Grain Size Analysis of Sediments from the Kissimmee River Basin

Submitted to South Florida Water Management District
Kissimmee Division
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Introduction

Florida Atlantic University's Center for Environmental Studies (CES) at Riverwoods Field Lab has been working with students in FAU's Geosciences Department for over a year to conduct Kissimmee River sediment grain size analyses. The project has been under the direction of Jose Valdes, Project Manager and Senior Hydrogeologist for the Kissimmee Division of the South Florida Water management District. Overall supervision of the work was provided by Loisa Kerwin, CES Director at Riverwoods. The FAU technical on-site supervisor has been Dr. Tara Root, FAU Geosciences Dept. The project has provided FAU's Geoscience students an opportunity to learn and perform laboratory procedures and analyses. The project results provide the District with options for determining the hydraulic conductivity of the Kissimmee River Basin sediments.

Grain size analyses were performed on 303 samples that were taken from 28 boreholes in the Kissimmee River Basin. Five different empirical formulas were used to estimate the hydraulic conductivity of the samples based on the results of the grain size analyses. Estimates of hydraulic conductivity based on grain size were compared to the hydraulic conductivity derived from slug tests performed in the field. By comparing the grain size estimates of hydraulic conductivity to the field estimates of hydraulic conductivity, we sought to identify the "best" empirical formula for estimating the hydraulic conductivity of the sediments in the Kissimmee River Basin.

Methods

Sediment Sampling

The U.S. Army Corps of Engineers performed the sediment sampling using a split spoon sediment sampler. One and a half foot segments of the core were placed in clear plastic bags then stored in white semi-translucent plastic containers and labeled for storage in a custom wooden crate **(Figures 2 & 3).** Samples from 29 well sites in the Lower Kissimmee Basin (Table 1, Figure 1) were used for the grain size analysis.

Table 1: Well site characteristics

Station	County	Latitude	Longitude	X COORD	Y COORD	Screen Interval (depth in ft below land surface)
LKBA1A	POLK	274124	810907	606955	1220057	10-15
LKBA2A	POLK	274447	811118	595236	1240571	10-15
LKBA2B	POLK	274454	811102	596679	1241303	10-15
LKBA3A	POLK	274609	811152	592169	1248862	10-15
LKBA3B	POLK	274623	811123	594812	1250286	10-15
LKBB1A	HIGHLANDS	273208	811315	584641	1163883	10-15
LKBB2A	HIGHLANDS	273429	811109	595967	1178139	10-15
LKBB2B	OKEECHOBEE	273310	811037	598833	1170185	10-15
LKBB3A	HIGHLANDS	273546	810924	605447	1185940	10-15
LKBB3B_S	OKEECHOBEE	273509	810801	612863	1182187	10-15
LKBB3B_D	OKEECHOBEE	273509	810801	612854	1182179	91-96
LKBC1B	HIGHLANDS	272433	811008	601343	1117932	10-15
LKBC1C	OKEECHOBEE	272558	810759	613044	1126495	10-15
LKBC2A	HIGHLANDS	272714	811057	596972	1134161	10-15
LKBC2B	OKEECHOBEE	272800	810905	607064	1138851	10-15
LKBC3A	HIGHLANDS	272953	811240	587694	1150262	10-15
LKBC3B	OKEECHOBEE	272927	811042	598309	1147637	10-15
LKBD1A	HIGHLANDS	272032	810259	640059	1093544	10-15
LKBD1B	OKEECHOBEE	271958	810118	649135	1090131	10-15
LKBD2B_S	OKEECHOBEE	272120	810049	651712	1098425	10-15
LKBD2B_D	OKEECHOBEE	272120	810049	651711	1098416	155-160
LKBD3A	HIGHLANDS	272140	810244	641373	1100412	10-15
LKBD3C	OKEECHOBEE	272311	810206	644779	1109588	10-15
LKBD4B	HIGHLANDS	272244	810542	625382	1106878	10-15
LKBD5B	HIGHLANDS	272302	810648	619345	1108785	10-15
LKBD5C	OKEECHOBEE	272439	810632	620820	1118574	10-15
RIVAC1_S	OKEECHOBEE	271951	810148	646466	1089459	59-94
RIVAC1_D	OKEECHOBEE	271951	810148	646455	1089459	95-125
RIVAC2_S	OKEECHOBEE	271910	810130	648010	1085330	59-94
RIVAC2_D	OKEECHOBEE	271910	810130	648048	1085325	95-125

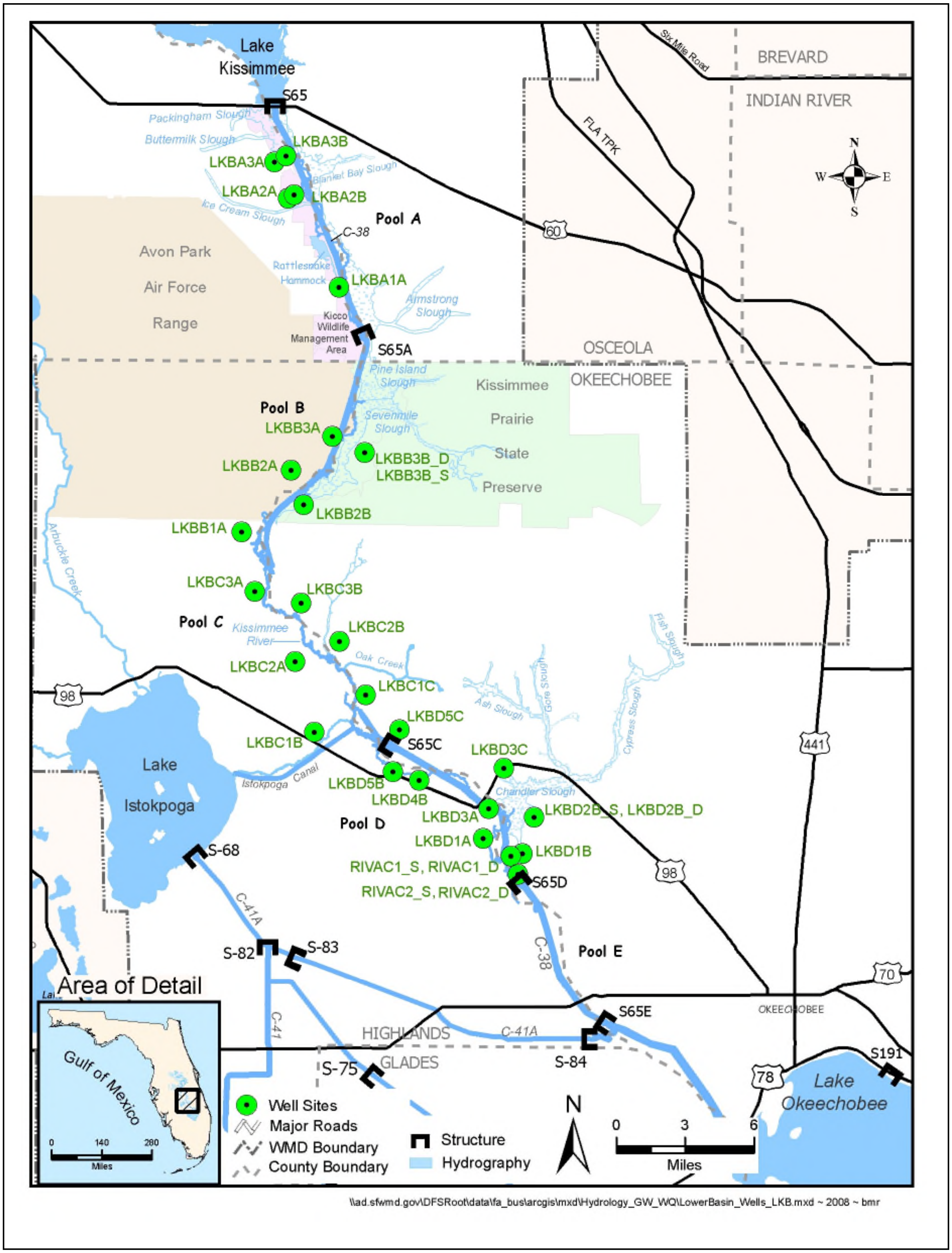


Figure 1: Locations of well sites

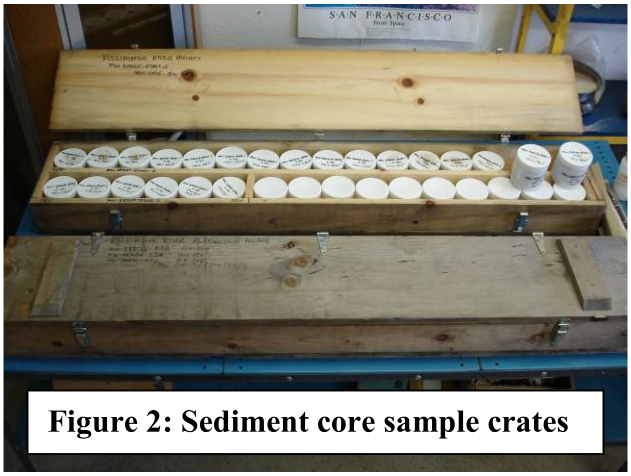


Figure 2: Sediment core sample crates

Figure 3: Sediment storage containers.

Slug Tests

Slug tests, performed by the US Army Corps of Engineers, are available for 27 well sites. Results of the slug test analyses are summarized in **Appendix A.**

Grain Size Analysis

Sample preparation was conducted by FAU Geosciences students in the FAU Lab in Boca Raton, FL. Each sample was visually inspected to record grain size, Munsell color, sorting, and presence of organics, etc. **Appendix B** outlines the steps of the laboratory procedures that were followed. **Figure 4** shows a visual illustration of one representative sample. Each sample was weighed, treated with dispersant and wet sieved to separate the fines from the coarser material. The coarse fraction was dried and sieved to determine grain size distribution. The grain size distribution of the fines was determined by pipette analysis. **Table 2** below illustrates the sampling times utilized for the pipette analysis.

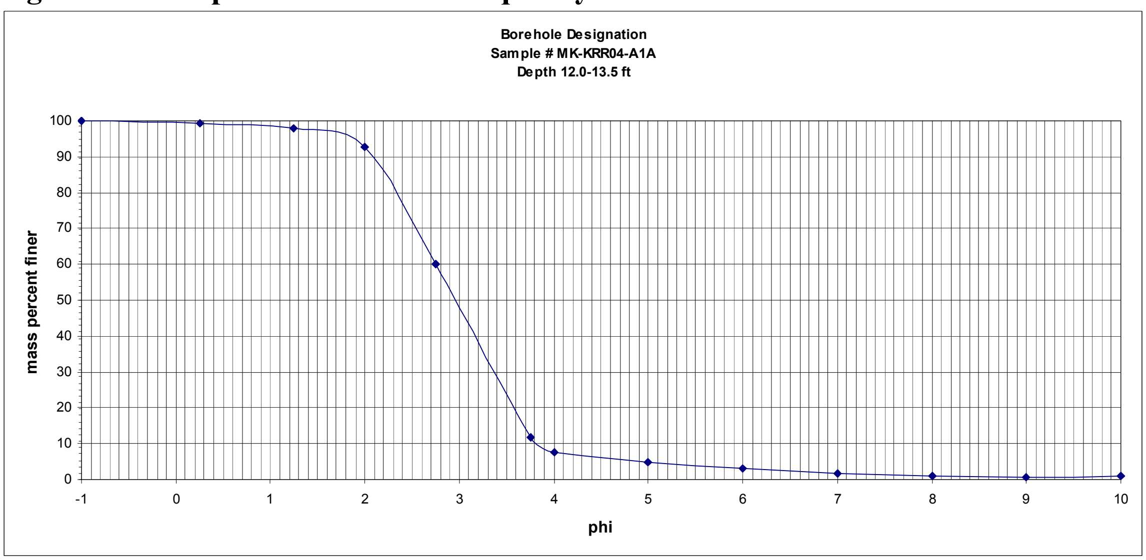
Figure 4

Table 2: Sampling times

Sample Time (hr:min:sec)	Beaker Number	Sample Depth (cm)	Particle size ℵ	Note
0:00:20	1	20	4	After taking this sample. Restir and restart timer.
0:01:56	2	10	5	After taking this sample. Restir and restart timer.
0:07:44	3	10	6	Do not stir or restart timer after sampling.
0:31:00	4	10	7	Do not stir or restart timer after sampling.
2:03:00	5	10	8	Do not stir or restart timer after sampling.
4:06:00	6	5	9	Do not stir or restart timer after sampling.
8:12:00	7	2.5	10	

The results of the grain size analysis were plotted on cumulative frequency curves that were used to determine the coefficients for the hydraulic conductivity calculations described below. **Figure 5** illustrates an example of a cumulative frequency curve. **Appendix C** on the enclosed CD summarizes the data, curves and calculations.

Figure 5: Example of cumulative frequency curve



Hydraulic Conductivity Estimations

The Beyer, Hazen, Cosby, Puckett, and Pavchich empirical formulas relating grain size to hydraulic conductivity were all used to estimate the hydraulic conductivity of each of the samples. These formulas are summarized below.

- *Beyer* (Kasenow, 2002): Recommended for materials where $0.06<d_{10}<0.6$ mm and $1<C<20$.

$$K = \beta_b d_{10}^2$$

Where K is estimated hydraulic conductivity in ms^{-1}, $\beta_b = 4.5 \times 10^{-3}\log(500/C)$, d10 = effective grain size in mm (read from grain size distribution graph), and C = uniformity coefficient = d_{60}/d_{10} (values read from grain size distribution graph).

- *Hazen* (Fetter, 1994): Applicable where $0.1<d_{10}< 0.3$ mm

  $$K = Cd_{10}^2$$

  Where K = estimated hydraulic conductivity in cms^{-1}. C = coefficient (assumed = 40), d_{10} = effective grain size in cm (read from grain size distribution graph).

- *Cosby* (Cosby et al., 1984):

  $$\log K = (0.0153 \times \%sand) - 0.884$$

  Where K = estimated hydraulic conductivity in $inhr^{-1}$, and % sand is the percent (by mass) of the sample that is less than -1Φ and greater than 3.75Φ.

- *Puckett* (Puckett et al., 1985):

  $$K = 4.36 \times 10^{-5} \exp(-0.1975 \times \%clay)$$

  Where K = estimated hydraulic conductivity in ms^{-1}, and % clay is the percent (by mass) of the sample that is less than 3.75Φ.

- *Pavchich* (Kasenow, 2002):

  $$K = 0.35\tau\left(d_{17}^2\right)$$

  Where K = estimated hydraulic conductivity in cms^{-1}, and τ = temperature coefficient (assumed = 1.55), and d_{17} is effective grain diameter in mm (read from grain size distribution graph).

Equivalent Horizontal Hydraulic Conductivity

The equivalent horizontal hydraulic conductivity of intervals corresponding to slug tests was estimated from the following equation (Freeze and Cherry, 1979, pg. 34):

$$K_h = \frac{\sum_{i=1}^{M} b_i K_i}{\sum_{i=1}^{M} b_i}$$

Where K_h = estimated equivalent horizontal hydraulic conductivity, K_i = grain size estimate of hydraulic conductivity for individual samples, b_i = thickness of interval tested by slug test.

Results and Conclusions

Data from the grain size analyses, grain size distribution curves, and hydraulic conductivity estimates are summarized in **Appendix A**.

As illustrated in **Table 3** below, the estimated equivalent horizontal hydraulic conductivities based on grain size analyses were all within four orders of magnitude of the slug test estimates of hydraulic conductivity, and most were within one order of magnitude.

Table 3: Comparison of slug test results and grain size estimates of equivalent horizontal hydraulic conductivity. Number of slug tests is 27.

	# of times equivalent K is within specified order of magnitude of slug test.				
Order of magnitude difference between equivalent K based on grain size analysis and the slug test estimate of K	Beyer	Hazen	Cosby	Puckett	Pavchich
0	14	10	19	15	16
1	6	11	8	11	7
2	1	0	0	0	1
3	0	0	0	0	0
4	0	0	0	1	0
N.A	6	6	0	0	3
	%of time equivalent K is within specified order of magnitude of slug test.				
Order of magnitude difference between equivalent K based on grain size analysis and the slug test estimate of K	Beyer	Hazen	Cosby	Puckett	Pavchich
0	52	37	70	56	59
1	22	41	30	41	26
2	4	0	0	0	4
3	0	0	0	0	0
4	0	0	0	4	0
N.A	22	22	0	0	11

Each empirical relationship for estimating hydraulic conductivity based on grain size was developed for a specific type of soil. The differences in the estimated hydraulic conductivities likely result from extending the relationships to other soil types. Previous researchers have found that different empirical relationships result in significantly different hydraulic conductivity estimates for the same soil and for this reason have cautioned against relying on grain size estimates of hydraulic conductivity (Muldoon, 1987). However, since most of the grain size estimates of hydraulic conductivity were within an order of magnitude of the slug test results in this study, empirical estimations of hydraulic conductivity based on grain size appear reasonable for these Kissimmee River Basin sediments.

None of the empirical relationships yielded K values that were consistently of the same order of magnitude as the slug test values. Depending on the future goals for this project and the level of accuracy desired for the hydraulic conductivity estimates, further analysis could be done to attempt to identify correlations between the accuracy of the hydraulic conductivity estimates and properties of the soil such as % clay, % silt, % sand, coefficient of curvature, coefficient of uniformity, or classification of soil type.

Without more detailed analysis, the following general conclusions can be drawn. As shown in **Table 3**, the formula that most frequently (70% of the time) resulted in an equivalent horizontal hydraulic conductivity of the same order of magnitude as that from the slug test was Cosby and others (1984). This formula was also found to be applicable to all of the sample grain size distributions encountered and 100% of the results obtained with this formula were within one order of magnitude of the slug test values. About half of the equivalent horizontal hydraulic conductivities calculated using the Hazen formula (where applicable) (Fetter, 1994) were an order of magnitude off from the slug test estimates**.** The hydraulic conductivities estimated using the Beyer, Puckett, and Pavchich formulas were of the same order of magnitude as the slug test estimates 50 to 60 percent of the time**.** Twenty two percent of the total number of samples was either too fine or too coarse for the Beyer or Hazen formulas to be used. Such was also the case with the Pavchich formula for 11% of the samples.

References

Cosby, B.J. and others. 1984. A statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils. *Water Resources Research* 20, no. 6:682-690.

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Muldoon, M.A. 1987. Hydrogeologic and geotechnical properties of pre-late Wisconsin till units in western Marathon County, Wisconsin. M.S. Thesis, University of Wisconsin - Madison.

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LAB PROCEDURES APPENDIX B

Grain Size Analysis (Note: the green italicized letters and numbers in parentheses indicate the cell in the results spreadsheet where the values referred to were entered.)

A. Materials Needed
1. balance
2. mortar and pestle
3. sieve set, brass (2Ø to +4Ø)
4. sieve shaker
5. wet sieve, stainless steel (+4Ø)
6. porcelain evaporating dish (1285ml capacity)
7. 50ml beakers
8. 1000ml graduated cylinders
9. 20ml pipette
10. washing bottles (1000ml capacity)
11. sediment stirring rod
12. dispersant – Calgon (Sodium Hexametaphosphate)
13. hand mixer
14. wax paper
15. parchment paper

B. Sample description and identification
1. For each new bore hole, open up "data template.xls".
   i. Save as a new file using the boring designation as the file name

2. Each sample should have its own worksheet in the bore hole's Excel file

3. For each sediment sample
   i. Describe grain size, color, sorting, presence of organics, etc. *(C10)*
   ii. Record the Munsell color and hue *(C11)*
4. Record the boring designation *(C6)*, the sample depth *(C7)*, and the sample number *(C8)*.

C. Preparation of Laboratory Equipment
1. Wash all lab equipment: graduated cylinders, beakers, mixer, evaporating dish, etc.

2. Weigh DRY beakers and note the weight on the side of each beaker with a graphite pencil. Record beaker weight *(C22-C28)*.

3. Mark appropriate depths on pipettes in indelible ink: 20cm, 10cm, 5cm and 2.5cm.

4. Set up each sample station with: 1000 ml graduated cylinder; sediment stirring rod; 20ml pipette; 7 small beakers (50ml), numbered and with weight recorded on them; beaker with deionized water for rinsing .

5. For each sediment sample, prepare a supply of dispersant solution by mixing 5.5g of Calgon in 1000ml of distilled water, in a wash bottle labeled for this sample number.

D. Preparation of sample

1. Weigh out approximately 100 g (plus or minus one gram) of sample. Record this weight *(D13)*.
   i. If the initial bulk sample is dry disaggregate it with the mortar and pestle, and then split with the mechanical splitter;
   ii. If the initial bulk sample is wet, split without bias by placing sample on greaseproof (wax) paper and cutting into 4 equal portions. Select two opposite portions for your sample. Cut again if this is too much.

E. Disaggregate, separate out fines, dry sieve coarse fraction

1. Use the hand mixer and stainless steel bowl with **some** of the dispersant mix to agitate materials and deflocculate clays. Mix until dispersant is totally saturated with fines, pour the liquid portion of sample through the +4Ø stainless steel wet sieve, repeat until all fines are removed. The dispersant should eventually look clear when mixing, showing that fines have been removed.

2. Once the dispersant rinse runs clear pour the remaining sample into the +4Ø stainless steel wet sieve and wash the sample gently with the dispersant catching any remaining fines in the porcelain evaporating dish.

3. Pour the fines into a 1000ml cylinder labeled with this sample number and wash the evaporating dish with the dispersant, emptying the wash water into the same cylinder **– do not top off the cylinder at this point.**
4. Wash the sediment retained on the wet sieve onto a pie tray lined with parchment paper and labeled with the sample number using WATER (NOT the dispersant). Place the pie tray + sample into a 75^{o}C oven to dry for at least 10 hours.

5. Remove the dried sample from oven, weigh the sample, and record the dry coarse weight *(D14)*.

6. Dry sieve the oven dried material through a regular sieve stack. Add any material that is collected in the pan (i.e., passing the +4Ø sieve) to the 1000ml graduated cylinder.

7. Weigh the sample fractions retained on the sieves. Record the retained weights *(I16-I21)*.

F. Grain size analysis of fines

1. Top off the graduated cylinder with dispersant to the 1000ml mark.

2. Stir the contents of the graduated cylinder vigorously with the stirring rod until all the sediment is uniformly distributed.

3. Start the timer immediately after withdrawal of the stirring rod.

4. You will extract a full 20ml sample at certain time periods, by putting the pipette into the cylinder to a certain depth (marked on the pipette). Insert pipette into the graduated cylinder to the proper depth at least 15 seconds prior to withdrawal of each sample, taking care to hold the pipette motionless. Pipette sample to ABOVE the 20ml line then release some liquid down to the 20ml line. Immediately but smoothly, remove the pipette, hold it over a beaker, and release the sample. Then rinse the pipette by drawing 20ml distilled water and pouring that rinse water into your sample beaker. Touch the end of the pipette onto the meniscus (top) of the sample to remove that last drop.
    a. Each sample will be taken out after a set time (Table 1):
        i. Stir thoroughly, remove rod, start timer and insert pipette
        ii. Sample after 20 seconds at 20cm mark
        iii. Stir again, remove rod, start timer
        iv. Sample after 1 minute 56 seconds at 10cm mark
        v. Stir again, remove rod, start timer
        vi. Sample after 7 minutes 44 seconds at 10cm mark
        vii. DO NOT stir again; LEAVE TIMER GOING for other samples!
        viii. Sample after 31 minutes at 10cm mark
        ix. Sample after 2 hours and 3 minutes at 10cm mark
        x. Sample after 4 hours and 6 minutes at 5cm mark
        xi. Sample after 8 hours and 12 minutes at 2.5cm mark

    b. On each beaker, you should note its number (1 through 7) and the particle size of sediments in it
    c. Oven dry beakers at 75°C for a minimum of 12 hours; do not allow the beakers to boil as this may cause the loss of some sample
    d. Remove the completely dried beakers from the oven and allow to cool to room temperature
    e. Weigh the beakers individually and record the beaker + 20 ml sub-sample weights *(B22-B28)*.
    f. Wash beakers and cylinders and rinse with distilled water.

9. Computation
    a. Enter data into the Excel spreadsheet. Keep a paper copy and an electronic copy of everything, and make backups.
    b. The cumulative frequency graphs and data for each sample are enclosed as **Appendix C** on the CD enclosed.