Appendix E: Coastal and Environmental Geosciences File Report No. 14-05: Susquehanna River Flat Surficial Sediment Survey, Harford and Cecil Counties, Maryland

Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Jeffrey P. Halka, Director

COASTAL AND ENVIROMENTAL GEOSCIENCES
FILE REPORT NO. 14-05

SUSQUEHANNA RIVER FLATS
SURFICIAL SEDIMENT SURVEY
HARFORD AND CECIL COUNTIES, MARYLAND

by
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INTRODUCTION

The Susquehanna River is the largest tributary to the Chesapeake Bay delivering one-half of all freshwater to the bay with a drainage basin incorporating six states. The mouth of this river is impounded by several dams with the last being Conowingo Dam. Historically, these dams functioned as sediment traps, reducing the amount of sediments and associated nutrients reaching the Chesapeake Bay. Over time, the trapping efficiency of these dams has diminished as the volume of sediment trapped behind the dams approached storage capacity. As a result, increasingly more sediments bypass the dams and enter into the Chesapeake Bay. There is growing concern that, if not properly managed, the increase in sediment delivery to the Chesapeake Bay will have deleterious effects on the ecosystem.

Sediment transport and storage is greatly controlled by the amount of energy within the water column, the extent which that energy exerts on the bottom sediments, and the character of the bottom sediments. As part of the Lower Susquehanna River Watershed Assessment, the Army Corps of Engineers, in cooperation with the Maryland Department of the Environment, has conducted a modeling effort to assess sediment transport under various flow conditions. Knowledge of the grain size characteristics of the bottom sediments is a requirement for accurate modeling both in the portion of the river below the dam and the Susquehanna Flats area of the Upper Chesapeake Bay.

In support of this need, the Resource Assessment Service, Maryland Geological Survey (MGS) collected a series of surficial grab samples in the Susquehanna Flats area of the Upper Chesapeake Bay (Figure 1) and analyzed the sediment samples for textural properties.

METHODS

Field Methods

On May 2, 2012, MGS staff collected 16 sediment grab samples in the Susquehanna Flats area of the Upper Chesapeake Bay (Figure 1). A 17-ft Boston Whaler was used to collect the samples. The sample locations were determined through consultation with the Army Corps of Engineers based on existing sediment sample data that was available and the appropriate locations for model input and verification. Two proposed sample locations (#1 and #2) were located in the Susquehanna River. However, preliminary flow modeling indicated that bedrock would be exposed at these locations (Email from Steve Scott to Jeff Halka, dated 3/23/2012). Therefore, these locations were not sampled.

Locations of the sediment samples were documented in the field using a Thales Navigation Promark 3 GPS receiver. Location coordinates were recorded in UTM, NAD83, meters.

Sediment samples were collected with a hand-operated LaMotte stainless-steel dredge which sampled a bottom surface area of 19 cm x 14 cm and a mean sediment depth of 5 cm. Upon collection, the samples were placed in Whirl-Pak™ bags and kept cool until delivery to the MGS laboratory where they were refrigerated at 4˚ C until analyses.

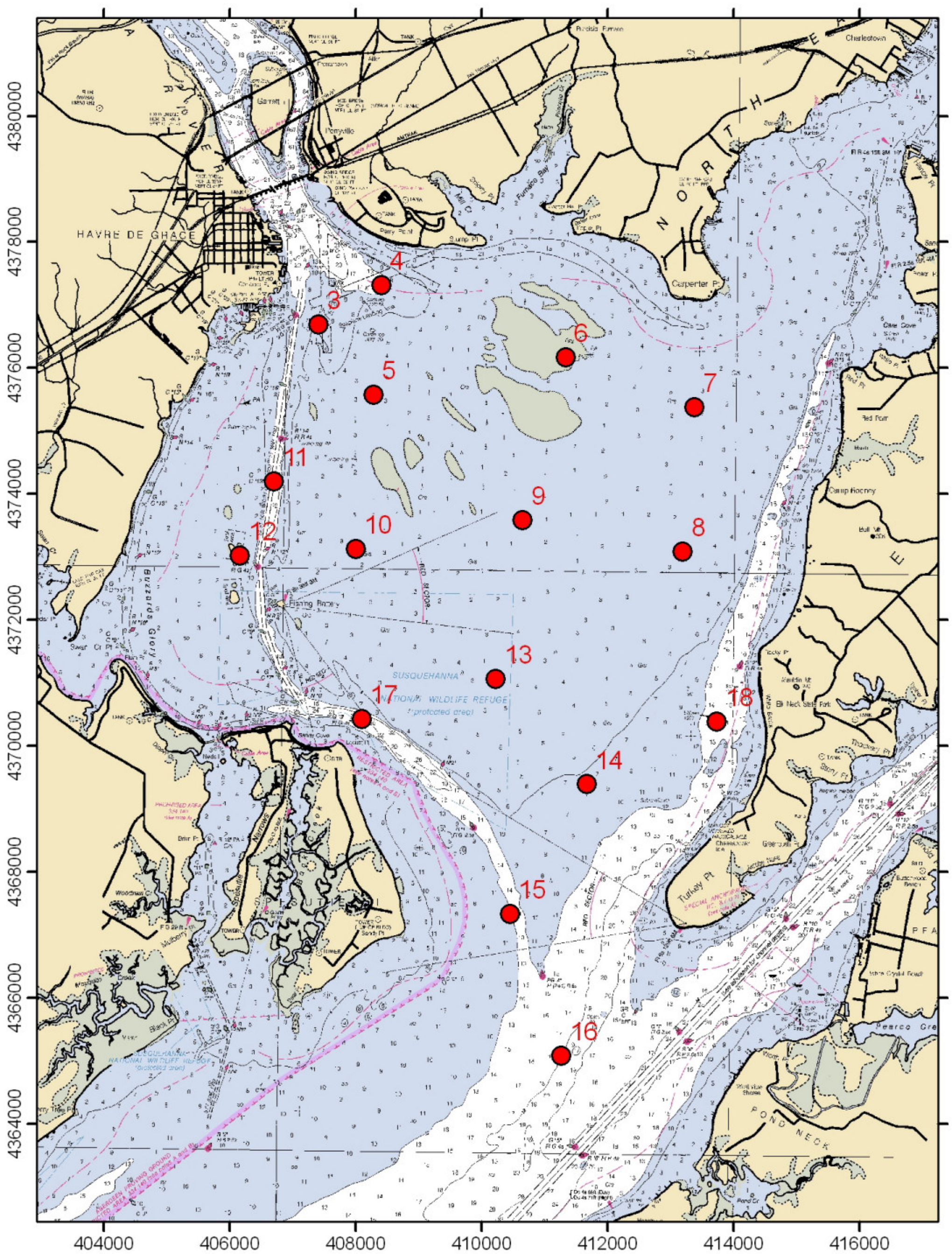

Figure 1. Locations of sediment samples collected in Susquehanna River Flats. Samples 1 and 2 were originally planned for upstream of the location map; however, the lack of sediment in the proposed locations created conditions that made sediment collection at those locations not possible with the methodology used in this study.

Laboratory Methods

Sediment grab samples were analyzed for water content, bulk density, and grain size (sand, silt, clay contents, as well as gravel, when present). Two homogeneous splits of each sample were processed, one for bulk property analyses and the other for grain-size characterization. Analyses were performed as soon as possible after sample collection, and all samples were refrigerated in sealed Whirl-Pak™ plastic bags prior to analysis.

Water content was determined by weighing 20-30 g of sediment; the sediment was dried at 65°C, and then re-weighing the dried sediment. Water content was calculated as the percentage of water weight to the weight of the wet sediment using Equation 1.

$$\%Water = \frac{W_w}{W_t} * 100 \qquad \text{Equation 1}$$

where: $\boldsymbol{W_w}$ is the weight of water;

and

$\boldsymbol{W_t}$ is the weight of wet sediment.

Wet bulk density (ρ_B) is calculated from water content utilizing Equation 2 by assuming an average grain density (ρ_s) of 2.72 g/cm^3 and saturation of voids with water of density ρ_w = 1.0 g/cm^3. This method was adopted from the work of Bennett and Lambert (1971):

$$\rho_B = \frac{W_t}{W_d \ / \ 2.72 + W_w} \qquad \text{Equation 2}$$

where $\boldsymbol{W_d}$ is the weight of dry sediment.

Gravel, sand, silt and clay contents were determined using the textural analysis detailed in Kerhin and others (1988). Grain size, in this report (Table 1), is given in phi units, a scale devised by Krumbein (1936) where phi is define as negative log (to the base 2) of the particle diameter (mm). For example, 4 phi corresponds to a particle with a diameter of 1 /2^4 mm (=1/16 mm, or 0.0625 mm or 62.5 microns).

Grain size analysis consisted of cleaning the sediment samples in solutions of 10 percent hydrochloric acid and 6 or 15 percent hydrogen peroxide (determined by water content) with subsequent rinsing with deionized water. This process removed soluble salts, carbonates, and organic matter that could interfere with the dis-aggregation of the individual grains. The samples were then treated with a 0.26 percent solution of the dispersant sodium hexametaphosphate ($(NaPO_3)_6$) to ensure that individual grains did not re-aggregate (flocculate) during pipette analysis.

The separation of sand and silt-clay (mud) portions of the sample was accomplished by wet-sieving through a 4-phi mesh sieve (0.0625 mm, U.S. Standard Sieve #230). The gravel-sand fraction (*i.e.* that portion of the sample not passing thought the sieve) was dried and weighed, and saved for further analysis. The finer silt and clay-sized particles (*i. e.*, passing the through the sieve) were suspended in a 1000 ml cylinder in a solution of 0.26 percent sodium hexametaphosphate. The suspension was agitated and, at specified times thereafter; 20 ml pipette withdrawals are made (Carver, 1971; Folk, 1974). The rationale behind this process is that larger particles settle faster than smaller ones (Stoke's law). By calculating the settling velocities for different sized particles, times for withdrawal can be determined at which all particles of a specified size will have settled past the point of withdrawal. Sampling times were calculated to permit the determination of the amount of particles corresponding to 4 phi, 5 phi, 6 phi, 7 phi (silt subclasses) and clay sized (8 phi) particles in the suspension. Withdrawn samples are dried at 65°C and weighed. From these data the percentages by dry weight of sand, silt, and clay were calculated for each sample and classified according to Shepard (1954) and Folk (1954) nomenclatures (Figures 2 and 3). Sample weight loss due to cleaning was determined; the weight loss approximates the amount of non-clastic component in the sediment.

The sand/gravel fractions of the samples were passed through a series of 3-inch sieves, at whole phi intervals. The largest sieve used corresponds to -2 phi (4 mm mesh). The resulting whole phi size fractions were converted to cumulative weight percentages and incorporated the silt and clay components of the sediment sample, extrapolating the fine-grained end to 14 phi (6×10^{-5} mm)).

Table 1. Sediment grain size definitions used in this study are based on the Wentworth (1922) scale. The term Mud is used to describe all particles smaller than sand (less than 0.0625 millimeters). The term Gravel is used to describe all rock fragment particles that are 2 millimeters or larger.

Descriptor	Grain Size (millimeters)	Class Sizes (phi)
Mud	< 0.0625	> 4
Clay	< 0.004	> 8
Silt	0.004 to 0.0625	> 4 to 8
Sand	0.0625 to 2	4 to -1
Very Fine Sand	0.0625 to 0.125	4 to 3
Fine Sand	0.125 to 0.25	3 to 2
Medium Sand	0.25 to 0.5	2 to 1
Coarse Sand	0.5 to 1	1 to 0
Very Coarse Sand	1 to 2	0 to -1
Gravel	2 to 4,096	-1 to -12
Granule	2 to 4	-1 to -2
Pebble	4 to 64	-1 to -6
Cobble	64 to 256	-6 to -8
Boulder	256 to 4,096	-8 to -12

Based on the cumulative weight distributions of the size fractions, the following Folk (1974) graphic statistical parameters were calculated for each sample.

The graphic mean (M_G) is defined by equation 3.

$$M_G = \frac{phi16 + phi50 + phi84}{3} \qquad \textbf{Equation 3}$$

where *phi16* (or *50, 84..*) is the phi class corresponding to 16th percentile (or 50%, 84%...) on the cumulative weight curve.

This graphic mean corresponds very closely to the mean as computed by the method of moments, yet is much easier to find. Inclusive Graphic Standard Deviation (SD_{IG}), defined by equation 4, gives the best overall measure of sorting (Table 2).

$$SD_{IG} = \frac{phi84 - phi16}{4} + \frac{phi95 - phi5}{6.6} \qquad \textbf{Equation 4}$$

Table 2. Folk definitions of sorting.

SD_{IG} Range	Verbal Description
< 0.35 phi	very well sorted
0.35 - 0.50 phi	well sorted
0.50 - 0.71 phi	moderately well sorted
0.71 - 1.00 phi	moderately sorted
1.00 - 2.00 phi	poorly sorted
2.00 - 4.00 phi	very poorly sorted
> 4.00 phi	extremely poorly sorted

Inclusive Graphic Skewness (Sk_{IG}), define by equation 5, measures the asymmetry of the distribution as well as the direction of the skewness (*i.e.,* excessive coarse tail (-) or excessive fine tail (+)).

$$Sk_{IG} = \frac{phi16 + phi84 - 2*phi50}{2*(phi84 - phi16)} + \frac{phi5 + phi95 - 2*phi50}{2*(phi95 - phi5)} \qquad \textbf{Equation 5}$$

Graphic Kurtosis (K_G) is defined by equation 6. This statistic defines the degree of peakedness or departure from the "normal" frequency or cumulative curve.

$$K_G = \frac{phi95 - phi5}{2.44*(phi75 - phi25)} \qquad \textbf{Equation 6}$$

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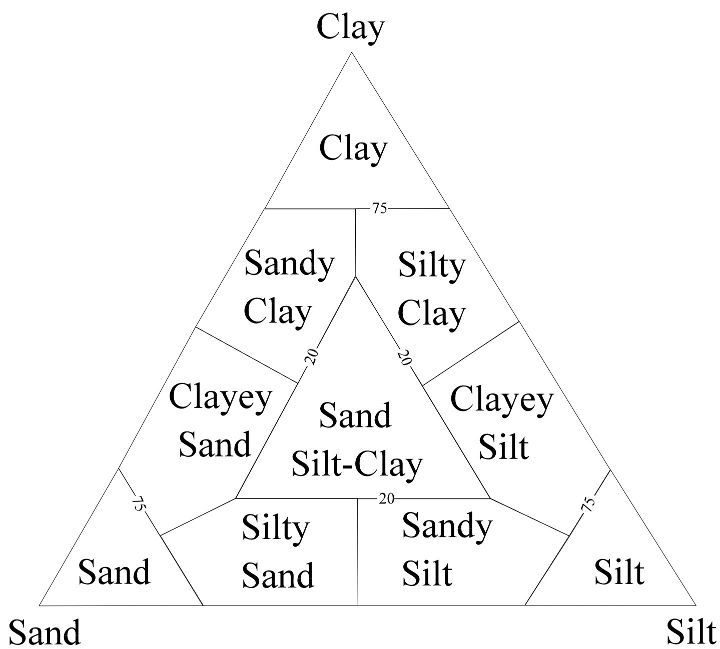
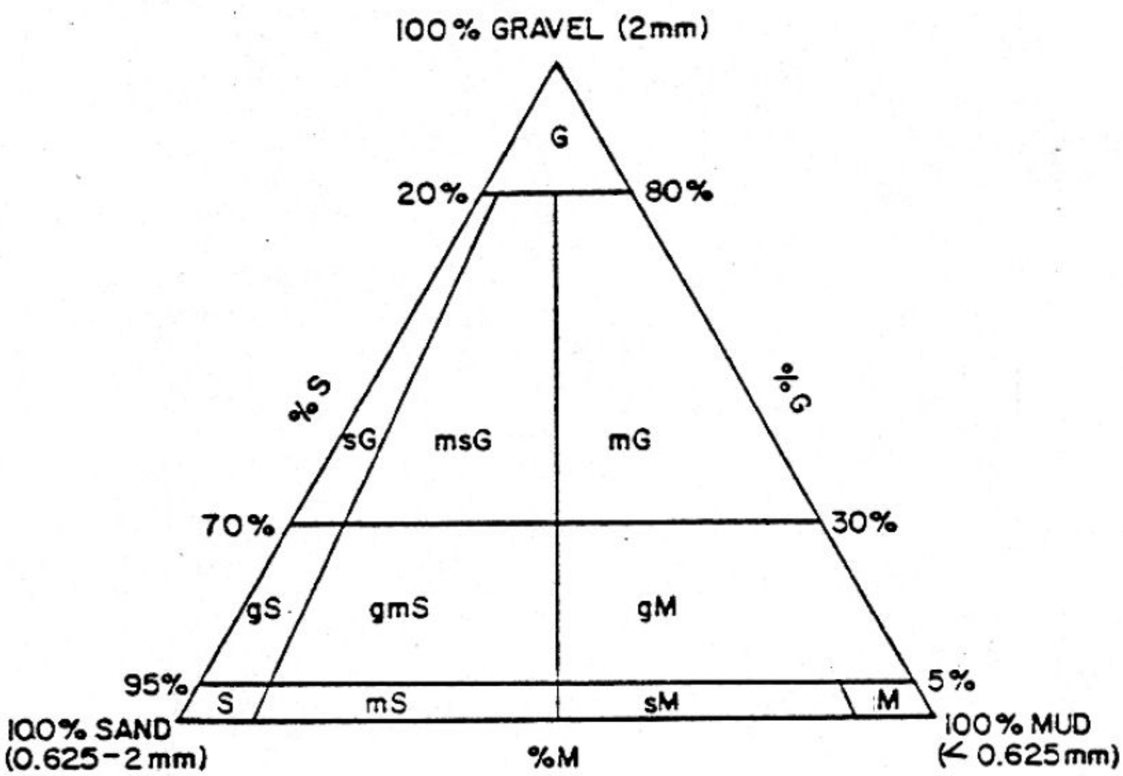


Figure 2. Shepard (1954) classification of sediment types. Sediment type classification is based on relative percentages of each size component (sand, silt and clay).

Figure 3. Folk (1974) classification of sediment types. Sediment type classification is



based on relative percentages of each size component (gravel, sand, and mud [i.e., silt plus clay]).

RESULTS

Field data and results of grain size analyses are presented in Tables 3 through 7. Cumulative grain size curves for each sample are plotted in Figure 4.

Table 3. Location coordinates for sediment grab samples collected on May 2, 2012 in the Susquehanna River Flats, with a count of shells in each sample at each sample site.

Sample ID	Easting (UTM, NAD88, m)	Northing (UTM, NAD88, m)	Depth (ft)	# of alive clams	# of dead clams	MacroAlgae
3	407400	4376697	5	0	0	0
4	408399	4377321	18	0	0	0
5	408276	4375580	2	0	0	0
6 *	411331	4376171	0.5	0	0	0
7	413380	4375384	4	10 (Asian??)	5 to 6	Yes
8	413187	4373089	3.5	0	0	0
9	410648	4373585	2	0	0	0
10	407994	4373124	3	0	0	0
11	406692	4374202	25	tiny?	0	0
12**	406156	4373022	1	0	0	0
13	410220	4371060	5	0	0	0
14	411666	4369390	7.5	0	5 Rangia	0
15	410443	4367334	13	0	4 to 5 Rangia	0
16	411261	4365082	20	5 Rangia	4	0
17	408087	4370427	25	0	0	0
18	413734	4370390	15	1 Rangia	0	0

*Sample #6: Originally planned site was too shallow (<0.5 foot depth) for navigation and collection. Sample was taken as close as possible to location approximately 400 meters from original location. Coordinates are of the actual location of the collected sample.

**Sample #12: Originally planned site was located on or behind an exposed shoal. Sample was taken as close to planned site as possible. Coordinates are of the actual location of the collected sample.

***Sample #17: Sample was very difficult to collect due to sediment type. Sediment was not homogenous as it contained clay balls in a fine well-packed sand matrix.

Table 4. Field descriptions of the sediment samples collected on the Susquehanna River Flats. Colors and color codes (e.g. 5 YR 3/4) from the Rock-Color Chart (Rock-Color Chart Committee, 1984).

Sample ID	Time collected*	Description^	Other
1		Did not sample	River bottom mostly in bedrock outcrop; site eliminated
2		Did not sample	River bottom mostly in bedrock outcrop; site eliminated
3	12:14	Medium brown (5 YR 3/4) m to c sand, several shells (clams), dead, disarticulated	dropped sampler many times; collected small sample
4	12:00	Medium brown (5 YR 3/4) slightly muddy, poorly sorted (f to c) sand, some gravel	very difficult to get sample; dropped sampler 10+ times; collected samples from multiple grabs, hard bottom?
5	9:30	Dark brown (10YR 2/2) to black (N2), vf to f sand; several rooted SAV	
6	11:04	Grey brown (5YR 3/2) f to m sand, with some black (N2) heavy minerals; several SAV roots/rhizomes	
7	10:44	Dark brown (5YR 3/2) slightly muddy vf to f sand with black (N2) heavy minerals and fecal strands; clams, dead, disarticulated	macroalgae and 4-5 clam shells (Asian clam), bagged
8	10:26	Dark brown (10YR 2/2) silty vf sand with black (N2) heavy minerals and fecal strands	
9	10:00	Dark brown (10YR 2/2) with black (N2) heavy minerals and coal particles, muddy, vf sand; rooted SAV; ~0.5 cm floc layer, medium brown (5YR 4/4)	
10	13:00	Medium brown (10YR 4/2) f to m sand, trace coarse sand, coal, trace silt	

Sample ID	Time collected*	Description^	Other
11	12:20	Medium brown (5 YR 3/4) m to c sand; lots of coal particles; juvenile clams, live	
12	12:45	Medium brown (5 YR 3/4) f to m sand with trace silt	
13	13:26	Grey brown (5YR 3/2), very slightly gritty mud, cohesive	
14	13:40	Grey brown (5YR 3/2) muddy, vf sand, few clams, both adult and juvenile, dead, disarticulated	
15	14:25	Medium brown (5 YR 3/4) silty vf to f sand; couple of clams, dead, disarticulated	
16	14:12	Medium brown (10YR 4/2) gritty mud, soft watery; abundant clams, both live and dead	when bagging samples, included some clams
17	15:00	Dark brown (5YR 3/2) slightly silty, very firm, f to m sand with few mud clasts	very difficult to get sample; dropped sampler 10+ times before getting a bottom sample, hard bottom?
18	13:53	Medium brown (10YR 4/2) slightly gritty mud, adult clam, live	
*All samples collected May 2, 2012			
^Size descriptors: vf= very fine; f= fine; m=medium; c= coarse			

Table 5. Cumulative weight percentages corresponding to phi class (whole phi intervals). These values are plotted in Figure 4.

Sample ID	Cumulative % Coarser than Phi Class										
	(-1) Φ	**0 Φ**	**1 Φ**	**2 Φ**	**3 Φ**	**4 Φ**	**5 Φ**	**6 Φ**	**7 Φ**	**8 Φ**	**14 Φ**
3	0.21	0.66	8.13	78.66	93.52	94.89	95.86	96.93	97.95	98.28	100.00
4	1.15	2.14	28.25	80.96	83.70	84.79	87.02	89.97	93.25	95.09	100.00
5	0.00	0.00	0.20	51.81	86.20	93.24	96.35	97.49	98.20	98.58	100.00
6	0.00	0.34	2.68	10.26	82.54	89.93	93.30	95.40	96.84	97.60	100.00
7	0.00	0.28	3.27	12.19	57.84	78.41	86.14	90.78	93.50	95.06	100.00
8	0.00	0.05	0.91	7.63	27.98	66.67	72.66	81.30	86.78	90.61	100.00
9	0.00	0.46	1.82	11.99	71.54	78.40	83.75	89.23	92.46	95.08	100.00
10	0.00	0.45	3.16	62.44	88.96	91.43	93.98	95.79	96.85	98.18	100.00
11	0.00	1.55	11.23	90.73	97.15	98.07	98.68	98.98	99.13	99.49	100.00
12	0.00	0.02	1.00	53.03	62.62	74.35	83.87	88.86	91.71	94.63	100.00
13	0.00	0.00	0.04	0.16	0.45	2.29	13.36	38.72	55.97	66.97	100.00
14	0.00	0.06	0.32	4.10	13.91	43.05	58.96	76.28	84.41	87.68	100.00
15	0.00	0.46	1.50	12.95	55.19	80.65	86.04	90.59	92.88	94.74	100.00
16	0.00	0.22	1.46	11.24	20.03	44.46	54.69	68.55	76.73	82.42	100.00
17	0.00	0.18	0.71	60.73	93.96	95.76	96.70	98.03	98.35	98.71	100.00
18	0.00	0.00	-0.01	0.16	1.40	10.07	17.75	46.13	62.09	72.44	100.00

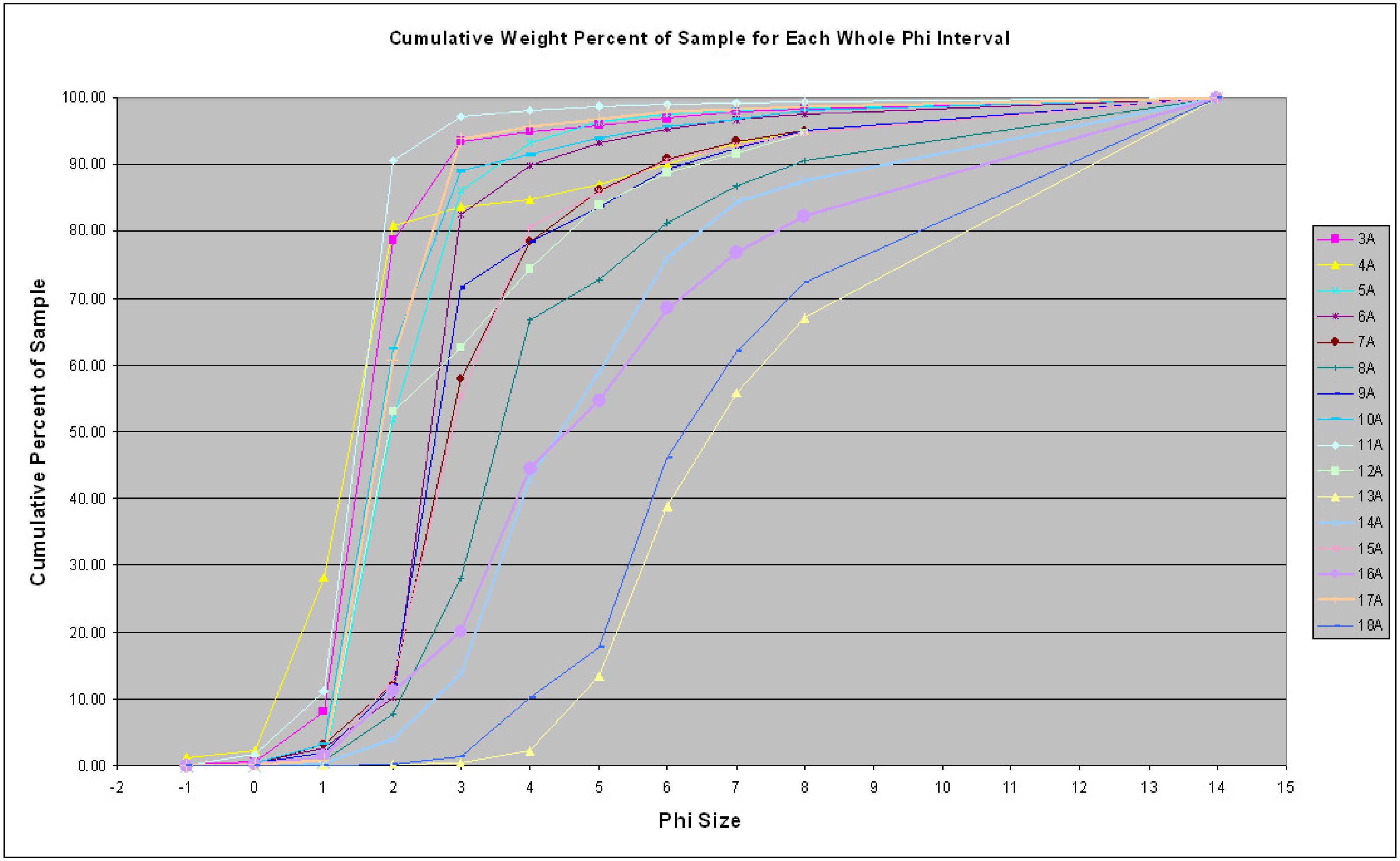


Figure 4. Plots of the cumulative weight percents for whole phi intervals for each sample. Median (by weight) grain size is identified where the data line crossed the 50% mark on the y-axis (Cumulative Percent of sample). The slope of the data line is indicative of the sorting or homogeneity of the sediment. The more vertical the data line is, the more uniform the sediment sample is. For example, Sample 11 is almost entirely composed of sediments in the 1-2 phi size range where sample 13 is composed of the much wider range of grain sizes between 4 and >8 phi..

Table 6. Phi size corresponding to various cumulative percentiles listed. These phi sizes were used to calculate the Folk graphic statistical parameters defined in equations 3 through 6). The graphic statistics for each sample are listed in Table 7.

Sample ID	Phi corresponding to cumulative percentile						
	5 %tile	**16 %tile**	**25 %tile**	**50 %tile**	**75 %tile**	**84 %tile**	**95 %tile**
3	0.58	1.11	1.24	1.59	1.95	2.36	5.06
4	0.11	0.53	0.88	1.41	1.89	3.3	9.91
5	1.09	1.31	1.48	1.96	2.67	2.94	5.56
6	1.31	2.08	2.2	2.55	2.9	3.23	6.81
7	1.19	2.08	2.28	2.83	3.84	5.72	9.93
8	1.61	2.41	2.85	3.57	6.27	7.49	11.87
9	1.31	2.07	2.22	2.64	3.51	6.05	9.94
10	1.03	1.22	1.37	1.79	2.47	2.81	6.56
11	0.36	1.06	1.17	1.49	1.8	1.92	2.67
12	1.08	1.29	1.46	1.94	5.06	6.03	10.28
13	5.24	6.1	6.46	7.65	10.97	12.06	13.39
14	2.09	3.07	3.38	5.43	6.93	7.95	12.38
15	1.31	2.07	2.29	2.88	3.78	5.61	10.2
16	1.36	2.54	3.2	5.54	7.79	10.36	12.86
17	1.07	1.25	1.4	1.82	2.43	2.7	3.61
18	3.42	5.77	6.26	7.24	10.37	11.68	13.27

Table 7. Summary of bulk properties and textural statistics for sediment samples.

Sample	%H20	Wet Bulk Density g/cm^3	WGHT LOSS %	Broad Textural Component				Sediment Classification		Folk (1974) Graphic Statistics			
				%GRAVEL	%SAND	%SILT	%CLAY	Shepard (1954)	Folk (1974)	Mean	Sorting	Skewness	Kurtosis
3	27.96	1.84	-0.74	0.21	94.74	3.33	1.72	Sand	Sand	1.69	0.99	0.39	2.59
4	33.50	1.73	3.03	1.15	83.74	10.20	4.91	Sand	muddy-Sand	1.75	2.18	0.55	3.97
5	19.85	2.03	3.67	0.00	93.32	5.26	1.42	Sand	Sand	2.07	1.08	0.4	1.53
6	23.11	1.95	3.25	0.00	90.85	6.75	2.40	Sand	Sand	2.62	1.12	0.36	3.26
7	26.02	1.88	3.95	0.00	78.51	16.54	4.94	Sand	muddy-Sand	3.54	2.23	0.61	2.3
8	39.73	1.62	7.20	0.00	66.75	23.86	9.39	Silty-Sand	muddy-Sand	4.49	2.82	0.58	1.23
9	33.22	1.73	4.54	0.00	78.48	16.59	4.92	Sand	muddy-Sand	3.58	2.3	0.7	2.74
10	21.70	1.98	1.89	0.00	91.45	6.73	1.82	Sand	Sand	1.94	1.24	0.5	2.05
11	22.94	1.95	1.64	0.00	98.09	1.39	0.51	Sand	Sand	1.49	0.56	0.01	1.5
12	35.58	1.69	5.14	0.00	74.44	20.19	5.37	Silty-Sand	muddy-Sand	3.09	2.58	0.77	1.05
13	62.04	1.32	13.46	0.00	2.39	64.59	33.03	Clayey-Silt	Mud	8.61	2.73	0.44	0.74
14	49.11	1.47	4.58	0.00	43.12	44.56	12.32	Sandy-Silt	sandy-Mud	5.49	2.78	0.19	1.19
15	34.80	1.70	3.56	0.00	80.80	13.94	5.26	Sand	muddy-Sand	3.52	2.23	0.6	2.43
16	56.22	1.38	3.65	0.00	44.51	37.91	17.58	Silty-Sand	sandy-Mud	6.15	3.7	0.25	1.03
17	26.42	1.87	1.17	0.00	95.86	2.86	1.29	Sand	Sand	1.93	0.75	0.31	1.02
18	54.37	1.41	15.63	0.00	10.15	62.29	27.56	Clayey-Silt	sandy-Mud	8.23	2.97	0.36	0.98

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