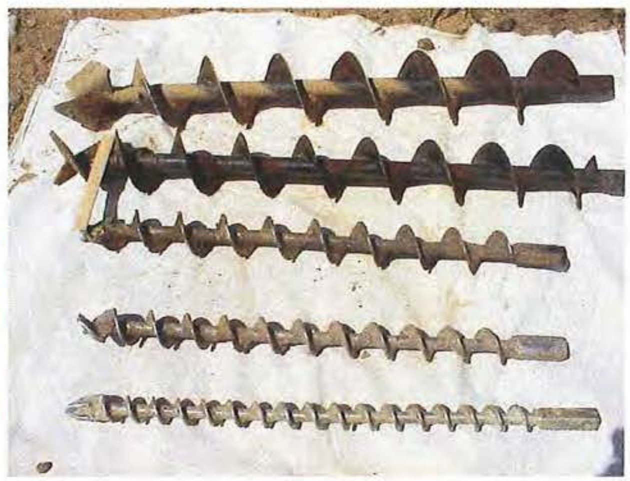
Analysis of Drilling and Sampling Techniques Used to Obtain Representative and Accurate Samples in Coarse Sand and Gravel Deposits



MN Department of Natural Resources
Division of Lands and Minerals
Project and Report # 347, 2003

Analysis of Drilling and Sampling Techniques Used to Obtain Representative and Accurate Samples in Coarse Sand and Gravel Deposits

Jonathan B. Ellingson
Industrial Minerals Geologist

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Minnesota Department of Natural Resources
Division of Lands and Minerals: Minerals Potential
500 Lafayette Road, St. Paul, MN 55155-4045

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INTRODUCTION

Drilling has traditionally been a cost effective means of evaluating sand and gravel deposits. It is used to collect samples that are representative of the deposit. These samples are typically sent to a material lab for sieve analysis to determine the particle size distributions. The particle size distributions of the samples help determine the overall texture of the deposit, which is a key factor in determining the value of the deposit. However, different drilling equipment specifications, sample collection techniques, and reduction techniques all affect the final results of the sieve analysis, which in turn can dramatically affect the final evaluation of the deposit.

This study was completed to analyze several different drilling and sampling techniques. The purpose was to determine the best methodologies to obtain representative and accurate samples in coarse sand and gravel deposits. Multiple samples were collected using several different sampling techniques to compare the effects of each technique on the material sampled (particle size distribution of the material). Five primary hypotheses were tested: (1) Drilling with larger diameter augers represents coarser sediment (>1.5") more accurately than smaller diameter augers, (2) Channel sampling represents coarser sediment more accurately than drilling, (3) Large channels represent coarser sediment more accurately than small channels, (4) Sediment sampled directly off of the auger under-represents coarse sediment, and (5) Sample splitting techniques affect the final size distribution.

A test site near Bayport, Minnesota, was selected where a sand and gravel pit provided a good exposure of a relatively homogeneous cobble-rich sand and gravel deposit. The site provided good accessibility for both drilling and channel sampling (Figures 1 and 2).

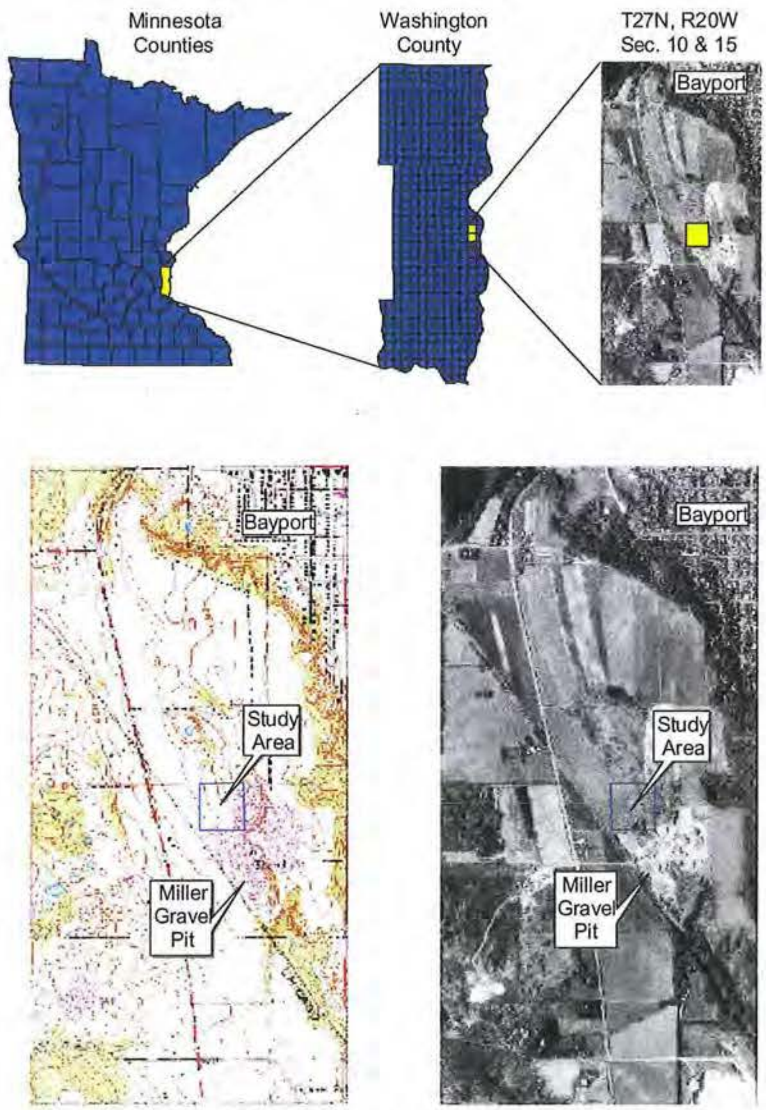


Figure 6. Location of test site: gravel pit near Bayport, MN.

Figure 2. Test Site: Gravel pit near Bayport, MN. This site provided good access for both drilling and channel sampling in a relatively homogeneous deposit. The flags represent drill hole and channel sampling locations.

GEOLOGICAL SETTING

The test site is located on the uppermost terrace within the St. Croix River Valley. This sand and gravel deposit is a large glaciofluvial terrace deposited by the draining of a large glacial lake. The material consists of a dry, very cobble-rich sand and gravel (Figure 3). The deposit was selected due to its coarse texture and homogeneity. The site is an active gravel pit that supplied fresh exposures on the vertical mine face.

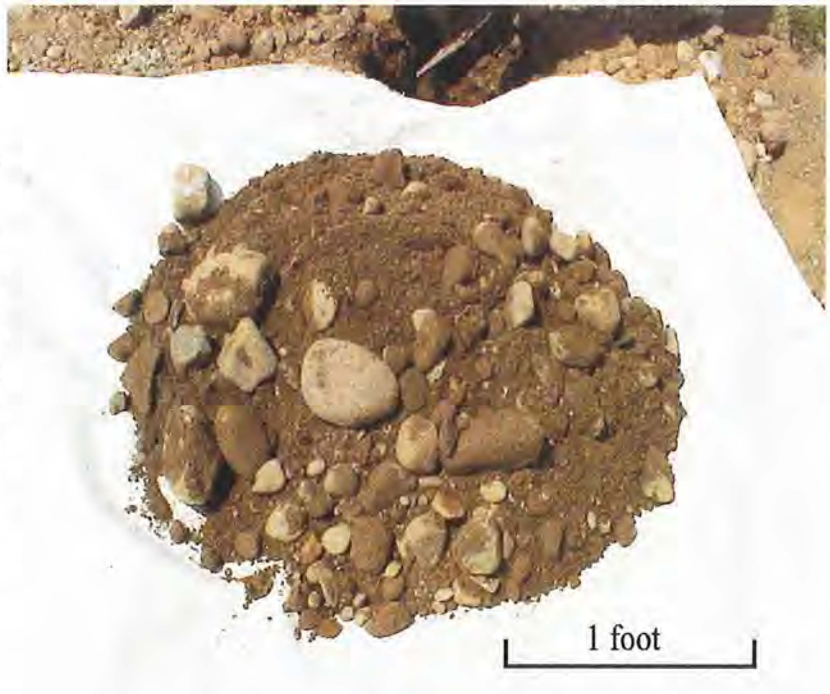


Figure 3. Typical material found at the Bayport site consisted of a cobble-rich sand and gravel.

DISCUSSION

Auger Diameter

It was observed by several of our geologists that the 4- inch auger did not seem to represent a coarse sand and gravel deposit accurately (it did not recover the coarser material). It was believed that the fine material was being over-represented and the coarse material was being under-represented. The 8- inch auger seemed to bring up much coarser material in the same deposit. To determine the extent of this possible sampling bias, 27 holes were drilled with 3 different sized augers (4,6, and 8-inch), the material was collected, and sediment analysis was completed. The analysis of the sediment collected by the different sized augers should answer these questions: 1) Does the diameter of the auger affect the material that is sampled? 2) How much does it affect the size distribution? 3) What are some alternatives we can use to minimize the affect? 4) What other observations / ideas / conclusions can be determined from the data that will help with our sampling?

Sampling Techniques

Four sampling techniques were utilized to determine what their effects were on the material collected. Does it make a difference if one of every four auger flights is collected by grabbing the sample and throwing it on the mat (random sampling) versus collecting all the material on the mat and then splitting the sample (quartering methods, discussed in methodology section)? Should the material on the auger be the only material sampled? Should the material on the mound around the hole be sampled as well? Should just the mound be sampled and not the auger? Which method represents the material most accurately?

METHODOLOGY

Six channel samples were excavated on a vertical mine face in order to compare the results of this technique to the results of the drilling. Twenty-seven holes were drilled using a Giddings soil probe using three different sized augers. The material was carefully collected and split through four sampling and splitting methods to determine the effect of each of these methods on the particle size distribution. Thirty pound samples were collected in bags and shipped to the Division's materials laboratory in Hibbing for sieve (particle size distribution) analysis. The results of the sieve analyses were then compiled and analyzed to determine if any trends existed. These results were used to determine what auger best represents the deposit, what sampling techniques work best, and to give some additional understanding to other general observations made while drilling and sampling.

Figure 4. A Giddings Soil Probe was used for the testing. The different diameter auger flights are interchangeable on this machine.

Auger Diameter

A truck mounted Giddings soil probe was used at the test site to drill multiple holes. The soil probe allows different diameter auger flights to be used interchangeably, which made this the ideal machine for the study. A total of 27 holes were drilled: 9 holes were drilled with an 8-inch diameter auger, 9 holes with a 6-inch diameter auger, and 9 holes with a 4-inch diameter auger (Figures 5 and 6). All of the 27 holes were drilled to a common depth of 5 feet and were all drilled within a 20-by-20 foot area in a relatively homogeneous sand and gravel deposit. Each set of 3 holes (4, 6, and 8-inch) were distributed in a staggered pattern, with approximately 6 feet between each of the sets (Figure 5).

The truck mounted auger was positioned over the appropriate flag of the predetermined pattern (Figures 4 and 5) and the hole was drilled. The material was collected through various sampling techniques and brought to the Division's materials laboratory in Hibbing for analysis.

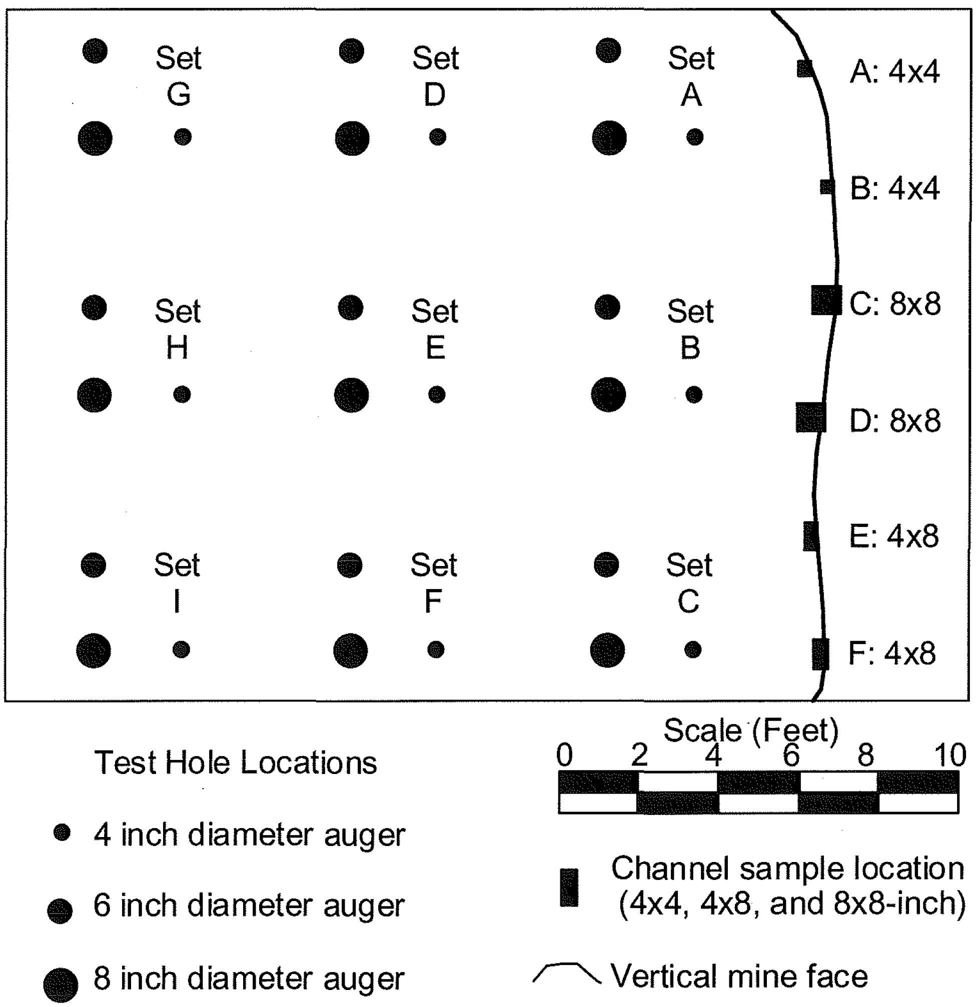


Figure 5. Location and distribution of drill holes and channel samples. All Samples were taken from a 20x20 foot area in order to minimize the variation of the material.

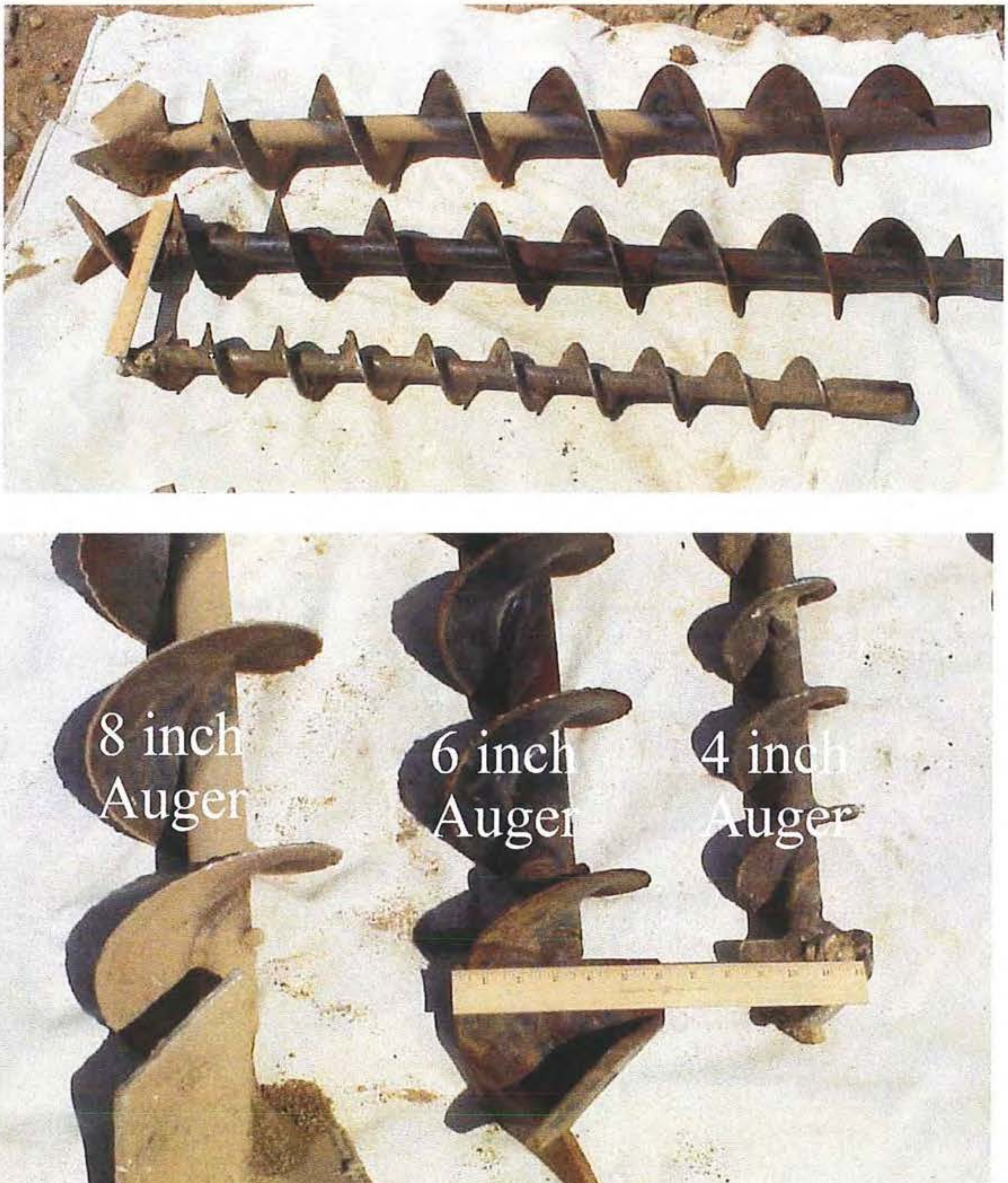


Figure 6. Different diameter augers used for drilling sand and gravel (top). The 8 inch, 6 inch, and 4 inch auger used in this study (bottom).

Sampling Techniques

There were 4 primary sampling techniques used to collect the material for sieve analysis. The first was the random sampling technique (Figure 7). The random sampling technique consisted of collecting material off the auger flights by randomly grabbing some material and throwing it on the mat. This sampling technique is a common technique used in the field when time is an issue. With this technique all the material that is collected on the mat is put into a bag for analysis. There is no reduction by splitting of the material required; only about 30 pounds are taken off the auger and only about 30 pounds are collected. The remainder of the material is discarded on the ground and later used to fill in the hole.

The second sampling technique consists of collecting all the material from the auger on a large mat (Figure 8) and later splitting the material using standard quartering techniques (ASTM techniques). This sometimes requires collecting well over a hundred pounds of material and can be much more time consuming. The splitting techniques are defined in the following section (Splitting Techniques).

Figure 7. Random sampling technique- sampling 1 in every 3 or 4 auger flights.

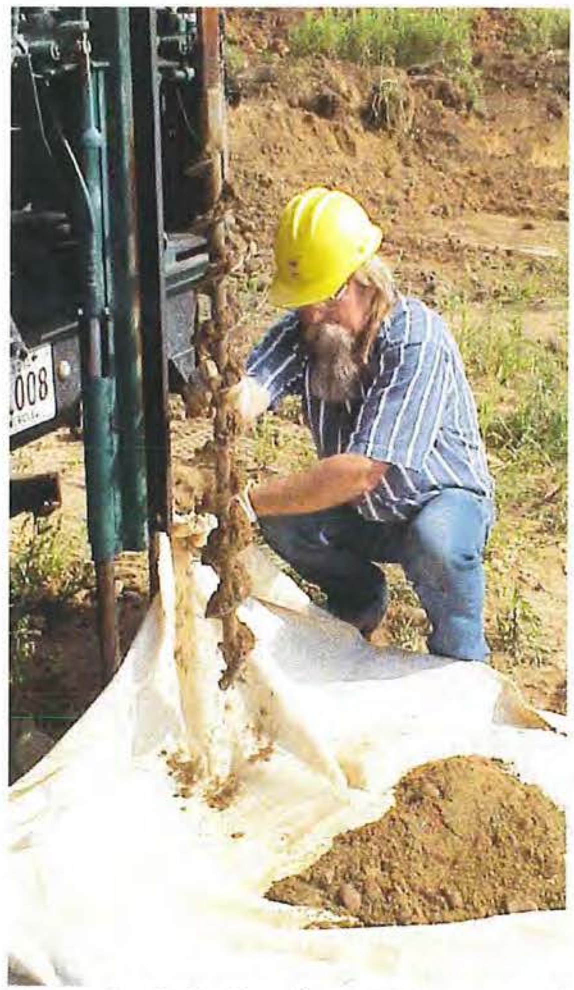


Figure 8. Collecting all material on mat and later splitting the sample with 1/4 method.

It was observed in the field that the 6-inch auger was capable of bringing up the coarser material from the hole; however, it fell off the auger as soon as the auger was pulled up above the surface, thus dropping the coarser material on the mound surrounding the hole. The third sampling technique consisted of collecting both the material off the auger and the material that formed the mound around the hole. The fourth sampling technique collected only the material from the mound and not the material from the auger.

Channel Sampling

Three different channel sizes were excavated on a vertical mine wall to determine if there were any differences in the size distribution of the sediment collected. The results of the channel sampling were also compared to the results of the drilling program to determine how channel sampling compared to drill hole sampling. The three channel (trench) sizes utilized were the 4x4-inch trench, the 4x8-inch trench, and the 8x8-inch trench (all 5 feet in height). The channels were excavated with the following technique: taking a shovel and digging a trench from 0-5 feet with the appropriate cross-section depth and width (e.g. 4x8-inch). A 4-inch wide shovel was used for the 4x4-inch trenches and an 8-inch shovel was used for the 4x8-inch and 8x8-inch trenches. All material was collected on a large mat, split (if needed), and put into 30-pound sample bags for sieve analysis in the Division's materials lab in Hibbing. The material collected from the 8x8-inch trench was designated as the "control" sample for this study.

Figure 9. Channel sampling. Six samples were collected using three different sized channels (4x4, 4x8, and 8x8 inch trenches).

Splitting Techniques

The material that was collected from the auger or from the channel often exceeded one hundred pounds. It is only necessary to collect approximately 30 pounds of sample for a representative sieve analysis, thus the material was divided into quarters using different splitting techniques and a 30 pound sample was collected. The first step was to properly mix the sample to assure homogeneity. That is, all of the material on the mat is mixed using standard ASTM methods to assure that no sorting has occurred during sampling, and then it is piled into a cone shape. Often when collecting samples on a large mat, the finer material will fall out first (closest to the auger) and the coarser material will fall out later (farther from the auger), thus mixing is very important. Once the material is mixed, the splitting can take place. Two splitting techniques were used: 1) the material was divided into 4 equal volume piles using a shovel (Figure 11) and 2) the material was divided into 4 equal volume piles by placing the handle of a shovel below the mat and lifting up once to divide the pile in two (Figure 12) and then the shovel was placed at an angle of 90 degrees to the first line and lifted to divide the material into 4 equally sized piles (Figure 13). For both splitting techniques, 3 of the 4 piles were discarded back into the hole and the fourth pile was collected in a sample bag, labeled, and shipped to the Division's materials laboratory for sieve analysis (Figures 14 and 15).

Figure 10. Mixing of the sediment.

Figure 11. Quartering the sample using the shovel method.

Figure 12. Splitting the sample in half using the shovel handle method.

Figure 13. Splitting the sample in quarters using the shovel handle method.

Sieve Analysis and Data Handling

Sieve analysis was completed in the Division's materials laboratory in Hibbing using a Gilson sieve shaker to determine the sediment size distribution. Fifteen sieves were used to determine the size distribution. The sizes ranged from 1.5 inch down to the #200 sieve (Table 1). The sieve analysis procedure was completed using standard techniques (ASTM specs). All the samples were processed using the same procedure (Figure 16).

Figure 14. Collecting the material.

A total of 33 samples were analyzed for this study; 27 of the samples represented the 27 test holes drilled, 2 of the remaining 6 samples represented the control channel samples, and the other 4 samples represented the experimental channel samples. Each sample analyzed represented one test hole or channel sample. The sieve data was entered into a database, summarized and analyzed using spreadsheets, and simple averages were calculated for each of the conditions tested. The information was then used to test each of the five hypotheses (discussed in the Results Section).

Figure 15. Labeling the sample bag before shipping.

Sieve Size	Ex: 6in-A
1.5 in.	38.88
1 in.	3.88
3/4 in.	5.26
5/8 in.	3.64
½ in.	7.40
3/8 in.	7.23
#4	5.44
#8	2.69
#10	3.51
#16	9.25
#30	3.96
#40	2.39
#50	2.73
#100	1.27
#200	1.53
PAN	0.94
Total	100.00

Table 1. Sieve sizes and example of the percentage of material retained on each sieve.

Figure 16. Division's materials laboratory in Hibbing.

RESULTS

After the sieve analysis was completed on the samples, the information was processed, summarized, and analyzed (Appendices A and B). Five primary hypotheses/trends were tested: (1) Drilling with larger diameter augers represents coarser sediment (>1.5") more accurately than smaller diameter augers, (2) Trenching represents coarser sediment more accurately than drilling, (3) Large trenches represent coarser sediment more accurately than small trenches, (4) Sediment sampled directly off of the auger under-represents coarse sediment, and (5) Different sample splitting techniques may affect the final size distribution.

Results - Channel Sampling Techniques

Three different sized channels (trenches) were excavated and the material from each was collected; two 8-inch by 8-inch (8x8-inch) channels, two 4-inch by 8-inch (4x8-inch) channels, and two 4-inch by 4-inch (4x4-inch) channels were excavated. The material collected from the 8x8-inch trench was used as the "control" sample for this study. The average percentage of material retained on the 1.5 inch sieve (coarse gravel) for the control sample (8x8-inch trench) was 42.9%, 34.6% for the 4x8-inch trench, and 30.8% for the 4x4-inch trench (Figure 17: Table 2). The weight recovery percent of the 4x8-inch and 4x4-inch channels is 81% and 72% respectively; the weight recovery percent is the percent of material retained on the 1.5 inch sieve for each technique relative to the control sample (8x8-inch channel). These numbers suggest that the larger channels are capable of collecting coarser material, whereas the narrower channels are not capable of representing coarse deposits (>1.5 inch material) adequately. The 4-inch restriction of the 4x4-inch and the 4x8-inch trenches limits the maximum size of material allowed to be collected, while the 8x8-inch trench allows a more accurate representation of the material. This is due to the relationship between the size of the cobbles and the volume of channel excavated. The volumes of material collected for the 8x8-inch, 4x8-inch, and 4x4-inch channels (5 feet in height) are 960, 1920, and 3840 cubic inches respectively (Appendix C). The larger volume channels allow a more representative sample to be taken in a cobble-rich gravel deposit.

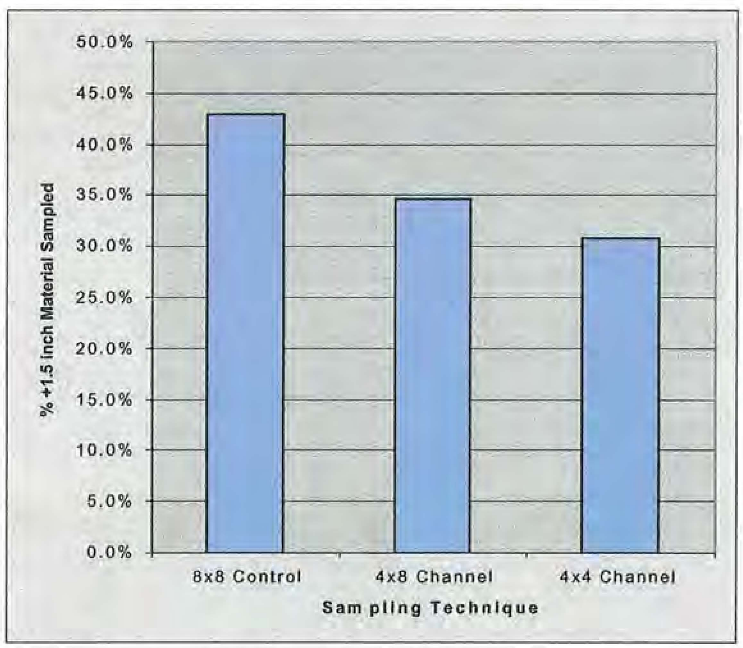


Figure 17. Results of the Channel Sampling. The percentage of material retained on 1.5 inch sieve (by weight) for the 8x8-inch channel was 42.9%, 34.6% for the 4x8-inch channel, and 30.8% for the 4x4-inch channel.

	Percentage of Material Retained			Weight Recovery Percentage		
Sieve	8x8 Channel	4x8 Channel	4x4 Channel	8x8 Channel	4x8 Channel	4x4 Channel
1.5	42.9%	34.6%	30.8%	100%	81%	72%
1	5.7%	5.9%	6.2%	100%	102%	108%
3/4	4.1%	4.4%	5.5%	100%	107%	134%
5/8	1.7%	3.4%	3.6%	100%	203%	214%
½	4.9%	5.1%	1.2%	100%	104%	24%
3/8	4.1%	5.4%	3.1%	100%	131%	75%
#4	6.0%	6.8%	8.5%	100%	112%	140%
#8	4.5%	3.7%	7.1%	100%	82%	159%
#10	2.1%	2.9%	3.7%	100%	137%	178%
#16	3.1%	7.9%	5.0%	100%	257%	163%
#30	9.5%	10.1%	12.4%	100%	106%	130%
#40	5.7%	4.4%	5.4%	100%	77%	95%
#50	2.4%	2.8%	3.5%	100%	117%	146%
#100	1.8%	1.6%	2.7%	100%	85%	146%
#200	0.4%	0.6%	0.7%	100%	142%	160%
PAN	0.9%	0.6%	0.6%	100%	66%	67%
Total	100.0%	100.0%	100.0%	100%	100%	100%

Table 2. Results of the Channel Samples. The values are given as percentage of material retained on the sieve by weight. The weight recovery percentage represents the percentage of material sampled relative to the control sample.

Results - Auger Diameter

Table 3 contains the results of the sieve analysis; this table summarizes the averages of the samples collected just from the auger. The average percentage of coarse (>1.5 inch) material collected was 29.2% with the 8-inch auger, 8.7% with the 6-inch auger, and 6.3% with the 4-inch auger. The recovery percentages of the 6- and 4-inch augers is 30% and 21% when compared to the 8-inch auger. That is the 6-inch auger was only capable of bringing up and holding 30% of the coarse (>1.5 inch) material and the 4-inch auger was only capable of bringing up and holding 21% of the coarse (>1.5 inch) material compared to the 8-inch auger. A similar trend exists with the 1 inch material, however it is not as pronounced.

This trend would suggest that the 8-inch auger represents coarse sand and gravel deposits better than the 6-inch auger, which represents such deposits better than the 4-inch auger. Because the 4 and 6-inch augers collect less of the coarser material (>1.5 inch), they then over-represent the finer material (Figure 18). The percentage of material retained on the 3/4 inch, 5/8 inch, ½ inch, 3/8inch, and #4 sieve are comparable for all three auger sizes. However, the 4- and 6-inch auger holes consistently have a higher percent of fine material than the 8-inch auger holes (Figure 18). This trend is observed in the material finer than the #8 sieve. The amount of silt and clay (<#200 sieve) is comparable between all samples. The data also seem to support that any of these auger sizes would be sufficient for a sand and gravel deposit with material smaller than 3/4 inch.

	Percentage of Material Retained			Weight Recovery Percentage		
Sieve	8 inch Auger	6 inch Auger	4 inch Auger	8 inch Auger	6 inch Auger	4 inch Auger
1.5	29.2%	8.7%	6.3%	100%	30%	21%
1	6.0%	3.4%	5.0%	100%	56%	83%
3/4	3.9%	4.2%	4.8%	100%	107%	122%
5/8	3.1%	2.7%	3.0%	100%	89%	99%
½	4.6%	3.7%	3.4%	100%	82%	73%
3/8	5.8%	3.2%	5.2%	100%	56%	89%
#4	8.0%	12.5%	10.3%	100%	156%	129%
#8	5.9%	11.7%	8.6%	100%	197%	145%
#10	4.2%	5.8%	5.5%	100%	137%	131%
#16	7.4%	7.7%	9.7%	100%	105%	132%
#30	10.1%	18.7%	17.2%	100%	186%	171%
#40	4.4%	7.1%	7.8%	100%	160%	177%
#50	3.2%	4.9%	6.2%	100%	150%	190%
#100	2.6%	4.4%	5.1%	100%	171%	195%
#200	0.9%	0.7%	1.2%	100%	80%	133%
PAN	0.7%	0.6%	0.8%	100%	87%	111%
Total	100.0%	100.0%	100.0%	100%	100%	100%

Table 3. Results of auger diameter tests. The values are given as the percentage of material retained on the sieves by weight. The weight recovery percentage represents the percentage of material relative to the 8-inch auger.

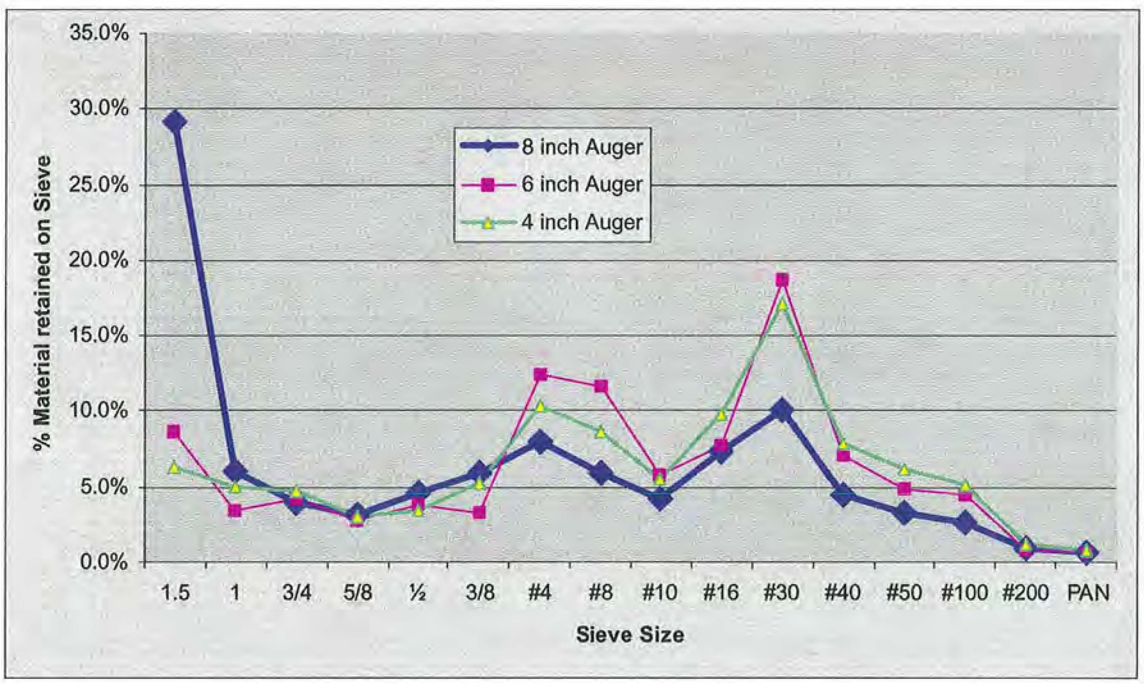


Figure 18. Particle size distribution curve of auger diameter tests. Note the 6 and 4- inch augers under-represent the coarse material and over-represent the fine material.

Results - Sampling Test Holes with Auger

It was observed in the field that the 4-inch and the 6-inch augers were capable of bringing up the coarser material from the hole, however it fell off the auger as soon as the auger was pulled up above the surface, thus dropping the coarser material in the mound surrounding the hole. Rather than collecting material only from the auger, material was collected from both the auger and the surrounding mound. Another sampling technique collected only the material from the mound and not the material from the auger. It was believed that this technique would over-represent the coarse material and under-represent the fine material. These two sampling techniques were then compared to the method of only collecting the material from the auger.

The sieve analysis results show that the percent of material retained on the 1.5 inch sieve for the samples collected from only the 4-inch auger ranged from 3.5% to 10.6% and averaged 6.3% (Table 4). When the material was collected from both the auger and the mound around the auger, the percent of material retained on the 1.5 inch sieve ranged from 17.5% to 23.0% and averaged 19.6%. These results indicate that the 4-inch auger is capable of bringing up some of the coarser material, but is unable to retain the material once it is out of the hole. The material on the auger thus under-represents the coarse material and over-represents the fine material (Figure 19).

The sieve analysis results show that the percent of material retained on the 1.5 inch sieve for the samples collected from just the 6-inch auger ranged from 3.6 and 12.73% and averaged 8.7% (Table 4). When the material was collected from both the auger and the mound around the auger, the percent of material retained on the 1.5 inch sieve ranged from 22.81% to 26.30% and averaged 24.7%. When the material was collected from just the mound and not from the auger the 1.5 inch material ranged from 26.27% to 33.36% and averaged 29.1% (Figure 20). Again, these results indicate that the 6-inch auger is capable of bringing up some of the coarser material but is unable to hold it on the auger once it is out of the ground. When the material is sampled only from the mound, and not from the auger, the amount of coarser material is greater due to the auger retaining the finer material (Figure 21).

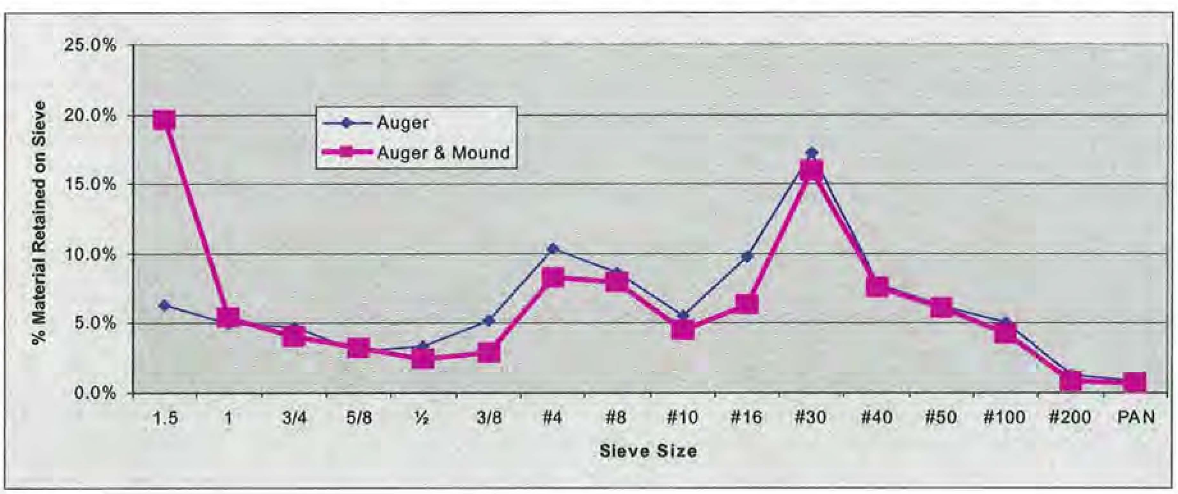


Figure 19. Results of the 4-inch auger: sampling auger versus the auger and mound. The material from just the auger under-represents the coarse material and over-represents the fine material.

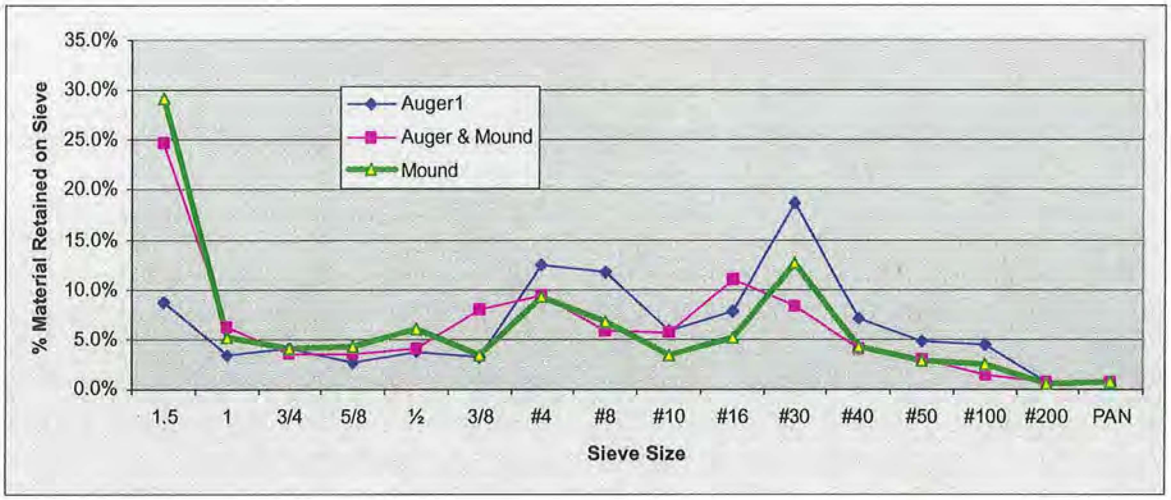


Figure 20. Results of the 6-inch auger: sampling only the auger, the auger and mound, and only the mound. Note the material samples from the auger alone under-represents the coarse material and over-represents the fine material.

	Sampling Using 4-Inch Auger		Sampling Using 6-Inch Auger		
Sieve	**Auger**	**Auger & Mound**	**Auger1**	**Auger & Mound**	**Mound**
1.5	6.3%	19.6%	8.7%	24.7%	29.1%
1	5.0%	5.4%	3.4%	6.2%	5.1%
3/4	4.8%	4.0%	4.2%	3.6%	4.1%
5/8	3.0%	3.3%	2.7%	3.5%	4.2%
½	3.4%	2.4%	3.7%	4.1%	6.1%
3/8	5.2%	2.9%	3.2%	7.9%	3.4%
#4	10.3%	8.3%	12.5%	9.5%	9.2%
#8	8.6%	7.9%	11.7%	5.9%	6.8%
#10	5.5%	4.5%	5.8%	5.6%	3.4%
#16	9.7%	6.3%	7.7%	10.9%	5.1%
#30	17.2%	15.9%	18.7%	8.3%	12.5%
#40	7.8%	7.6%	7.1%	4.1%	4.3%
#50	6.2%	6.1%	4.9%	3.0%	2.8%
#100	5.1%	4.3%	4.4%	1.4%	2.5%
#200	1.2%	0.9%	0.7%	0.6%	0.6%
PAN	0.8%	0.7%	0.6%	0.6%	0.7%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4. Results of sampling using a 4 and 6-inch auger for drilling. Note the different sampling techniques. The values are given as percentages of the material retained on each sieve by weight.

Figure 21. Material collected from the 6-inch auger drilling. Material collected only from the auger (top). Material collected only from the mound (bottom). Note the auger material is much finer than the material collected from the mound.

Results - Channel Sampling versus Drilling

In the previous section it was determined that the best sampling technique, when using an auger, is to sample both the material from the auger and the mound surrounding the hole. As this method best represents the material most accurately, while using an auger, this is the method that will be compared to the channel sampling technique. The average percentage of material retained on the 1.5 inch (coarse gravel) sieve for the control sample (8x8-inch trench) was 42.9%, 34.6% for the 4x8-inch trench, and 30.8% for the 4x4-inch trench. This percentage is higher than what was obtained from any of the 8, 6, or 4-inch auger samples, which were 29.2%, 24.7%, and 19.6% respectively (Tables 5 and 6; Figures 22 and 23). The percentage of coarser material was higher and the amount of finer material (<#4 inch sieve) was lower in the channel samples. The channel sampling method is believed to represent the material most accurately followed by the 8-inch auger, 6-inch auger, and 4-inch auger respectively (Table 6: weight recovery).

The optimum way to collect sand and gravel deposits has traditionally been the channel sampling method, otherwise known as the back-hoe method. This is often the preferred method as it gives a more accurate representation of the deposit's characteristics. This method works well with shallow sand and gravel deposits and in areas that can be disturbed without consequences. However, many sand and gravel deposits are thicker (>15 feet) and drilling is required to reach these greater depths. Drilling is also often a more desirable method for exploration because it minimally disturbs the land surface (e.g. it minimizes the effects on vegetation). However, where it is appropriate to use a back-hoe, the channel sampling method is the preferred method. It gives a bigger picture of the deposit and represents the material much better (for coarser deposits with > 1 inch material).

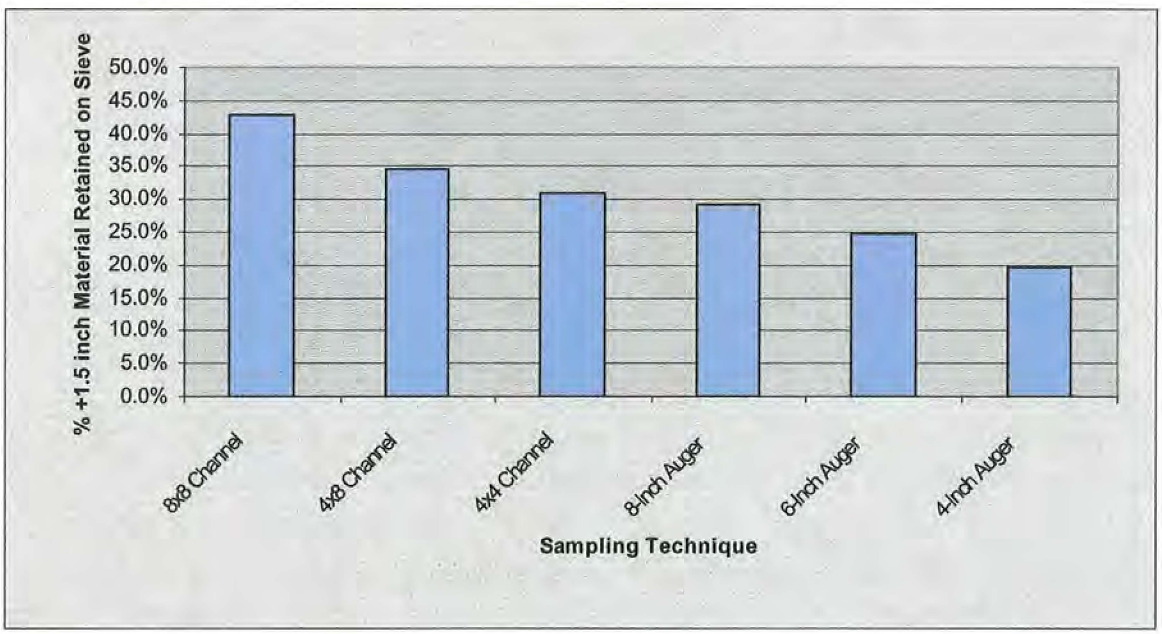


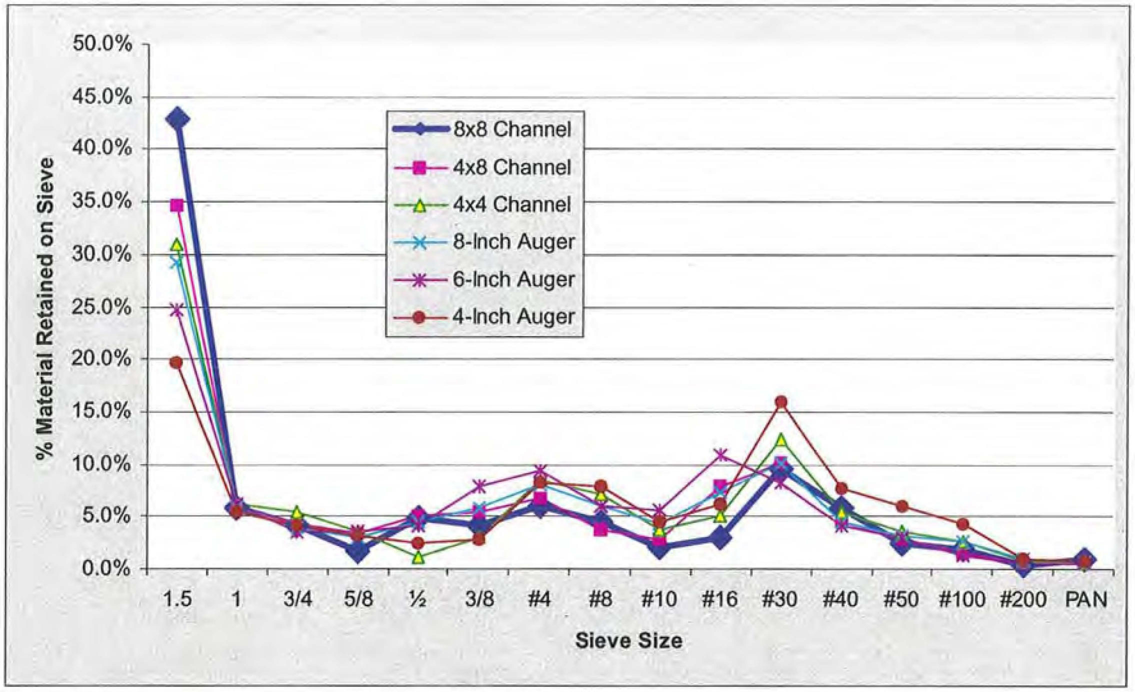
Figure 22. Results of channel sampling versus drilling (percentage of material retained on the 1.5 inch sieve). The 8x8-inch channel, 4x8-inch channel, 4x4-inch channel, 8-inch auger, 6-inch auger, and 4-inch auger values are 42.9%, 34.6%, 30.8%, 29.2%, 24.7%, and 19.6% respectively.

Sieve	8x8 Channel	4x8 Channel	4x4 Channel	8-Inch Auger	6-Inch Auger	4-Inch Auger
1.5	42.9%	34.6%	30.8%	29.2%	24.7%	19.6%
1	5.7%	5.9%	6.2%	6.0%	6.2%	5.4%
3/4	4.1%	4.4%	5.5%	3.9%	3.6%	4.0%
5/8	1.7%	3.4%	3.6%	3.1%	3.5%	3.3%
½	4.9%	5.1%	1.2%	4.6%	4.1%	2.4%
3/8	4.1%	5.4%	3.1%	5.8%	7.9%	2.9%
#4	6.0%	6.8%	8.5%	8.0%	9.5%	8.3%
#8	4.5%	3.7%	7.1%	5.9%	5.9%	7.9%
#10	2.1%	2.9%	3.7%	4.2%	5.6%	4.5%
#16	3.1%	7.9%	5.0%	7.4%	10.9%	6.3%
#30	9.5%	10.1%	12.4%	10.1%	8.3%	15.9%
#40	5.7%	4.4%	5.4%	4.4%	4.1%	7.6%
#50	2.4%	2.8%	3.5%	3.2%	3.0%	6.1%
#100	1.8%	1.6%	2.7%	2.6%	1.4%	4.3%
#200	0.4%	0.6%	0.7%	0.9%	0.6%	0.9%
PAN	0.9%	0.6%	0.6%	0.7%	0.6%	0.7%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5. Results of channel sampling versus drilling. The values represent the percentage of material retained on the 1.5 inch sieve. The 8x8-inch channel, 4x8-inch channel, 4x4-inch channel, 8-inch auger, 6-inch auger, and 4-inch auger values are 42.9%, 34.6%, 30.8%, 29.2%, 24.7%, and 19.6% respectively.

Sieve	8x8 Channel	4x8 Channel	4x4 Channel	8-Inch Auger	6-Inch Auger	4-Inch Auger
1.5	100.0%	80.6%	71.8%	67.9%	57.5%	45.6%
1	100.0%	102.4%	107.7%	103.8%	108.8%	93.2%
3/4	100.0%	106.5%	133.6%	94.7%	86.5%	98.2%
5/8	100.0%	202.9%	214.4%	184.4%	208.9%	195.9%
½	100.0%	103.7%	24.3%	93.7%	83.2%	49.3%
3/8	100.0%	130.6%	74.9%	141.5%	192.6%	69.2%
#4	100.0%	112.0%	140.2%	132.4%	156.4%	137.5%
#8	100.0%	81.7%	158.7%	132.0%	131.6%	176.2%
#10	100.0%	137.4%	178.2%	202.2%	267.2%	214.4%
#16	100.0%	257.0%	163.4%	239.0%	354.9%	203.4%
#30	100.0%	105.8%	129.9%	105.8%	87.5%	167.7%
#40	100.0%	77.1%	94.5%	77.0%	71.6%	132.5%
#50	100.0%	116.9%	145.8%	134.1%	122.4%	250.1%
#100	100.0%	84.6%	145.8%	140.9%	76.1%	232.7%
#200	100.0%	142.2%	159.7%	211.8%	148.9%	196.8%
PAN	100.0%	65.9%	66.5%	79.5%	74.0%	85.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6. Weight recovery results for channel sampling versus drilling. The values represent the percentage of material sampled compared to the control sample (8x8-inch channel sample).



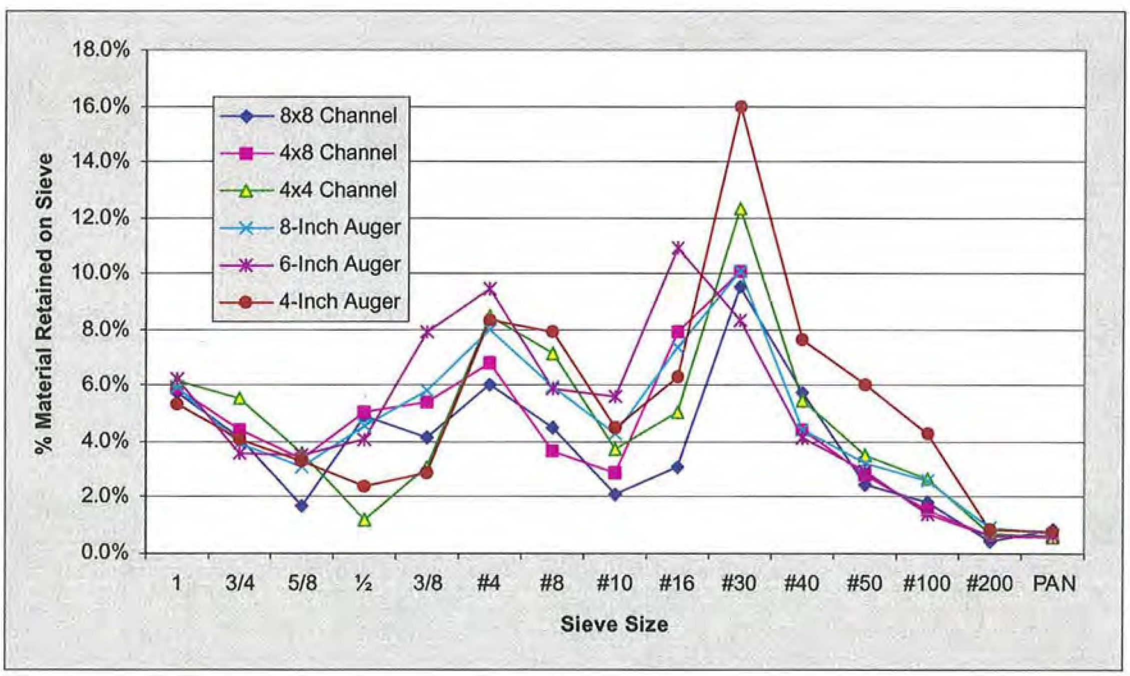


Figure 23. Particle size distribution curve for the results of channel sampling versus drilling. The top graph represents the percentage of material retained on each sieve by sampling technique. The bottom graph is the same as the above (zoomed in on material <1 inch in size).

Results - Sample Splitting / Sample Reduction

Three sample splitting/reducing techniques were used in conjunction with the 8-inch auger. The first two sample splitting techniques consisted of collecting all the material on a large mat and splitting it with a shovel; these techniques are discussed in the methodology section (Figures 11 and 12). The third method of reducing the sample size consists of only collecting one in every 3 or 4 auger flights of material (random sampling). The average percentage of material retained on the 1.5 inch sieve ranged from 25.8% for one of the shovel splitting techniques to 32.2% for the other shovel splitting technique. The average percent of material retained on the 1.5 inch sieve for the random sampling technique was 29.5%, which falls directly between the two ASTM certified shovel splitting techniques (Table 7). The weight recovery percentages are generally within 10% of the average for all techniques (Table 7).

Analysis of the sample splitting/sample reduction techniques suggests that any of the three methods are acceptable. The random sampling technique is typically the most widely used, as the drilling process is frequently a fast one and there is little time for collecting, splitting, and then putting the material in the bag. The random sampling technique takes the sample directly from the auger into the bag resulting in a much more efficient and time saving technique in homogeneous sand and gravel deposits.

	Percentage of Material Retained				Weight Recovery Percentage		
Sieve	**Shovel**	**Cone**	**Random**	**Average**	**Shovel**	**Cone**	**Random**
1.5	25.8%	32.2%	29.5%	29.2%	88.3%	110.4%	101.3%
1	4.7%	6.6%	6.5%	6.0%	79.2%	111.0%	109.7%
3/4	3.9%	3.7%	4.2%	3.9%	99.4%	93.8%	106.8%
5/8	3.4%	2.7%	3.1%	3.1%	111.3%	88.9%	99.8%
½	4.8%	3.3%	5.6%	4.6%	105.2%	72.9%	121.9%
3/8	6.4%	4.9%	6.2%	5.8%	109.9%	84.2%	105.9%
#4	7.8%	8.1%	8.1%	8.0%	97.0%	101.6%	101.4%
#8	5.6%	6.8%	5.4%	5.9%	94.3%	115.4%	90.3%
#10	5.1%	3.6%	4.1%	4.2%	119.1%	84.5%	96.4%
#16	10.2%	4.9%	7.0%	7.4%	138.3%	66.4%	95.3%
#30	9.0%	12.2%	9.0%	10.1%	89.0%	121.2%	89.8%
#40	4.7%	4.5%	4.1%	4.4%	105.3%	102.8%	91.9%
#50	3.6%	2.9%	3.2%	3.2%	112.3%	88.3%	99.4%
#100	2.7%	2.2%	2.9%	2.6%	105.3%	84.8%	109.9%
#200	1.5%	0.6%	0.6%	0.9%	166.8%	65.9%	67.2%
PAN	0.9%	0.7%	0.5%	0.7%	126.0%	94.7%	79.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 7. Results of sieve data for sample splitting / sample reduction techniques. The values on the left represent the percentages of material retained on each sieve by sampling technique. The weight recovery was calculated by the difference from the average of all techniques.

CONCLUSIONS

Hypotheses Tested

The purpose of this study was to test five primary hypotheses: (1) Drilling with larger diameter augers represents coarser sediment (>1.5") more accurately than smaller diameter augers, (2) Trenching represents coarser sediment more accurately than drilling, (3) Large trenches represent coarser sediment more accurately than small trenches, (4) Sediment sampled directly off of the auger under-represents coarse sediment, and (5) Different sample splitting techniques may affect the final size distribution.

(1) Drilling with larger diameter augers represents coarser sediment (>1.5") more accurately than smaller diameter augers.
Three different sized augers (4, 6, and 8-inch diameter) were used to drill several 5 foot holes. The material was collected from just the auger and analyzed for particle size distribution. The average percentage of coarse material (>1.5 inch) collected was 29.2% with the 8-inch auger, 8.7% with the 6-inch auger, and 6.3% with the 4-inch auger. Thus the weight recovery percentages for the 4- and 6-inch augers is 30% and 21% when compared to the 8-inch auger. This would suggest that the 8-inch auger represents coarse sand and gravel deposits better than the 6-inch auger, which represents the deposit better than the 4-inch auger. Because the 4 and 6-inch augers collect less of the coarser material (>1.5 inch), they reflect an over-representation of the finer material.

(2) Trenching represents coarser sediment more accurately than drilling.
The average percentage of material retained on the 1.5 inch (coarse gravel) sieve for the control sample (8x8-inch trench) was 42.9%, 34.6% for the 4x8-inch trench, and 30.8% for the 4x4-inch trench. This percentage is higher than what was obtained from any of the 8, 6, or 4-inch auger samples, which were 29.2%, 24.7%, and 19.6% respectively (sampling from both the auger and the mound). The percentage of coarser material was higher and the amount of finer material (<#4 inch sieve) was lower in the channel samples. The channel sampling method is believed to represent the material most accurately followed by the 8-inch auger, 6-inch auger, and 4-inch auger respectively.

(3) Large channels (trenches) represent coarser sediment more accurately than small channels.
Three different sized channels (4x4, 4x8, and 8x8-inch) were excavated and the material from each was collected. The average percent material retained on the 1.5 inch sieve was 30.8% for the 4x4-inch trench, 34.6% for the 4x8-inch trench, and 42.9% for the 8x8-inch trench (Table 3). These numbers suggest that the larger trenches are capable of collecting coarser material, whereas the narrower trenches (like the smaller augers) are not capable of representing coarse deposits (>1.5 inch material) adequately.

(4) Sediment sampled directly off of the auger under-represents coarse sediment.
It was observed in the field that the 4-inch and the 6-inch augers were capable of bringing up the coarser material from the hole, but as soon as the auger was pulled up above the hole, the material fell off, dropping the coarser material around the hole. The percent of material retained on the 1.5 inch sieve for the samples collected only from the auger averages 6.3% and 8.7% for the 4 and 6-inch augers respectively. However, when the material was collected from both the auger and the mound

around the auger, the percent of material retained on the 1.5 inch sieve averaged 19.6% and 24.7% for the same augers. It is clear that the 4 and 6-inch augers are capable of bringing up some of the coarser material, but are unable to retain the material once the auger is out of the ground.

(5) Different sample splitting techniques may affect the final size distribution.
Three reducing techniques were used in conjunction with the 8-inch auger. The first two sample splitting techniques consisted of collecting all the material on a large mat and splitting it with a shovel. The third method of reducing the sample size consists of only collecting one in every 3 or 4 auger flights of material (random sampling). The average percent of material retained on the 1.5 inch sieve was 25.8% for one of the shovel splitting techniques, 32.2% for the other shovel splitting technique, and 29.5% using the random sampling technique. Analysis of the sample reduction techniques suggests that any of the three methods are acceptable since similar results were obtained.

Summary

Whenever possible, it is best to use the channel sampling technique to obtain samples in a coarse sand and gravel deposit. It is recommended that an 8x8-inch trench (or larger) be excavated, all the material be collected, mixed, and then the sample should be split, using either of the shovel techniques described in the methodology section. However, many sand and gravel deposits are thick (>10 or 15 feet) making trench sampling unfeasible. In these cases drilling is required to reach greater depths. Drilling is also often a more desirable method for exploration because it does not disturb the land surface as much as trenching. Not only does drilling minimize the affects on vegetation, but drilling is also faster and less expensive than trenching.

When drilling a deposit with material smaller than one inch in size, any of the 4, 6, or 8-inch diameter augers should work well. However, when drilling a deposit with material typically greater than one inch, it is recommended that larger diameter augers be used (8-inch, or 10-inch if available). It is recommended that all the material removed from the hole (including the material on the auger and from the mound) be sampled, not just the material retained on the auger. Collect the material on a mat, mix, and divide it using either of the shovel splitting techniques. Random sampling should only be used with larger diameter augers (8-inch, 10-inch, or larger diameters). If random sampling is used on smaller augers, it is important to sample from both the auger and the mound around the auger at equal proportions; sample one in every three augers, and then collect about one third of the mound.

The above described techniques will represent a coarse sand and gravel deposit with much more accuracy. Using a smaller diameter auger in a coarse deposit, such as the one at Bayport, will under represent the coarse material and over represent the fine material. If an 8 or 10-inch auger is not available, it is still very important to collect both the material off the auger and from the mound around the hole.

The results discussed above show several interesting and distinct trends. However, further statistical analysis and much more drilling, sampling, and geo-statistics are necessary. This study was meant to confirm and quantify some of the field observations that were observed by several of our geologists and was not meant to be a detailed statistical analysis of the data.

APPENDICES

APPENDIX A
(Sieve Analysis Data)

Sieve	4in-A	4in-B	4in-C	4in-D	4in-E	4in-F	4in-G	4in-H	4in-I
1.5	18.2	23.0	17.5	4.8	10.6	5.1	3.5	7.1	6.6
1	3.0	6.0	7.0	6.9	5.8	4.3	4.7	3.7	4.5
3/4	2.5	4.0	5.7	5.5	3.0	2.8	5.2	7.2	4.8
5/8	4.1	2.4	3.3	3.0	1.7	2.5	2.3	4.7	3.9
½	1.9	1.8	3.5	3.7	2.5	5.2	2.3	3.4	3.1
3/8	2.9	3.6	2.1	4.0	3.8	2.9	5.7	3.1	11.6
#4	8.0	8.6	8.4	9.3	10.8	9.6	12.5	9.2	10.4
#8	7.0	8.9	7.8	8.1	9.8	8.9	10.8	8.4	5.7
#10	4.0	5.4	4.2	4.1	5.1	5.0	5.2	5.0	8.9
#16	6.1	7.0	5.7	6.1	7.6	7.2	7.2	7.2	23.3
#30	18.8	13.8	15.2	19.6	19.2	18.9	18.3	20.0	7.0
#40	9.5	5.6	7.7	9.5	8.1	9.3	7.0	8.8	4.2
#50	7.6	4.0	6.5	7.3	6.0	9.2	4.7	6.6	3.2
#100	4.9	4.0	4.0	5.7	4.4	7.4	7.4	3.9	1.6
#200	0.9	0.9	0.8	1.6	0.9	1.1	2.2	0.8	0.6
PAN	0.7	1.0	0.5	0.8	0.6	0.5	1.1	0.9	0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sieve analysis results using the 4-inch auger; numbers represent the percent of material retained on each sieve (by weight).

Sieve	6in-A	6in-B	6in-C	6in-D	6in-E	6in-F	6in-G	6in-H	6in-I
1.5	26.3	22.8	25.0	12.7	9.6	3.6	26.3	33.4	27.6
1	6.2	7.0	5.6	3.2	2.7	4.2	8.8	2.8	3.7
3/4	5.0	3.0	2.7	3.0	3.9	5.6	4.8	4.1	3.5
5/8	3.0	3.6	3.8	2.6	2.4	3.3	3.5	5.1	4.1
½	4.8	4.1	3.4	3.9	4.3	3.1	6.0	6.8	5.6
3/8	4.4	10.2	9.2	4.0	3.2	2.5	3.6	2.7	3.7
#4	11.0	9.8	7.6	11.6	12.0	13.8	10.6	8.9	8.2
#8	8.2	5.6	3.9	11.5	10.5	13.1	7.6	6.4	6.4
#10	3.7	7.8	5.4	5.5	5.0	6.9	3.2	3.2	3.9
#16	4.8	12.8	15.3	7.4	6.8	9.0	4.5	4.9	6.0
#30	11.7	6.1	7.2	19.1	18.5	18.4	11.0	11.8	14.7
#40	4.5	2.8	5.1	7.0	7.8	6.5	3.6	4.3	5.0
#50	2.7	2.5	3.6	4.2	5.8	4.6	2.2	2.8	3.3
#100	2.1	0.8	1.2	3.2	5.8	4.3	2.4	1.9	3.2
#200	0.7	0.5	0.7	0.6	1.0	0.6	0.8	0.4	0.6
PAN	0.8	0.7	0.4	0.5	0.7	0.6	1.2	0.4	0.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sieve analysis results using the 6-inch auger; numbers represent the percent of material retained on each sieve (by weight).

Sieve	8in-A	8in-B	8in-C	8in-D	8in-E	8in-F	8in-G	8in-H	8in-I
1.5	38.9	18.7	19.6	34.0	29.5	33.1	28.6	28.2	31.8
1	3.9	3.9	6.4	4.7	4.2	11.0	10.1	4.4	5.1
3/4	5.3	2.8	3.5	2.1	3.8	5.1	3.0	4.0	5.5
5/8	3.6	3.0	3.7	2.3	2.7	3.2	3.4	2.1	3.7
½	7.4	2.3	4.7	5.1	1.9	3.1	7.3	4.4	5.0
3/8	7.2	2.5	9.5	5.6	5.4	3.8	3.7	5.8	9.1
#4	5.4	7.7	10.2	8.4	7.9	8.0	9.1	7.8	7.5
#8	2.7	8.4	5.7	7.2	7.6	5.7	5.9	6.2	4.0
#10	3.5	5.1	6.6	3.3	4.1	3.3	3.0	3.3	6.0
#16	9.2	7.4	13.9	4.5	5.8	4.4	4.7	4.5	11.9
#30	4.0	16.7	6.2	12.3	14.1	10.1	11.5	11.8	3.8
#40	2.4	7.1	4.5	4.5	5.4	3.7	3.8	5.9	2.5
#50	2.7	4.6	3.6	2.6	3.4	2.6	2.3	5.2	2.1
#100	1.3	6.2	0.8	1.9	2.8	2.0	2.4	4.9	1.2
#200	1.5	2.3	0.7	0.7	0.7	0.4	0.6	0.9	0.4
PAN	0.9	1.2	0.4	0.6	0.8	0.6	0.6	0.6	0.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sieve analysis results using the 8-inch auger; numbers represent the percent of material retained on each sieve (by weight).

Sieve	Tr4x4-A	Tr4x4-B	Tr8x8-C	Tr8x8-D	Tr4x8-E	Tr4x8-F
1.5	31.4	30.2	40.2	45.6	32.2	36.9
1	4.4	8.0	4.8	6.7	6.9	4.8
3/4	5.3	5.7	5.9	2.4	2.3	6.5
5/8	3.1	4.0	2.3	1.0	3.1	3.6
½	0.0	2.4	5.5	4.3	4.6	5.6
3/8	4.7	1.5	2.8	5.4	7.3	3.5
#4	7.6	9.3	6.5	5.6	6.1	7.4
#8	6.6	7.6	5.2	3.8	2.9	4.5
#10	3.5	4.0	2.7	1.5	3.9	1.9
#16	4.7	5.4	4.1	2.0	13.1	2.7
#30	13.1	11.6	10.1	8.9	9.9	10.2
#40	6.2	4.6	4.8	6.6	3.2	5.7
#50	4.2	2.9	2.2	2.7	2.6	3.1
#100	3.5	1.9	1.5	2.2	0.6	2.5
#200	1.0	0.4	0.4	0.5	0.7	0.5
PAN	0.7	0.5	1.0	0.7	0.6	0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Sieve analysis results using channel sampling; numbers represent the percent of material retained on each sieve (by weight). Three channel samples were excavated: 4x4, 4x8, and 8x8-inch by 5 feet.

APPENDIX B
(Sieve Analysis Data-by technique)

Sieve	Tr-A	Tr-B	4x4
1.5	31.4	30.2	30.8
1	4.4	8.0	6.2
3/4	5.3	5.7	5.5
5/8	3.1	4.0	3.6
½	0.0	2.4	1.2
3/8	4.7	1.5	3.1
#4	7.6	9.3	8.5
#8	6.6	7.6	7.1
#10	3.5	4.0	3.7
#16	4.7	5.4	5.0
#30	13.1	11.6	12.4
#40	6.2	4.6	5.4
#50	4.2	2.9	3.5
#100	3.5	1.9	2.7
#200	1.0	0.4	0.7
PAN	0.7	0.5	0.6
Total	100.0	100.0	100.0

Sieve	Tr-C	Tr-D	8x8
1.5	40.2	45.6	42.9
1	4.8	6.7	5.7
3/4	5.9	2.4	4.1
5/8	2.3	1.0	1.7
½	5.5	4.3	4.9
3/8	2.8	5.4	4.1
#4	6.5	5.6	6.0
#8	5.2	3.8	4.5
#10	2.7	1.5	2.1
#16	4.1	2.0	3.1
#30	10.1	8.9	9.5
#40	4.8	6.6	5.7
#50	2.2	2.7	2.4
#100	1.5	2.2	1.8
#200	0.4	0.5	0.4
PAN	1.0	0.7	0.9
Total	100.0	100.0	100.0

Sieve	Tr-E	Tr-F	4x8
1.5	32.2	36.9	34.6
1	6.9	4.8	5.9
3/4	2.3	6.5	4.4
5/8	3.1	3.6	3.4
½	4.6	5.6	5.1
3/8	7.3	3.5	5.4
#4	6.1	7.4	6.8
#8	2.9	4.5	3.7
#10	3.9	1.9	2.9
#16	13.1	2.7	7.9
#30	9.9	10.2	10.1
#40	3.2	5.7	4.4
#50	2.6	3.1	2.8
#100	0.6	2.5	1.6
#200	0.7	0.5	0.6
PAN	0.6	0.6	0.6
Total	100.0	100.0	100.0

Sieve	Avg. 4x4	Avg. 4x8	Avg. 8x8
1.5	30.8	34.6	42.9
1	6.2	5.9	5.7
3/4	5.5	4.4	4.1
5/8	3.6	3.4	1.7
½	1.2	5.1	4.9
3/8	3.1	5.4	4.1
#4	8.5	6.8	6.0
#8	7.1	3.7	4.5
#10	3.7	2.9	2.1
#16	5.0	7.9	3.1
#30	12.4	10.1	9.5
#40	5.4	4.4	5.7
#50	3.5	2.8	2.4
#100	2.7	1.6	1.8
#200	0.7	0.6	0.4
PAN	0.6	0.6	0.9
Total	100.0	100.0	100.0

Results and breakdown of the sieve analysis of the channel samples with values given as percentage of material retained on the sieve by weight. Three different sized channels were cut on a vertical mine wall; two 4x4-inch trenches, two 4x8-inch trenches, and two 8x8-inch trenches. Note the natural variation between the samples ranges from 0.6 - 2.7% within each sampling technique.

Sieve	8in-A	8in-B	8in-C	Shovel
1.5	38.9	18.7	19.6	25.8
1	3.9	3.9	6.4	4.7
3/4	5.3	2.8	3.5	3.9
5/8	3.6	3.0	3.7	3.4
½	7.4	2.3	4.7	4.8
3/8	7.2	2.5	9.5	6.4
#4	5.4	7.7	10.2	7.8
#8	2.7	8.4	5.7	5.6
#10	3.5	5.1	6.6	5.1
#16	9.2	7.4	13.9	10.2
#30	4.0	16.7	6.2	9.0
#40	2.4	7.1	4.5	4.7
#50	2.7	4.6	3.6	3.6
#100	1.3	6.2	0.8	2.7
#200	1.5	2.3	0.7	1.5
PAN	0.9	1.2	0.4	0.9
Total	100.0	100.0	100.0	100.0

Sieve	8in-D	8in-E	8in-F	Cone
1.5	34.0	29.5	33.1	32.2
1	4.7	4.2	11.0	6.6
3/4	2.1	3.8	5.1	3.7
5/8	2.3	2.7	3.2	2.7
½	5.1	1.9	3.1	3.3
3/8	5.6	5.4	3.8	4.9
#4	8.4	7.9	8.0	8.1
#8	7.2	7.6	5.7	6.8
#10	3.3	4.1	3.3	3.6
#16	4.5	5.8	4.4	4.9
#30	12.3	14.1	10.1	12.2
#40	4.5	5.4	3.7	4.5
#50	2.6	3.4	2.6	2.9
#100	1.9	2.8	2.0	2.2
#200	0.7	0.7	0.4	0.6
PAN	0.6	0.8	0.6	0.7
Total	100	100	100	100.0

Sieve	8in-G	8in-H	8in-I	Rndm
1.5	28.6	28.2	31.8	29.5
1	10.1	4.4	5.1	6.5
3/4	3.0	4.0	5.5	4.2
5/8	3.4	2.1	3.7	3.1
½	7.3	4.4	5.0	5.6
3/8	3.7	5.8	9.1	6.2
#4	9.1	7.8	7.5	8.1
#8	5.9	6.2	4.0	5.4
#10	3.0	3.3	6.0	4.1
#16	4.7	4.5	11.9	7.0
#30	11.5	11.8	3.8	9.0
#40	3.8	5.9	2.5	4.1
#50	2.3	5.2	2.1	3.2
#100	2.4	4.9	1.2	2.9
#200	0.6	0.9	0.4	0.6
PAN	0.6	0.6	0.4	0.5
Total	100.0	100.0	100.0	100.0

Sieve	Avg. Shovel	Avg. Cone	Avg. Rndm
1.5	25.8	32.2	29.5
1	4.7	6.6	6.5
3/4	3.9	3.7	4.2
5/8	3.4	2.7	3.1
½	4.8	3.3	5.6
3/8	6.4	4.9	6.2
#4	7.8	8.1	8.1
#8	5.6	6.8	5.4
#10	5.1	3.6	4.1
#16	10.2	4.9	7.0
#30	9.0	12.2	9.0
#40	4.7	4.5	4.1
#50	3.6	2.9	3.2
#100	2.7	2.2	2.9
#200	1.5	0.6	0.6
PAN	0.9	0.7	0.5
Total	100.0	100.0	100.0

Results and breakdown of the sieve analysis of the 8-inch auger samples. Three different splitting/reducing techniques were used to decrease the sample size to 30 pounds. Two of the splitting techniques (shovel and cone) are similar to ASTM methods and the third method consisted of random (Rndm) sampling off the auger. Note the natural variation between the samples for the random and cone techniques only ranges from 1.3 to 2.7%, but is much larger for the shovel method.

Sieve	4in-A	4in-B	4in-C	Agr/Mnd
1.5	18.2	23.0	17.5	19.6
1	3.0	6.0	7.0	5.4
3/4	2.5	4.0	5.7	4.0
5/8	4.1	2.4	3.3	3.3
½	1.9	1.8	3.5	2.4
3/8	2.9	3.6	2.1	2.9
#4	8.0	8.6	8.4	8.3
#8	7.0	8.9	7.8	7.9
#10	4.0	5.4	4.2	4.5
#16	6.1	7.0	5.7	6.3
#30	18.8	13.8	15.2	15.9
#40	9.5	5.6	7.7	7.6
#50	7.6	4.0	6.5	6.1
#100	4.9	4.0	4.0	4.3
#200	0.9	0.9	0.8	0.9
PAN	0.7	1.0	0.5	0.7
Total	100.0	100.0	100.0	100.0

Sieve	4in-D	4in-E	4in-F	Auger1
1.5	4.8	10.6	5.1	6.8
1	6.9	5.8	4.3	5.7
3/4	5.5	3.0	2.8	3.8
5/8	3.0	1.7	2.5	2.4
½	3.7	2.5	5.2	3.8
3/8	4.0	3.8	2.9	3.6
#4	9.3	10.8	9.6	9.9
#8	8.1	9.8	8.9	8.9
#10	4.1	5.1	5.0	4.7
#16	6.1	7.6	7.2	7.0
#30	19.6	19.2	18.9	19.2
#40	9.5	8.1	9.3	9.0
#50	7.3	6.0	9.2	7.5
#100	5.7	4.4	7.4	5.8
#200	1.6	0.9	1.1	1.2
PAN	0.8	0.6	0.5	0.7
Total	100.0	100.0	100.0	100.0

Sieve	4in-G	4in-H	4in-I	Auger2
1.5	3.5	7.1	6.6	5.7
1	4.7	3.7	4.5	4.3
3/4	5.2	7.2	4.8	5.7
5/8	2.3	4.7	3.9	3.6
½	2.3	3.4	3.1	2.9
3/8	5.7	3.1	11.6	6.8
#4	12.5	9.2	10.4	10.7
#8	10.8	8.4	5.7	8.3
#10	5.2	5.0	8.9	6.4
#16	7.2	7.2	23.3	12.5
#30	18.3	20.0	7.0	15.1
#40	7.0	8.8	4.2	6.7
#50	4.7	6.6	3.2	4.8
#100	7.4	3.9	1.6	4.3
#200	2.2	0.8	0.6	1.2
PAN	1.1	0.9	0.6	0.9
Total	100.0	100.0	100.0	100.0

Sieve	Avg. Agr/M	Avg. Auger1	Avg. Auger2
1.5	19.6	6.8	5.7
1	5.4	5.7	4.3
3/4	4.0	3.8	5.7
5/8	3.3	2.4	3.6
½	2.4	3.8	2.9
3/8	2.9	3.6	6.8
#4	8.3	9.9	10.7
#8	7.9	8.9	8.3
#10	4.5	4.7	6.4
#16	6.3	7.0	12.5
#30	15.9	19.2	15.1
#40	7.6	9.0	6.7
#50	6.1	7.5	4.8
#100	4.3	5.8	4.3
#200	0.9	1.2	1.2
PAN	0.7	0.7	0.9
Total	100.0	100.0	100.0

Results and breakdown of the sieve analysis of the 4-inch auger samples. Two sampling techniques were used to determine how much of the coarse material fell off the auger when it came out of the ground. For samples A-C both the material on the auger and on the ground (mound/pile) were collected, whereas for samples D-I only the material on the auger was sampled.

Sieve	6in-A	6in-B	6in-C	Agr/Mnd
1.5	26.3	22.8	25.0	24.7
1	6.2	7.0	5.6	6.2
3/4	5.0	3.0	2.7	3.6
5/8	3.0	3.6	3.8	3.5
½	4.8	4.1	3.4	4.1
3/8	4.4	10.2	9.2	7.9
#4	11.0	9.8	7.6	9.5
#8	8.2	5.6	3.9	5.9
#10	3.7	7.8	5.4	5.6
#16	4.8	12.8	15.3	10.9
#30	11.7	6.1	7.2	8.3
#40	4.5	2.8	5.1	4.1
#50	2.7	2.5	3.6	3.0
#100	2.1	0.8	1.2	1.4
#200	0.7	0.5	0.7	0.6
PAN	0.8	0.7	0.4	0.6
Total	100.0	100.0	100.0	100.0

Sieve	6in-D	6in-E	6in-F	Auger
1.5	12.7	9.6	3.6	8.7
1	3.2	2.7	4.2	3.4
3/4	3.0	3.9	5.6	4.2
5/8	2.6	2.4	3.3	2.7
½	3.9	4.3	3.1	3.7
3/8	4.0	3.2	2.5	3.2
#4	11.6	12.0	13.8	12.5
#8	11.5	10.5	13.1	11.7
#10	5.5	5.0	6.9	5.8
#16	7.4	6.8	9.0	7.7
#30	19.1	18.5	18.4	18.7
#40	7.0	7.8	6.5	7.1
#50	4.2	5.8	4.6	4.9
#100	3.2	5.8	4.3	4.4
#200	0.6	1.0	0.6	0.7
PAN	0.5	0.7	0.6	0.6
Total	100.0	100.0	100.0	100.0

Sieve	6in-G	6in-H	6in-I	Mound
1.5	26.3	33.4	27.6	29.1
1	8.8	2.8	3.7	5.1
3/4	4.8	4.1	3.5	4.1
5/8	3.5	5.1	4.1	4.2
½	6.0	6.8	5.6	6.1
3/8	3.6	2.7	3.7	3.4
#4	10.6	8.9	8.2	9.2
#8	7.6	6.4	6.4	6.8
#10	3.2	3.2	3.9	3.4
#16	4.5	4.9	6.0	5.1
#30	11.0	11.8	14.7	12.5
#40	3.6	4.3	5.0	4.3
#50	2.2	2.8	3.3	2.8
#100	2.4	1.9	3.2	2.5
#200	0.8	0.4	0.6	0.6
PAN	1.2	0.4	0.5	0.7
Total	100.0	100.0	100.0	100.0

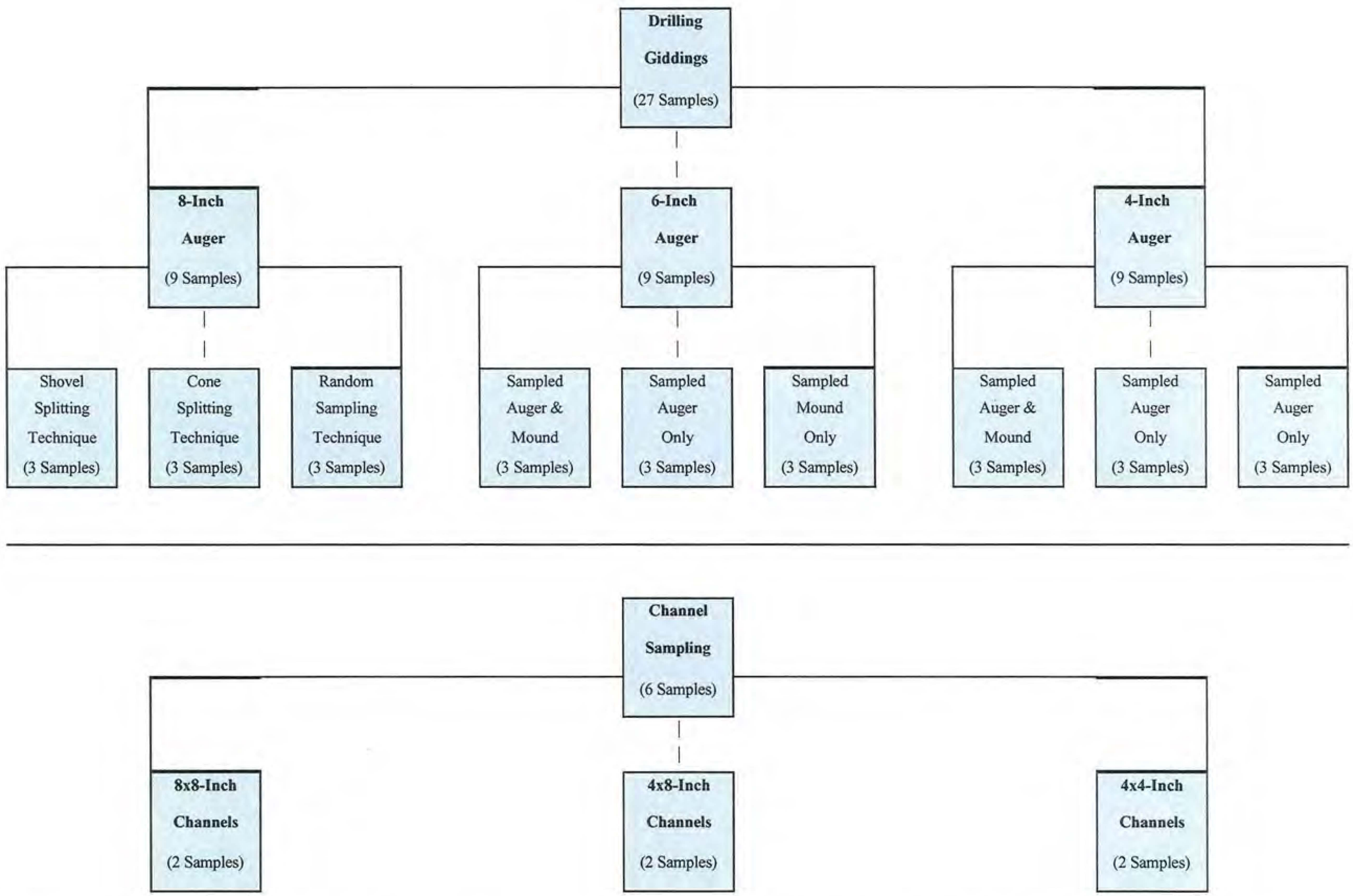
Sieve	Avg. Agr/M	Avg. Auger	Avg. Mound
1.5	24.7	8.7	29.1
1	6.2	3.4	5.1
3/4	3.6	4.2	4.1
5/8	3.5	2.7	4.2
½	4.1	3.7	6.1
3/8	7.9	3.2	3.4
#4	9.5	12.5	9.2
#8	5.9	11.7	6.8
#10	5.6	5.8	3.4
#16	10.9	7.7	5.1
#30	8.3	18.7	12.5
#40	4.1	7.1	4.3
#50	3.0	4.9	2.8
#100	1.4	4.4	2.5
#200	0.6	0.7	0.6
PAN	0.6	0.6	0.7
Total	100.0	100.0	100.0

Results and breakdown of the sieve analysis of the 6-inch auger samples. Two sampling techniques were used to determine how much of the coarse material fell off the auger when it came out of the ground. For samples A-C and G-I, both the material on the auger and on the ground (mound/pile) were collected, whereas for samples D-F only the material on the auger was sampled.

APPENDIX C
(Volumes of Channels and Test Holes)

Sampling Technique	Volume (cubic in.)
4x4-inch Channel x 60 inches	960
4x8-inch Channel x 60 inches	1920
8x8-inch Channel x 60 inches	3840
4-inch Drill Hole x 60 inches	754
6-inch Drill Hole x 60 inches	1698
8-inch Drill Hole x 60 inches	3016

APPENDIX D
(Summary Table of Techniques and Results)



Summary of the different sampling and reduction techniques used within this study for both drilling and channel sampling.

Test (Hypotheses)	Sampling Technique	Samples Collected	1.5-in Material Retained	Weight Recovery
Channel Sampling Techniques	8x8-inch Channel (Control Sample)	TR-C & D	42.9%	100%
	4x8-inch Channel	TR-E & F	34.6%	81%
	4x4-inch Channel	TR-A & B	30.8%	72%
Auger Sampling (best method)	8-inch Auger	8in-A,B,C,D,E,F,G,H, & I	29.2%	68%
	6-inch Test Hole - Auger & Mound	6in-A,B, & C	24.7%	58%
	4-inch Test Hole - Auger & Mound	4in-A,B, & C	19.6%	46%
Auger Diameter Testing	8-inch Auger	8in-A,B,C,D,E,F,G,H, & I	29.2%	68%
	6-inch Auger	6in-D,E, & F	8.7%	20%
	4-inch Auger	4in-D,E,F,G,H, & I	6.3%	15%
Sample Reduction Techniques	8-inch Test Hole - Shovel	8in-A,B, & C	25.8%	60%
	8-inch Test Hole - Cone	8in-D,E, & F	32.2%	75%
	8-inch Test Hole - Random	8in-G,H, & I	29.5%	69%
Sampling Techniques (auger vs. mound)	6-inch Test Hole - Mound	6in-G,H, & I	29.1%	68%
	6-inch Test Hole - Auger & Mound	6in-A,B, & C	24.7%	58%
	6-inch Test Hole - Auger	6in-D,E, & F	8.7%	20%
Sampling Techniques (auger vs. mound)	4-inch Test Hole - Auger & Mound	4in-A,B, & C	19.6%	46%
	4-inch Test Hole - Auger	4in-D,E, & F	6.8%	16%
	4-inch Test Hole - Auger	4in-G,H, & I	5.7%	13%

RESULTS: Summary table listing the hypothesis tested, the sampling technique used, the samples used, the percentage of material retained on the 1.5 inch sieve (by weight), and the weight recovery percent (relative to the 8x8-inch channel control sample).