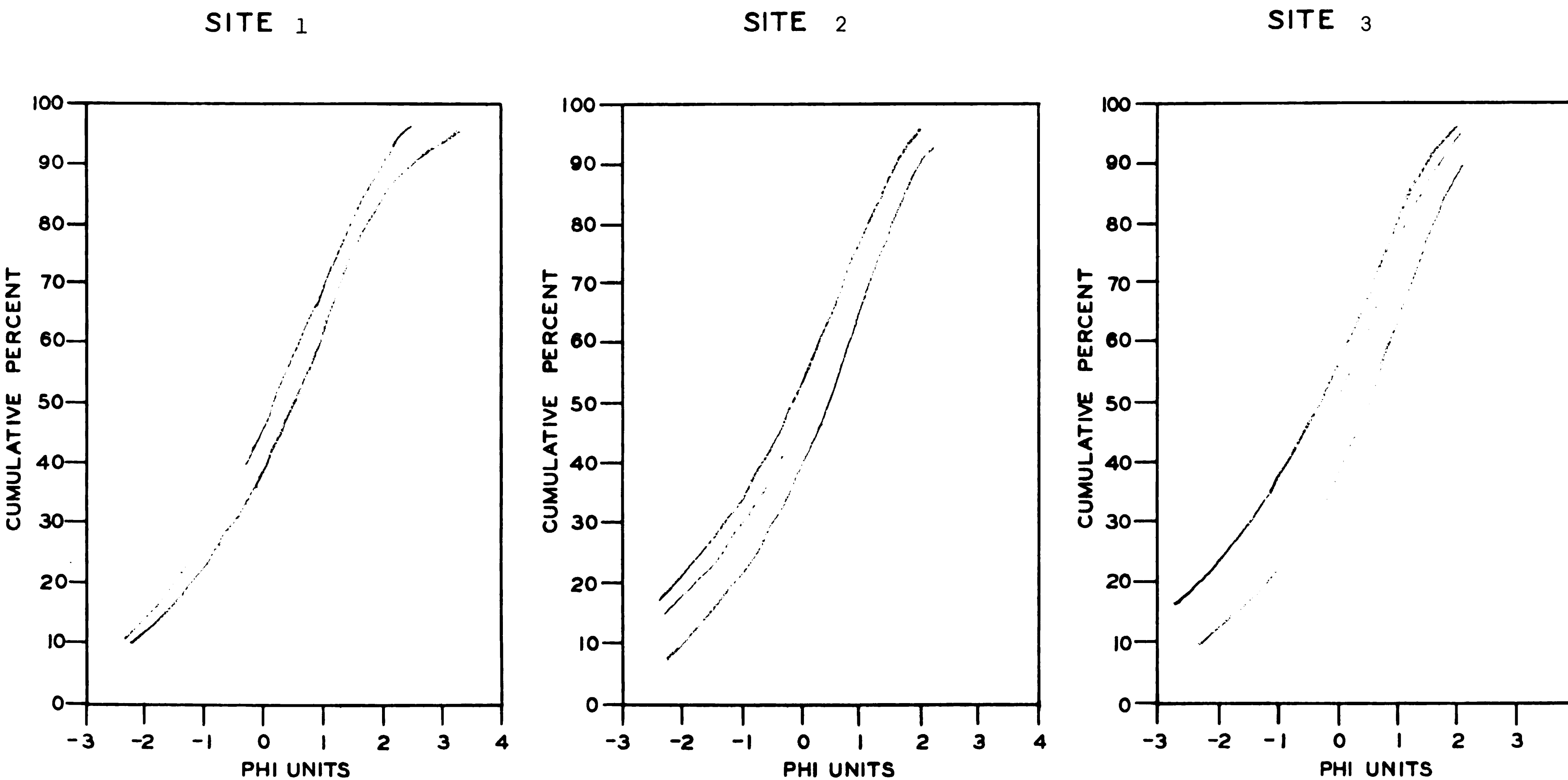
Site Number	Unit Thickness (Ft.)	Description
1	4.5	Cobbles and pebbles grading to finer material at bottom
	11.0	Cross-bedded sand, pebbles, grading to larger material at bottom
	4.0	Cobbles, pebbles and coarse sand
2	2.5	Cobbles and pebbles grading to finer material at bottom
	3.0	Cross-bedded gravel gradational into cross-bedded sand
	1.5	Fine sand
	9.0	Cross-bedded coarse sand
	7.0	Cobbles, pebbles, coarse sand
3	2.5	Cobbles, pebbles grading to finer material at bottom
	12.0	Cross-bedded coarse sand
	7.0	Cobbles, pebbles with a few boulders
5	6.0	Cobbles, pebbles gradational into cross-bedded coarse sand at bottom
	2.0	Fine sand
	8.0	Cross-bedded coarse sand and pebbles
	4.0	Cobbles, pebbles with a few boulders
	2.0	Sand
6	5.0	Cobbles, pebbles gradational into cross-bedded coarse sand
	12.0	Cross-bedded coarse sand with a few pebbles and cobbles
	4.0	Cobbles, pebbles grading to fine sand
	2.0	Fine sand

Site Number	Unit Thickness (Ft.)	Description
7	6.0	Cobbles, pebbles, gradation into cross-bedded coarse sand
	12.0	Cross-bedded coarse sand with a few pebbles and cobbles
	4.0	Cobbles, pebbles grading to fine sand
	2.0	Fine sand
8	6.0	Cobbles, pebbles, gradational into cross-bedded coarse sand
	12.0	Cross-bedded coarse sand with a few cobbles and pebbles
	3.0	Cobbles, pebbles, grading to fine sand
	1.0	Fine sand
10	4.0	Cobbles, pebbles, gradational into cross-bedded coarse sand
	13.0	Cross-bedded coarse sand
	5.0	Cobbles, pebbles, grading to sand
11	5.0	Cobbles, pebbles, gradational into cross-bedded coarse sand
	13.0	Cross-bedded coarse sand with a few pebbles
	4.0	Cobbles, pebbles grading to sand

APPENDIX 3

CUMULATIVE SIZE-FREQUENCY DISTRIBUTION CURVES FOR EACH SAMPLING METHOD AT EACH SITE, MINUS 3/8-INCH FRACTION

The size-frequency distribution curves for each method at each site show close agreement between the channel and grab methods. The curves for the auger method are usually similar to the other methods but tend to have more fine material present. The displacement of the auger values from the grab and channel values is probably due in part to the size selectivity of the auger and the distance between the samples for each method.

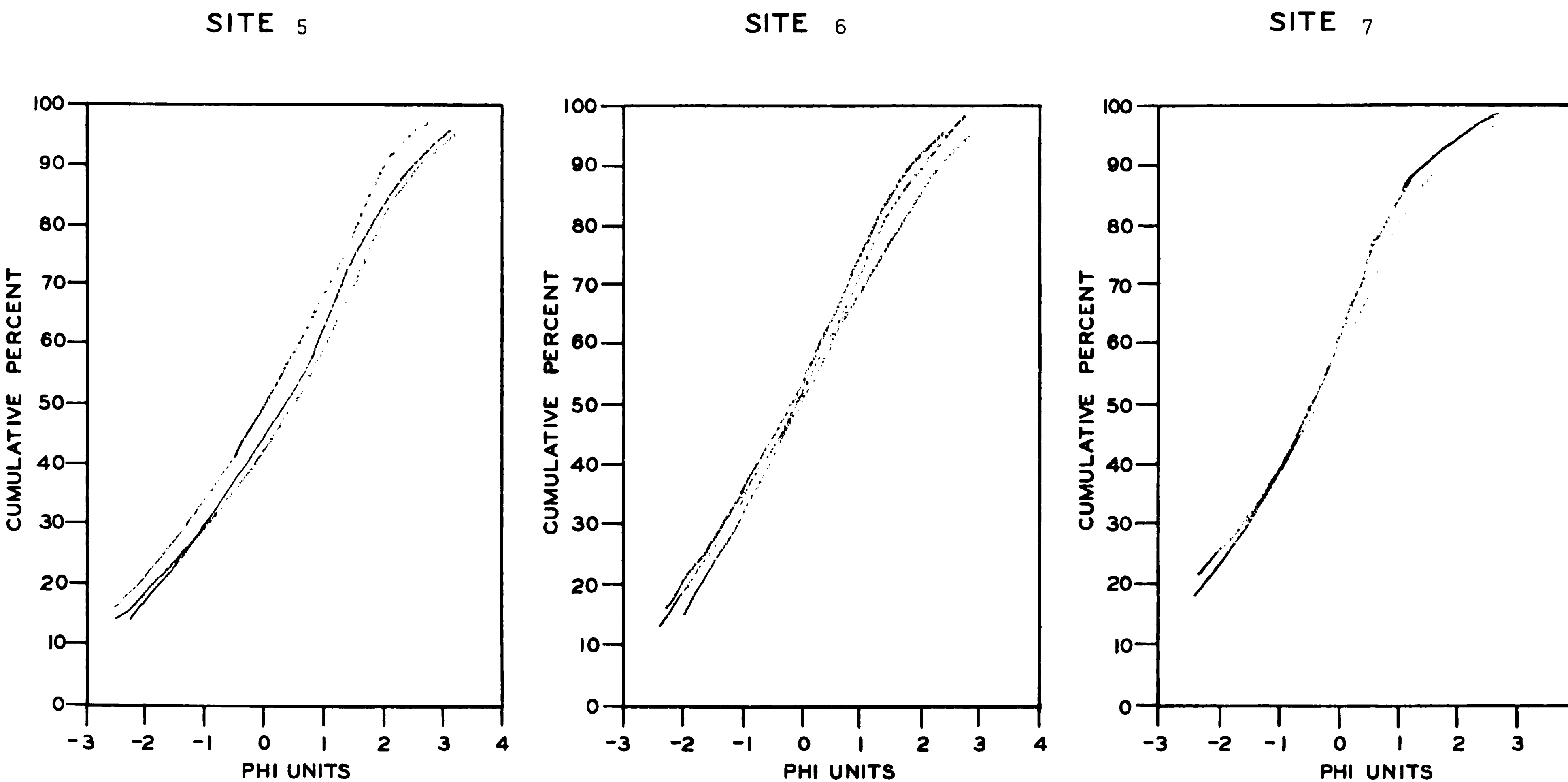


Auger

Grab Composite

Channel

Cumulative size-frequency distribution curves for each sampling method at each site, minus 3/8-inch fraction.

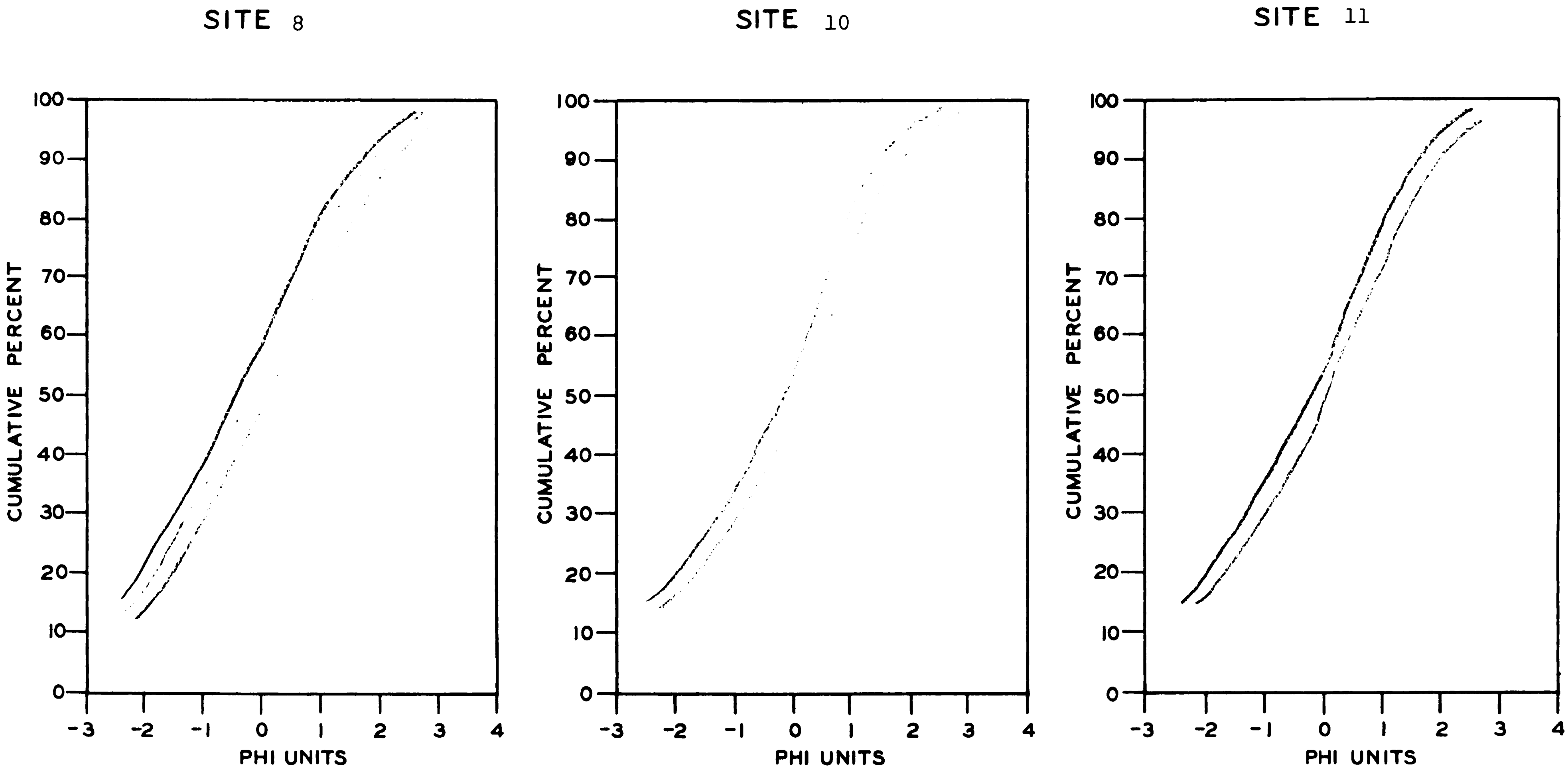


Auger

Grab Composite

Channel

Cumulative size-frequency distribution curves for each sampling method at each site, minus 3/8-inch fraction.



Auger

Grab Composite

Channel

Cumulative size-frequency distribution curves for each sampling method at each site, minus 3/8-inch fraction.