Correlation of Total Suspended Solids (TSS) and Suspended Sediment Concentration (SSC) Test Methods

Final Report

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Executive Summary

A number of innovative storm water treatment technologies have recently been developed in response to new Federal and State storm water rules, especially pertaining to removal of suspended solids from runoff before they are discharged into receiving waters. However, three different laboratory methods have been used to quantify the amount of solids contained in the storm water samples. The use of different methods typically yields significantly different results. A direct comparison of performance of different storm water treatment devices, a part of the Best Management Practices (BMPs), is thus very difficult when different laboratory methods are used to determine solids removal. Therefore, there is a need to evaluate the difference and establish correlation among these three different methods.

All three methods evaluate the amount of solids contained in the storm water samples through filtering the water, and drying and weighing the residue left on the filter. However, the three methods differ in the sub-sample preparation. The EPA's TSS (total suspended solids) Method stirs and collects the sub-sample by pouring from the whole sample container. The Standard TSS Method stirs and collects the sub-sample using a pipette to draw from the whole sample container. The ASTM's SSC (suspended sediment concentration) Method uses the whole sample.

The water samples of nine (9) different particle concentrations over a range from 0 to 1000 mg/L and of seven (7) different particle size distributions over a range from 0 to 1000 microns were prepared. They were subsequently sent to an outside, certified laboratory for analysis of the solids concentrations using the three different analytical methods.

It was found that the measured SSC was very close to the true concentration of solids, TSS measured using EPA Method's sub-sample pouring procedure was well correlated with the measured SSC, but TSS measured using Standard Method's pipette sub-sampling procedure was not well correlated with the measured SSC.

It was also found that the difference between the measured SSC and the measured TSS-EPA was well correlated with the particle size. The difference was larger as the particle size increased. A regression relationship was established. This regression relationship could be used to predict TSS-EPA from the reliably measured SSC if the particle size (or the equivalent particle size) is known.

The use of a more accurate and precise solids concentration measurement methodology would lead to a more reliable performance certification process and greater water quality benefits.

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Introduction

New Jersey Department of Environmental Protection (NJDEP)'s Bureau of Sustainable Communities and Innovative Technologies is responsible for certifying innovative energy and environmental technologies, in accordance with the Energy and Environmental Technology Verification (EETV) Act, to allow permitting for use by the agency's regulatory programs. A number of innovative storm water treatment technologies have recently been developed in response to new Federal and State storm water rules, especially pertaining to removal of suspended solids from runoff before they are discharged into receiving waters. However, three different laboratory methods have been used to quantify the amount of solids contained in the storm water samples taken from the field. The use of different methods typically yields significantly different results (Gray et al., 2000). A direct comparison of performance of different storm water treatment devices, a part of the Best Management Practices (BMPs), is thus very difficult when different laboratory methods are used to determine solids removal. Therefore, there is a need to evaluate the difference and establish correlation among these three different methods, especially for the particle gradation specified for New Jersey.

All three methods evaluate the amount of solids contained in the storm water samples through filtering the water, and drying and weighing the residue left on the filter. However, the three methods differ in the sub-sample preparation. The EPA's TSS (total suspended solids) Method (USEPA 1999) stirs and collects the sub-sample by pouring from the whole sample container. The Standard TSS Method (also referred to as APHA's TSS Method) (APHA 1995) stirs and collects the sub-sample using a pipette to draw from the whole sample container. The ASTM's SSC (suspended sediment concentration) Method (ASTM 1997) uses the whole sample.

Therefore, the primary objective of this research was to conduct an extensive laboratory evaluation of the three different laboratory analysis methods, and to establish correlations between TSS and SSC concentrations, if any exist. The subsequent objective was to evaluate potential impacts of the research results on certification of the storm water BMP technologies.

The laboratory evaluation of the three different methods started with preparation of water samples containing specific amount of solids of known size distributions. Sediments/solids with gradation specified in NJ's TSS lab test procedures (NJDEP 2003) was used. An outside company was used to manufacture the sediments of the specified gradation. Rutgers then prepared the water samples with different solids concentrations and particle size ranges. The water samples of nine (9) different particle concentrations over a range of 0 to 1000 mg/L, and seven (7) different combinations of particle size distributions over a range of 0 to 1000 microns were prepared. The prepared water samples (one liter each in volume) were subsequently sent to an outside, certified laboratory for analysis. The lab analyzed the water samples using the three (3) separate methods and reported the results back to Rutgers. The lab results were finally observed and statistically analyzed for any trends and correlations among the results generated from the three different methods.

Manufacturing of Solids

The materials of various size distributions were manufactured by Powder Technology, Inc. (PTI), Burnsville, Minnesota. The materials were made of quartz, which has a density of 2,650 kg/m^3.

Seven particle size distributions were chosen in this project. The first one was to mimic the distribution specified by NJDEP for laboratory testing of solids removal performance of the stormwater manufactured treatment devices (NJDEP 2003). This material had its particle size ranging from 0 to 1000 microns, and is called blend or mixed material in this project. The other six types of materials had the nominal particle sizes of 0 to 8 microns, 8 to 53 microns, 53 to 106 microns, 106 to 250 microns, 250 to 500 microns, and 500 to 1000 microns, representing six different factions of the NJDEP-specified blend material. The six types of materials were prepared first. They were subsequently blended together proportionally to simulate the NJDEP-specified particle size distribution.

The particle size distribution (PSD) of the manufactured solid materials was analyzed using three different methods: the sieve method for particles larger than 53 microns, the Coulter particle counter for particles from 0 to 106 microns, and the laser particle counter for all sizes of particles. The detailed PSD results are included in Appendix A.

The sieve method was considered to be the most accurate, the Coulter counter not as accurate as the sieve method, and the laser counter - the least accurate. Therefore, results from the sieve method for the materials of 53 to 106 microns, 106 to 250 microns, 250 to 500 microns, 500 to 1000 microns, and 0-1000 microns and results from the Coulter counter for the materials of 0 to 8 microns and 8 to 53 microns were used. Mean diameters (d_{50}) of the materials are shown in Table 1, and PSDs are shown in Figures 1 and 2. Results obtained from the sieve method and from the Coulter counter for the overlapping range (53 to 106 microns) were close (Table 1). However, results obtained from the laser counter were significantly different from those of the two other methods and were not used.

Table 1. Mean Particle Size of Manufactured Materials

Solids	Mean diameter (microns) (Analysis Method)
0 to 8 microns	4.3 (Coulter)
8 to 53 microns	21.5 (Coulter)
53 to 106 microns	69.9 (Sieve) / 73.1 (Coulter)
106 to 250 microns	142.0 (Sieve)
250 to 500 microns	302.5 (Sieve)
500 to 1000 microns	605.0 (Sieve)
0 to 1000 microns (NJDEP Blend)	68.5 (Sieve)

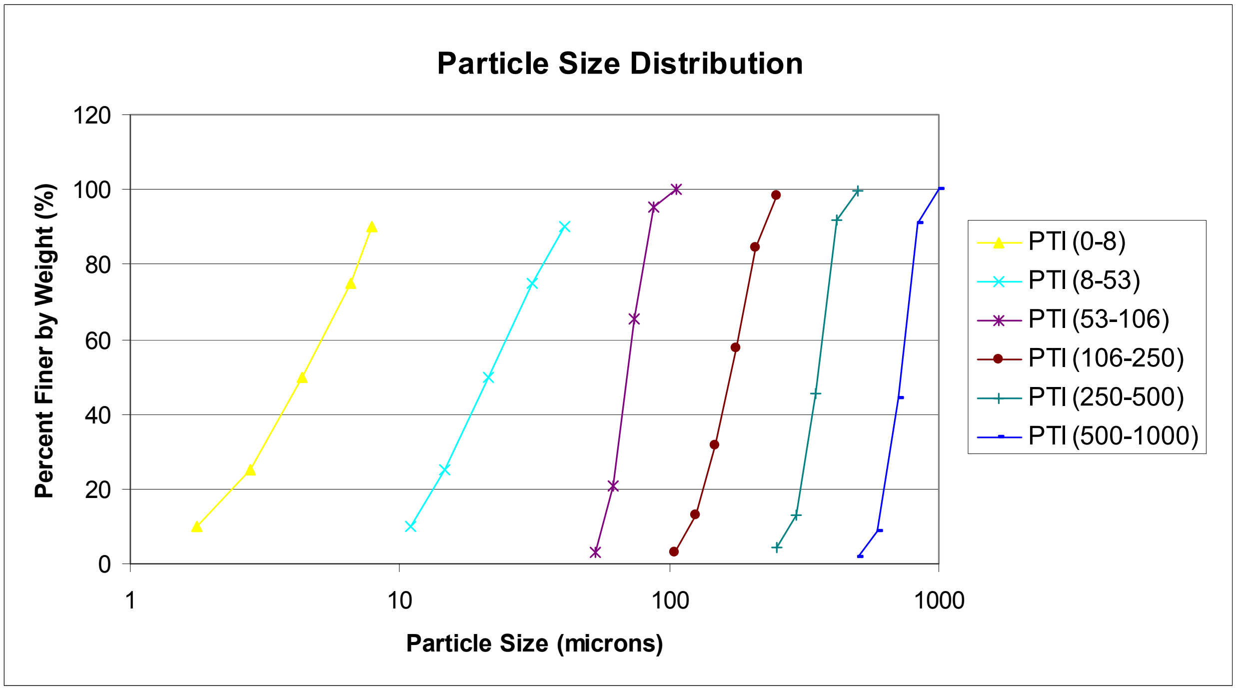

Figure 1. Particle Size Distributions of Manufactured Materials (0 to 8, 8 to 53, 53 to 106, 106 to 250, 250 to 500, and 500 to 1000 microns)

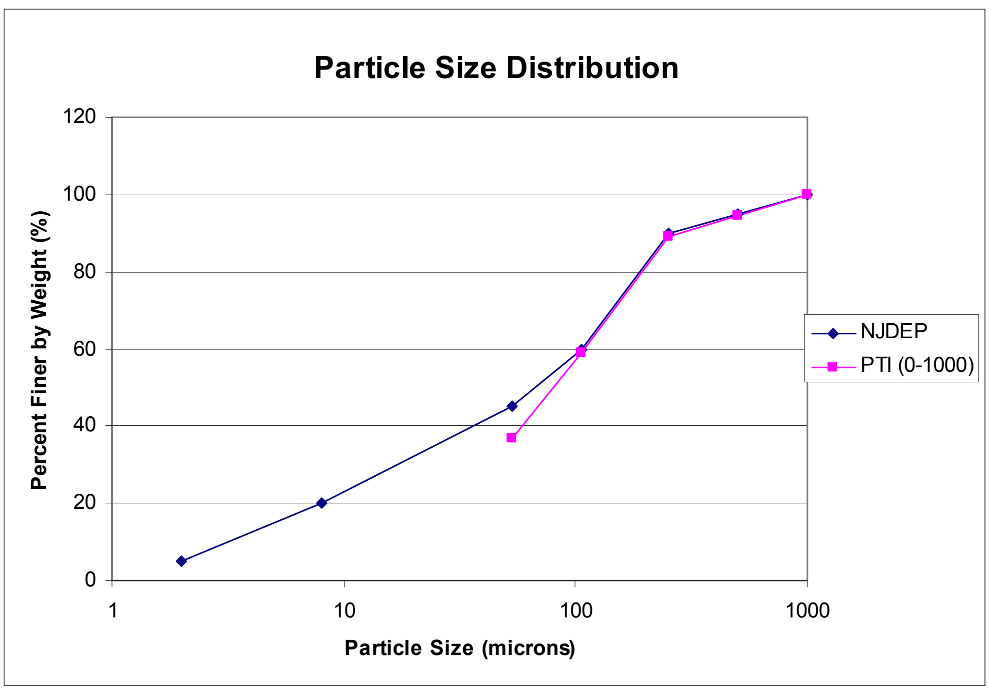

Figure 2. Particle Size Distributions of Manufactured Blend Material (0 to 1000 microns) and NJDEP Specified Material.

Preparation of Water Samples

Water samples of nine (9) different concentrations were prepared for each of the seven (7) nominal sizes of the solids materials. The nine chosen concentrations were 20 mg/L, 50 mg/L, 100 mg/L, 150 mg/L, 200 mg/L, 300 mg/L, 400 mg/L, 500 mg/L, 600 mg/L, and 1000 mg/L.

Water samples were prepared in the Fluid Mechanics/Hydraulics Lab of Rutgers University by a graduate student (Mr. Jung Hoon Kim). A known amount of solids was put into a one-liter water bottle to achieve the desired solids concentration. The weight of solids was measured by using an analytical balance with the reading down to one tenth of a milli-gram (mg). The weight of solids was measured before and after its introduction to the empty bottle, that is, weight on the paper sheet and weight inside the bottle, to ensure no loss of the solids during the transfer. Then, the bottle was filled with one liter of de-ionized water.

Concentrations of solids in the prepared water samples were controlled to very close to the targeted concentrations, with the difference less than two percent even at the lowest concentration of 20 mg/L. The targeted concentrations were designated as the true concentrations in this project.

For each of nine (9) desired concentrations of solids of seven (7) different size distributions, three (3) bottles of water samples were prepared. Three bottles were prepared because three different analytical methods (described below) were used to measure the solids concentrations.

A blank water sample, that is, a de-ionized water sample without introduction of any solids, was also prepared for each batch of water samples that was sent to an outside laboratory for the solids concentration analysis.

The temperature of the water at the time of sample preparation was also recorded.

All of the prepared water samples are listed in Appendix B.

Laboratory Analysis of Solids Concentrations

The prepared water samples were sent to an outside, certified laboratory for analysis of solids concentrations. Three different methods were used. The three methods were EPA's TSS (total suspended solids) Method 160.2 (USEPA, 1999), Standard TSS Method (also referred to as APHA's TSS Method) 2540 D (APHA, 1995), and ASTM's SSC (suspended sediment concentration) Method D3977-97B (ASTM, 1997). Each of the three methods measures the amount of the solids left on the filter. The differences were the amount of water used for the filtration and how the chosen amount of water was sub-sampled from the original sample.

It was not specified in the EPA Method how much water should be used since the filtration time was the determining factor. The method of sub-sampling was not specified either. In this project, 100 mL of sub-sample was taken from the original one-liter sample bottle, and the sub-sample was taken by pouring from the original sample bottle. The original water sample was shaken and subsequently magnetically stirred. The sub-sample of 100 mL was poured into the filtration apparatus. The PCI scientific Grade 111 filter, which has a diameter of 4.7 cm, was used. The minimum reporting level of the EPA Method is 4 mg/L. The EPA Method is the method normally used for the TSS analysis by this particular outside laboratory.

The Standard Method did not specify the amount of water to be used either. However, the sub-sample was specified to be taken using a pipette. In this project, 100 mL of sub-sample was taken from the original one-liter sample bottle. The whole sample was stirred with the magnetic stirrer. A center vortex was created during the mixing, and sub-sampling was done by using the sample from the center of the vortex. A Class A pipette with 100 mL capacity was used. The PCI scientific Grade 111 filter, which has a diameter of 4.7 cm, was used. The minimum reporting level of the Standard Method is 4 mg/L.

The ASTM Method did specify the use of whole original water samples without sub-sampling. In this project, the entire one-liter original water sample was used. The AH-934 grade Whatman microfiber filter, which has a 4.7 cm diameter, was used. The minimum reporting level of the ASTM Method is 5 mg/L.

All of the water samples were kept refrigerated at 4^{o} C before the analysis.

Results of Laboratory Analysis

All of the laboratory analysis results are shown in Appendix C.

For the first batch of water samples, due to miscommunications, the Standard Method of TSS measurement was not used. In addition, recovery of solids by the ASTM Method of SSC measurement for all the water samples in the blend material group was poor. To eliminate any bias, lab results from the entire first batch of water samples were discarded. New samples were prepared and re-sent to the lab for analysis.

The lab results are shown in Table 2. Note that the concentration of 4 mg/L in Table 2 is the minimum laboratory reporting level (RL).

Table 2. Measured Solids Concentrations of Water Samples

Particle Size (microns)	True Conc. (*mg/l*)	TSS-EPA (*mg/l*)	TSS-SM (*mg/l*)	SSC (*mg/l*)
0 - 1000	20	10	13	18.1
0 - 1000	50	31	24	48.9
0 - 1000	100	63	50	101
0 - 1000	150	82	85	144
0 - 1000	200	110	120	200
0 - 1000	300	180	140	288
0 - 1000	400	200	260	390
0 - 1000	600	360	400	593
0 - 1000	1000	570	670	963
0 - 8	20	17	24	19
0 - 8	50	40	45	49.8
0 - 8	100	96	82	98.2
0 - 8	150	140	130	149
0 - 8	200	200	180	199
0 - 8	300	290	300	297
0 - 8	400	400	380	398
0 - 8	600	610	570	599
0 - 8	1000	980	990	971
8 - 53	20	14	13	24.2
8 - 53	50	41	40	45.4
8 - 53	100	89	90	94.5
8 - 53	150	130	120	150
8 - 53	200	170	170	199
8 - 53	300	240	280	299
8 - 53	400	380	350	399
8 - 53	600	510	520	592
8 - 53	1000	1000	900	976
53 - 106	20	15	17	19.7
53 - 106	50	28	20	49
53 - 106	100	66	65	98.5
53 - 106	150	82	85	146
53 - 106	200	110	130	200
53 - 106	300	180	220	299
53 - 106	400	250	290	398
53 - 106	600	350	400	598
53 - 106	1000	770	610	995
106 - 250	20	4	4	20
106 - 250	50	4	160	50.7
106 - 250	100	4	300	98.4
106 - 250	150	5	460	144
106 - 250	200	18	570	190
106 - 250	300	16	410	306
106 - 250	400	7	600	394
106 - 250	600	9	580	600
106 - 250	1000	18	1200	978
250 - 500	20	4	15	23.2
250 - 500	50	4	47	51.9
250 - 500	100	4	110	99.5
250 - 500	150	4	85	150
250 - 500	200	4	4	200
250 - 500	300	4	4	292
250 - 500	400	4	4	405
250 - 500	600	4	5	599
250 - 500	1000	4	300	997
500 - 100	20	4	4	20
500 - 100	50	4	4	49.7
500 - 100	100	4	4	100
500 - 100	150	4	4	144
500 - 100	200	4	4	201
500 - 100	300	4	4	301
500 - 100	400	4	4	364
500 - 100	600	4	4	533
500 - 100	1000	4	4	971

Data Analysis

Recovery of Solids and Correlation among TSS, SSC, and True Concentrations

The lab results were plotted, observed, and quantified for degree of deviation, trend and correlation among the results generated from the three different methods.

Correlation between TSS-EPA, TSS-SM, SSC and the true concentration are shown in Figures 3 a to g. Note that the intercept was assumed to be zero in developing the regression line (the trendline), where applicable.

From the graphs, we can see that the SSC concentration analyzed by the ASTM Method was always very close to the true concentration no matter what the particle size range and concentration were. This was because the whole water sample was used and no sub-sampling bias was introduced in this method.

For the very fine, fine, and medium-size particles (0 to 106 microns), both the TSS concentration analyzed by the EPA Method (TSS-EPA) and the TSS concentration analyzed by the Standard Method (TSS-SM) were well correlated with the true concentration. However, differences between the true concentration and TSS-EPA and TSS-SM increased from less than 2% to 36% as the particle size increased. For the medium-size to coarse particles (106 to 1000 microns), neither TSS-EPA nor TSS-SM was well correlated with the true concentration. For the coarse particles (500 to 1000 microns), both TSS-EPA and TSS-SM were below the method detection level.

The measured difference between TSS and SSC was a result of the inability of the sub-sampling methods (pouring and pipetting) to pick up the large particles from the original whole sample. During application of the EPA TSS Method, as the sub-sample (100 mL) was poured from top surface of the whole sample (1000 mL), large (actually heavy) particles settled to the bottom of the whole sample container and were excluded from the sub-sample. During application of the Standard TSS Method, the magnetic stirring was possibly not strong enough to keep the large (actually heavy) particles suspended in the entire water column while the sub-sample was taken using the pipette.

The percentages of solids recovery and observations of correlation for each of the particle size ranges are described below:

1. For the NJDEP blend material (0 to 1000 microns), the SSC concentration analyzed by the ASTM Method, the TSS concentration analyzed by the EPA Method (TSS-EPA), and the TSS concentration analyzed by the Standard Method (TSS-SM) were all well correlated with the true concentration. SSC was almost the same as the true concentration (within 3% difference). However, both TSS-EPA and TSS-SM were smaller than the true concentration. They were 57% and 65% respectively of the true concentration.

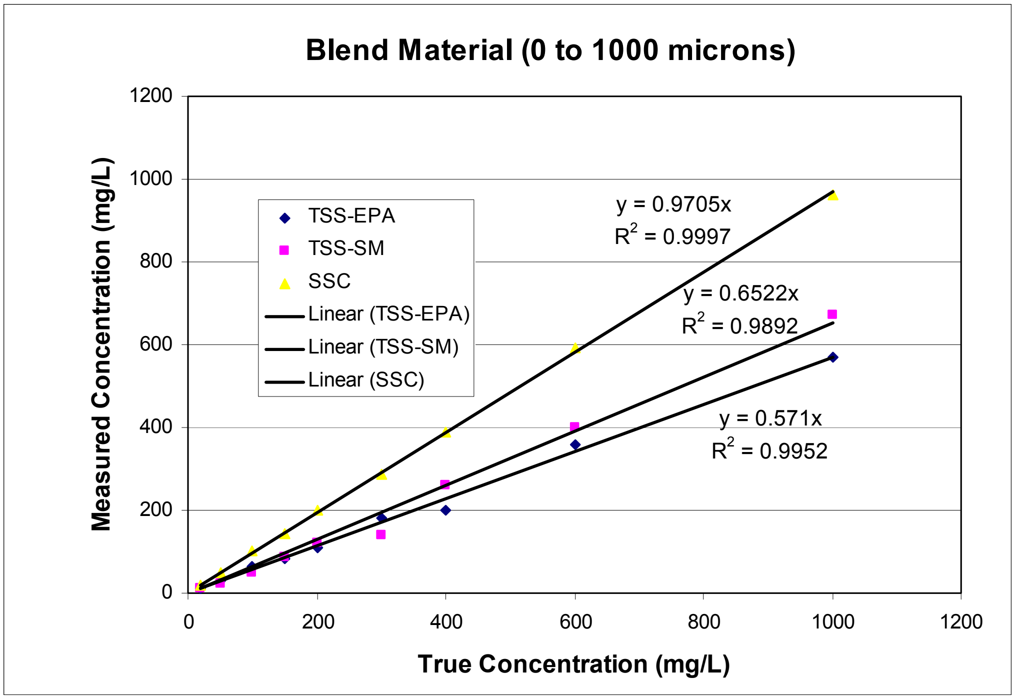

Figure 3 a. Correlations between True Concentration and Measured TSS-EPA, TSS-SM, and SSC Concentrations for NJDEP Blend Material with Particle Size Ranging from 0 to 1000 Microns.

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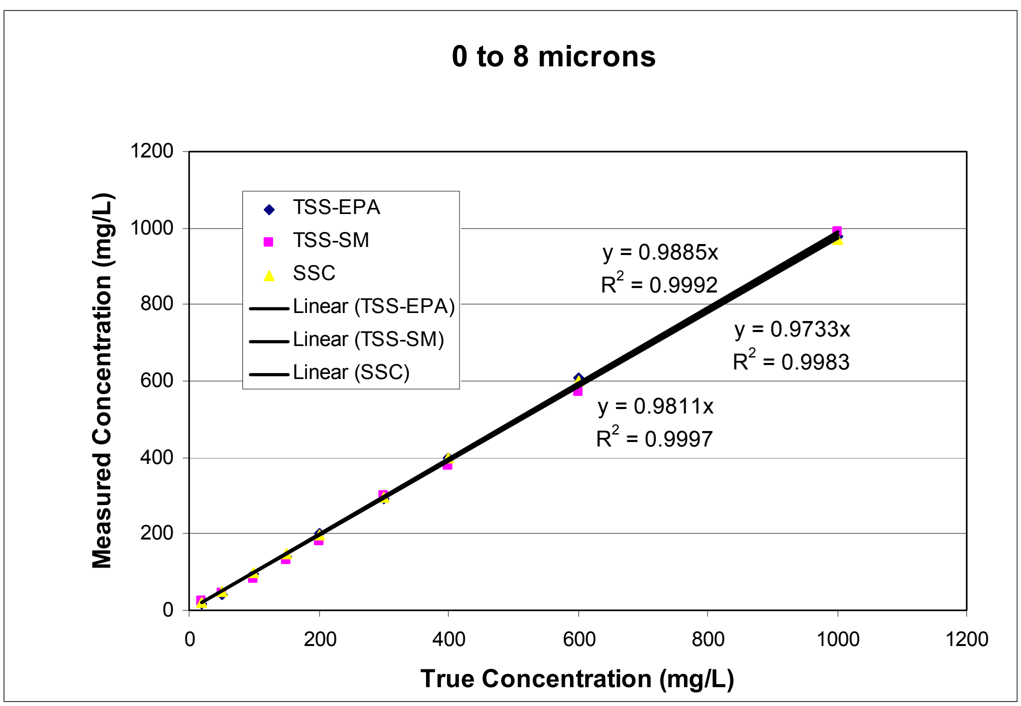

Figure 3 b. Correlations between True Concentration and Measured TSS-EPA, TSS-SM, and SSC Concentrations for Particle Size Ranging from 0 to 8 Microns.

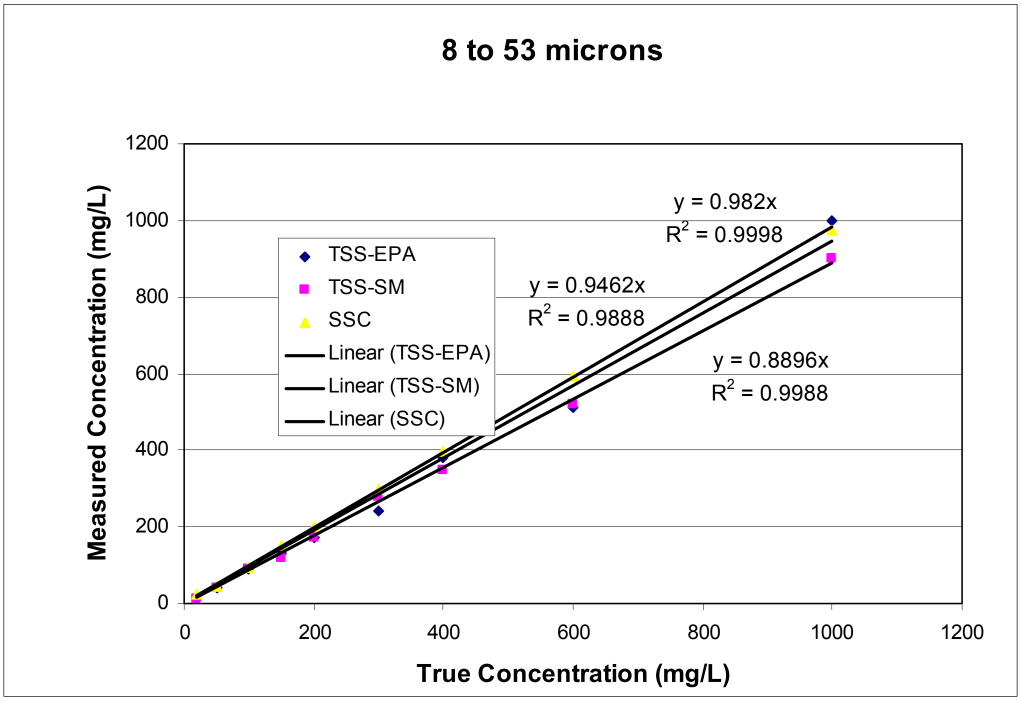

Figure 3 c. Correlations between True Concentration and Measured TSS-EPA, TSS-SM, and SSC Concentrations for Particle Size Ranging from 8 to 53 Microns.

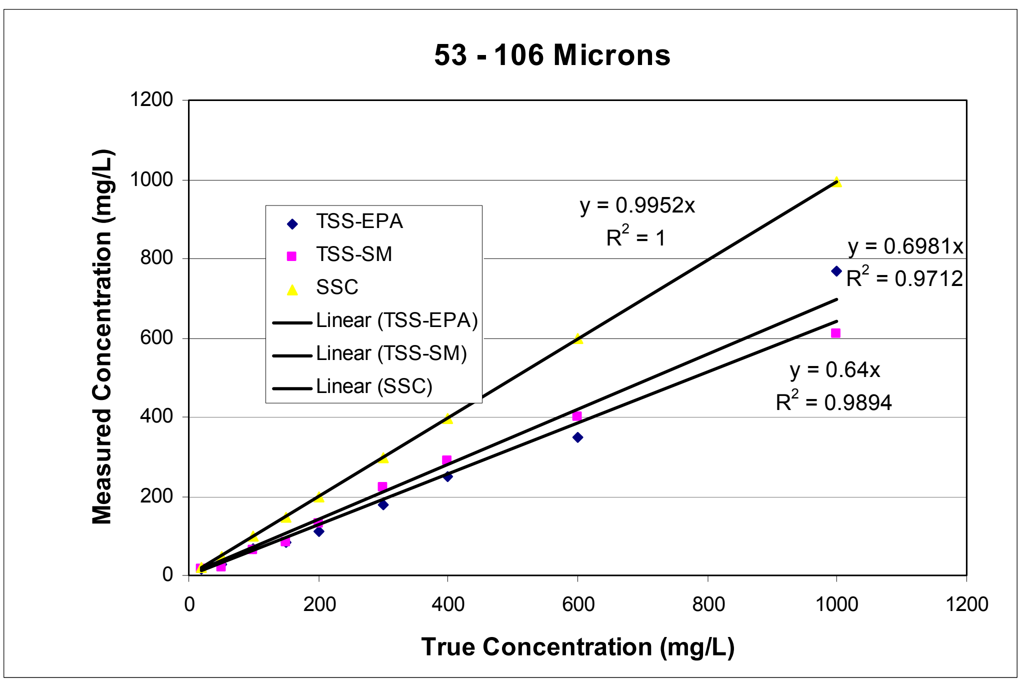

Figure 3 d. Correlations between True Concentration and Measured TSS-EPA, TSS-SM, and SSC Concentrations for Particle Size Ranging from 53 to 106 Microns.

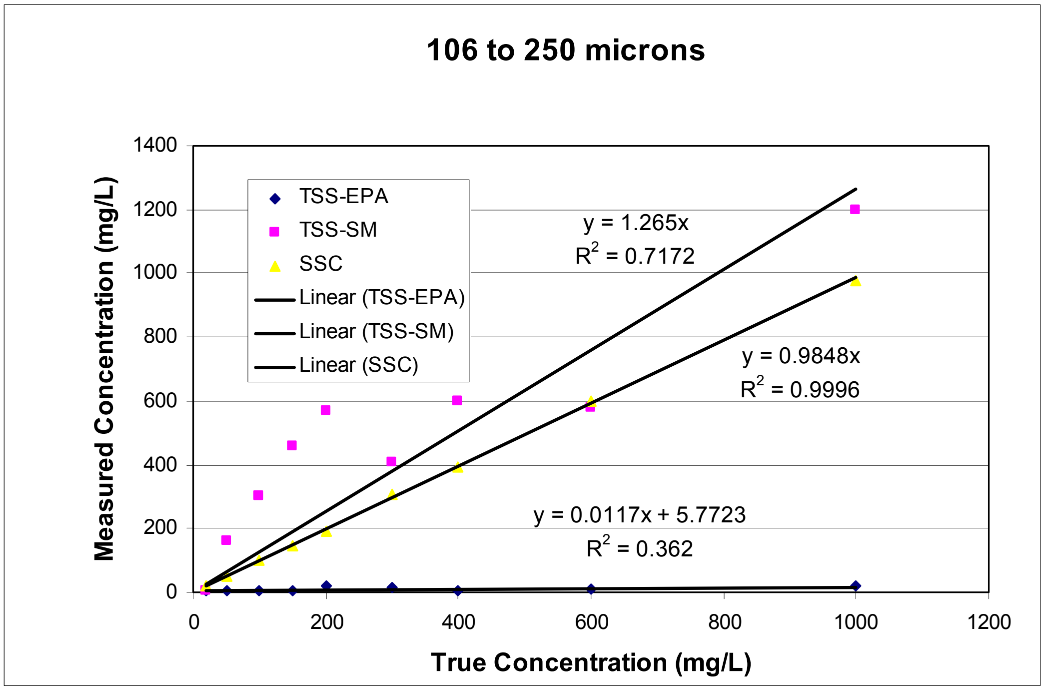

Figure 3 e. Correlations between True Concentration and Measured TSS-EPA, TSS-SM, and SSC Concentrations for Particle Size Ranging from 106 to 250 Microns.

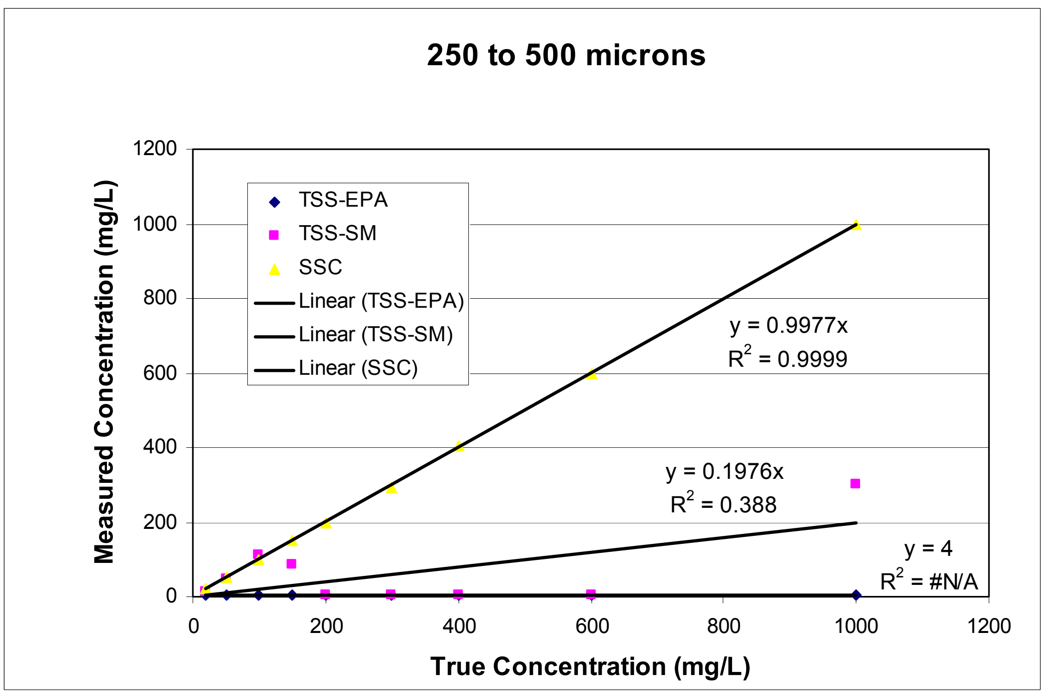

Figure 3 f. Correlations between True Concentration and Measured TSS-EPA, TSS-SM, and SSC Concentrations for Particle Size Ranging from 250 to 500 Microns.

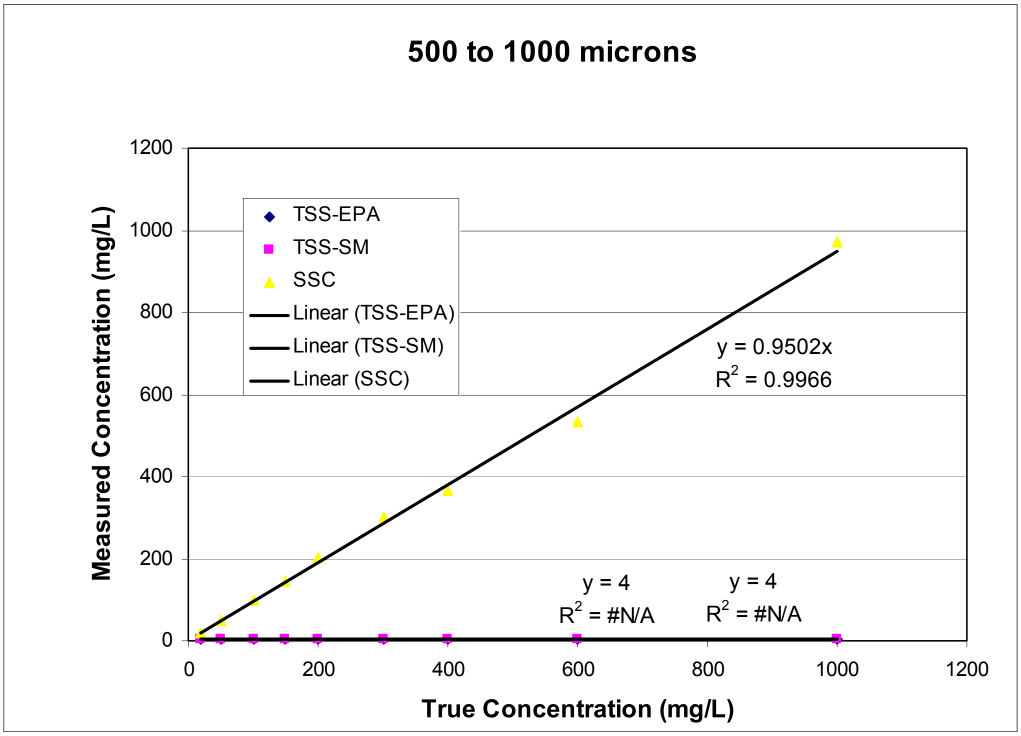

Figure 3 g. Correlations between True Concentration and Measured TSS-EPA, TSS-SM, and SSC Concentrations for Particle Size Ranging from 500 to 1000 Microns.

Both TSS-EPA and TSS-SM were well correlated with SSC. However, TSS-EPA was only 67% of SSC, and TSS-SM was only 59% of SSC.

2. For very fine particles (0 - 8 microns), SSC, TSS-EPA and TSS-SM were all well correlated with the true concentration and very close to the true concentration. The difference was less than 4%.

Both TSS-EPA and TSS-SM were well correlated with SSC, and they were essentially the same. The difference among these three concentrations was less than 2%.

3. For fine particles (8 - 53 microns), SSC, TSS-EPA, and TSS-SM were well correlated with the true concentration. However, they were slightly smaller or moderately smaller than the true concentration. SSC was 95% of the true concentration. TSS-EPA was 98% of the true concentration. TSS-SM was 89% percent of the true concentration.

Both TSS-EPA and TSS-SM were well correlated with SSC. However, TSS-EPA was slightly larger than SSC (less than 4% larger), and the TSS-SM was smaller than SSC (about 6 percent smaller).

4. For fine to medium-size particles (53 to 106 microns), SSC was well correlated with and very close to the true concentration (less than 1% difference). Both TSS-EPA and TSS-SM were well correlated with the true concentration. However, both TSS-EPA and TSS-SM were smaller than the true concentration, 70% and 64% respectively of the true concentration.

Both TSS-EPA and TSS-SM were well correlated with SSC. However, TSS-EPA was only 70% of SSC, and TSS-SM was only 64% of SSC.

5. For medium-size particles (106 to 250 microns), SSC was well correlated with and very close to the true concentration (about 2% difference).

Neither TSS-EPA nor TSS-SM was correlated with the true concentration and SSC. TSS-SM was sometimes larger and sometimes smaller than the true concentration and SSC. TSS-EPA was always very small, slightly above or at the method detection level (4 mg/L).

6. For medium-size to coarse particles (250 to 500 microns), SSC was well correlated with and very close to the true concentration (less than 1% difference).

Neither TSS-EPA nor TSS-SM was correlated with the true concentration and SSC. TSS-SM was sometimes equal to and sometimes much smaller than the true concentration and SSC. TSS-EPA was always below the method detection level (4 mg/L).

7. For coarse particles (500 to 1000 microns), SSC was well correlated with and close to the true concentration (less than 5% difference).

Neither TSS-EPA nor TSS-SM was correlated with the true concentration. Both TSS-SM and TSS-EPA were always below the method detection level (4 mg/L).

Correlation between TSS and SSC was implicitly plotted in Figures 3a – g. The percentage recovery of TSS as SSC and observation of TSS with SSC are explicitly described above and listed in Table 3.

Table 3. Percentage of TSS as SSC and Correlation of TSS with SSC for Each Particle Size Range

Particle Size Range (microns – microns)	TSS-EPA as Percentage of SSC (%)	Does TSS-EPA have a Good Correlation with SSC?	TSS-SM as Percentage of SSC (%)	Does TSS-SM have a Good Correlation with SSC?
0 – 1000 (NJDEP)	59	Yes	67	Yes
0 – 8	100	Yes	99	Yes
8 – 53	96	Yes	91	Yes
53 – 106	70	Yes	64	Yes
106 – 250	2	No	128	No
250 – 500	0	No	20	No
500 – 1000	0	No	0	No

Correlation between the TSS-True Concentration Difference and the Mean Particle Size

As described above, the TSS measurements were close to the true concentration for small particles but were very different for coarse particles. To illustrate the particle size impacts clearly, the results were re-plotted using the mean particle size as the horizontal axis, as shown in Figures 4 and 5.

Similar to that observed above, the TSS-EPA method (using the sub-sample pouring procedure) yielded more consistent results than the TSS-SM method (using a pipette for sub-sampling).

A linear regression line was developed between the TSS-EPA concentration and the true concentration excluding the two large particle size ranges (250 to 500 microns and 500 to 1000 microns). Three different solids concentrations (100 mg/L, 200 mg/L, and 300 mg/L) are shown separately in Figure 6. It can be seen that variation of the concentrations had an insignificant effect on the correlation between the TSS-EPA concentration and the true concentration. Therefore, data from these three solids concentrations are combined in Figure 7.

The data for the NJDEP blend material (particle size ranging from 0 to 1000 microns) are additionally included in Figure 8. This blend material had a much wider particle distribution (Figure 1 vs. Figure 2), but its data still fell close to the linear regression line. This is indeed remarkable.

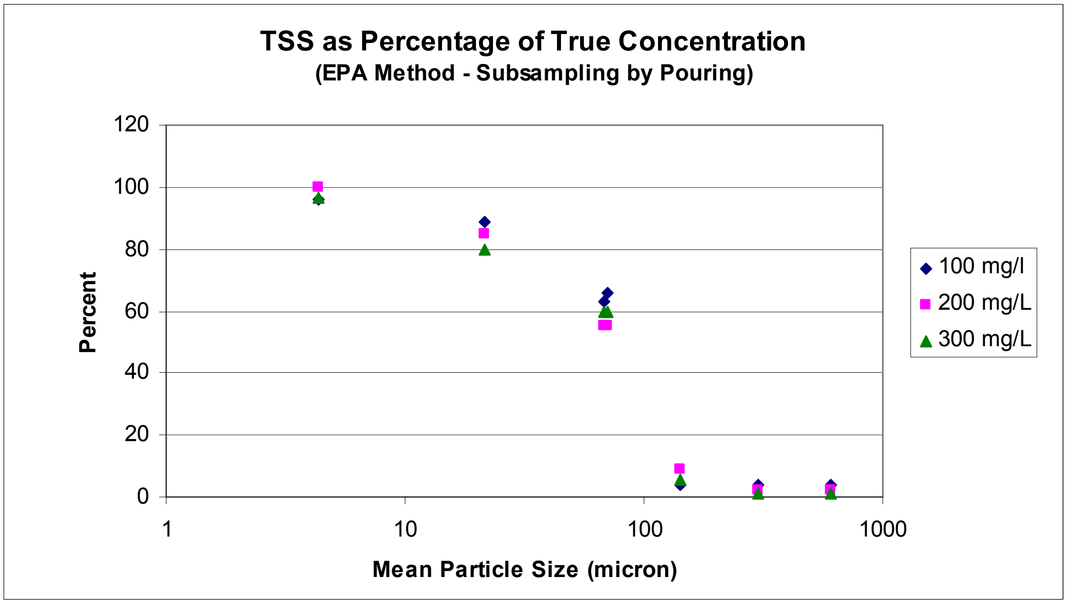

Figure 4. Difference between TSS-EPA Concentration and True Concentration at Different Mean Particle Sizes

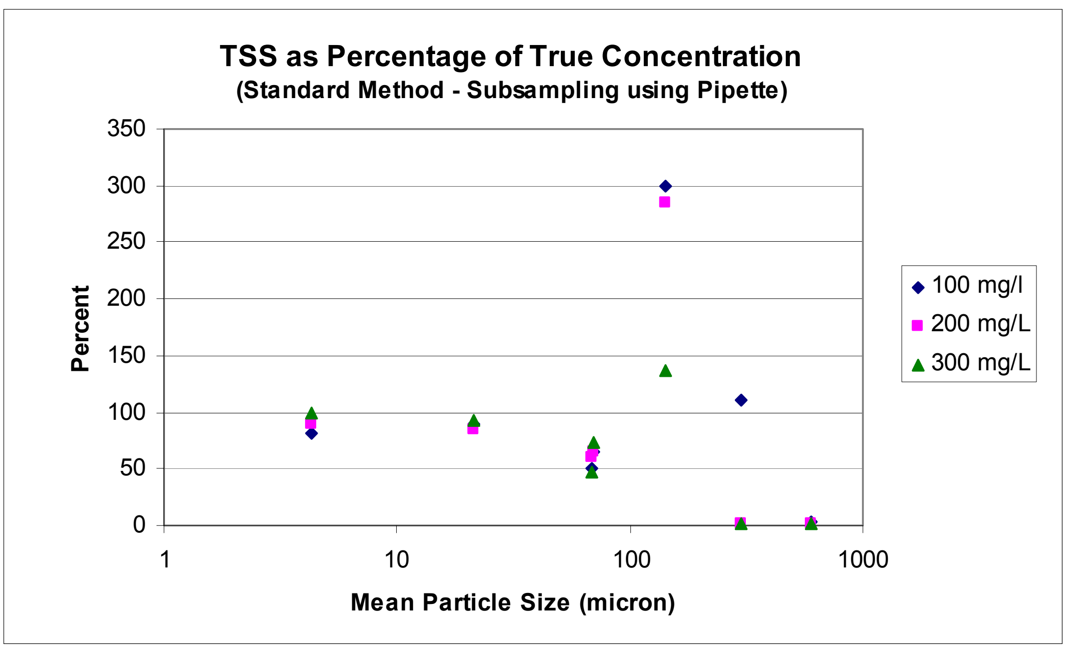

Figure 5. Difference between TSS-SM Concentration and True Concentration at Different Mean Particle Sizes

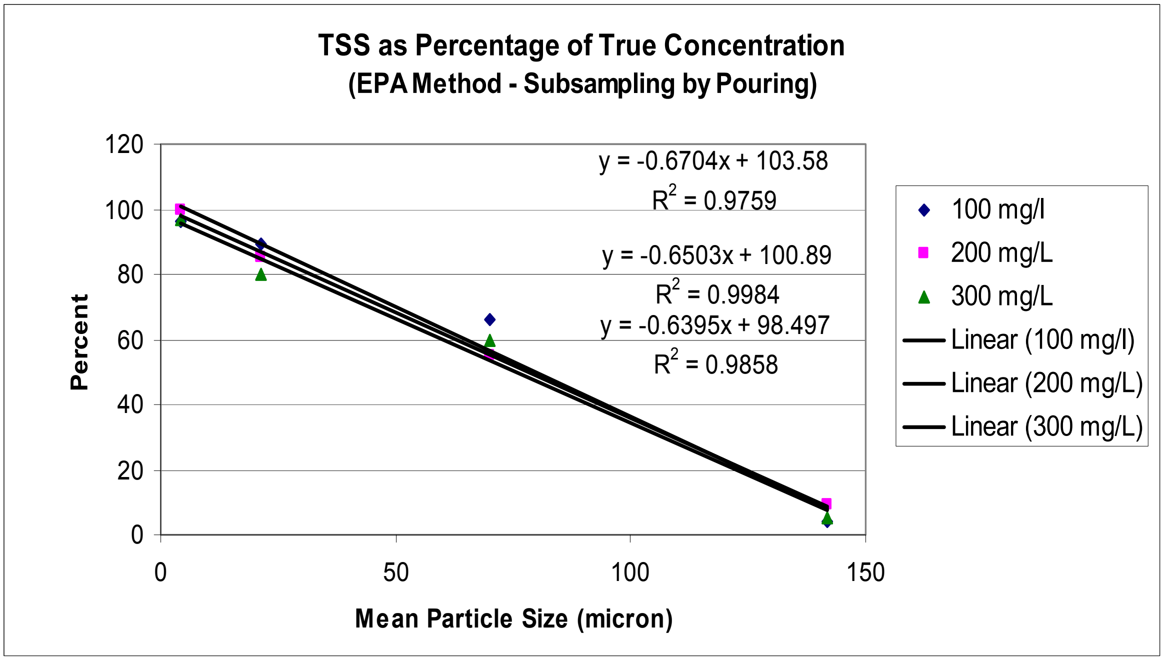

Figure 6. Correlation between the TSS-EPA Concentration and True Concentration Difference and the Mean Particle Size for Three Separate Solids Concentrations

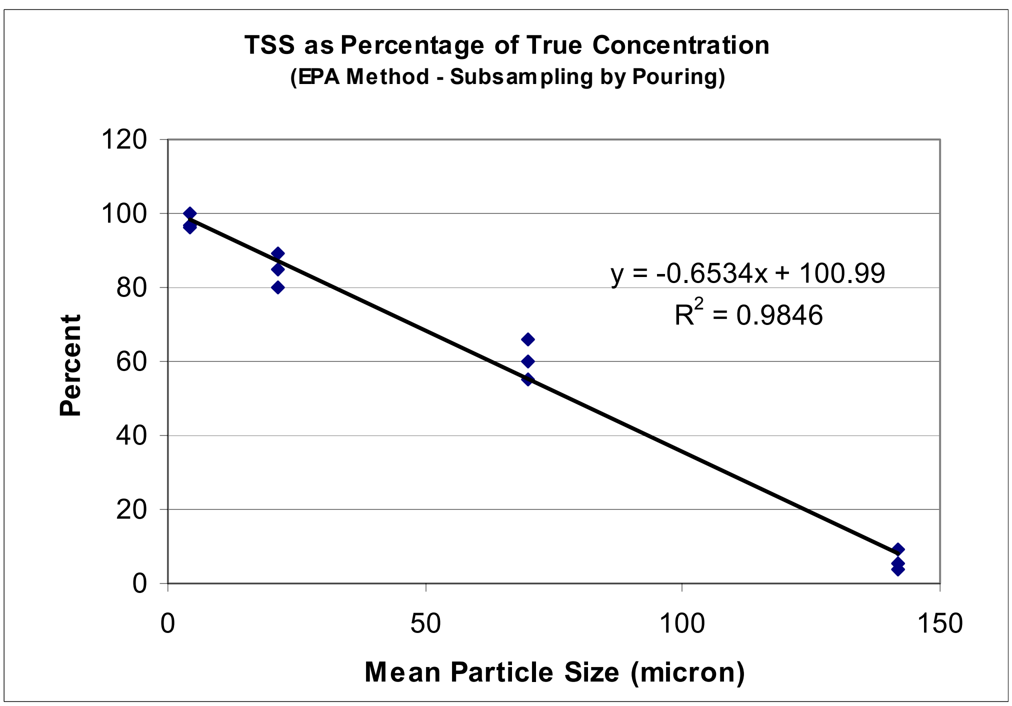

Figure 7. Correlation between the TSS-EPA Concentration and True Concentration Difference and the Mean Particle Size with Three Different Solids Concentrations Combined

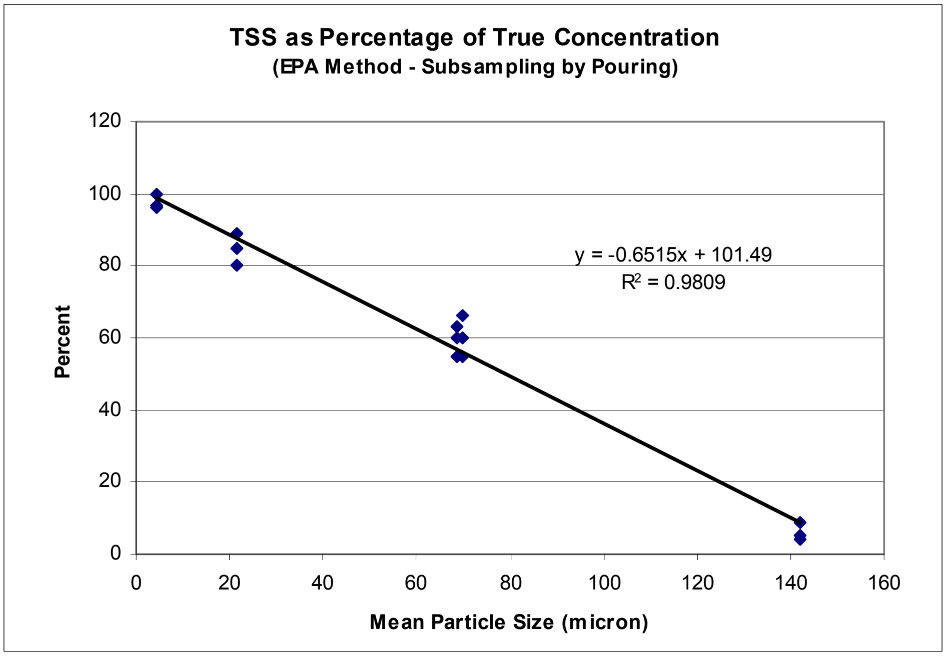

Figure 8. Correlation between the TSS-EPA Concentration and True Concentration Difference and the Mean Particle Size with Three Different Solids Concentrations Combined and Blend Materials Included

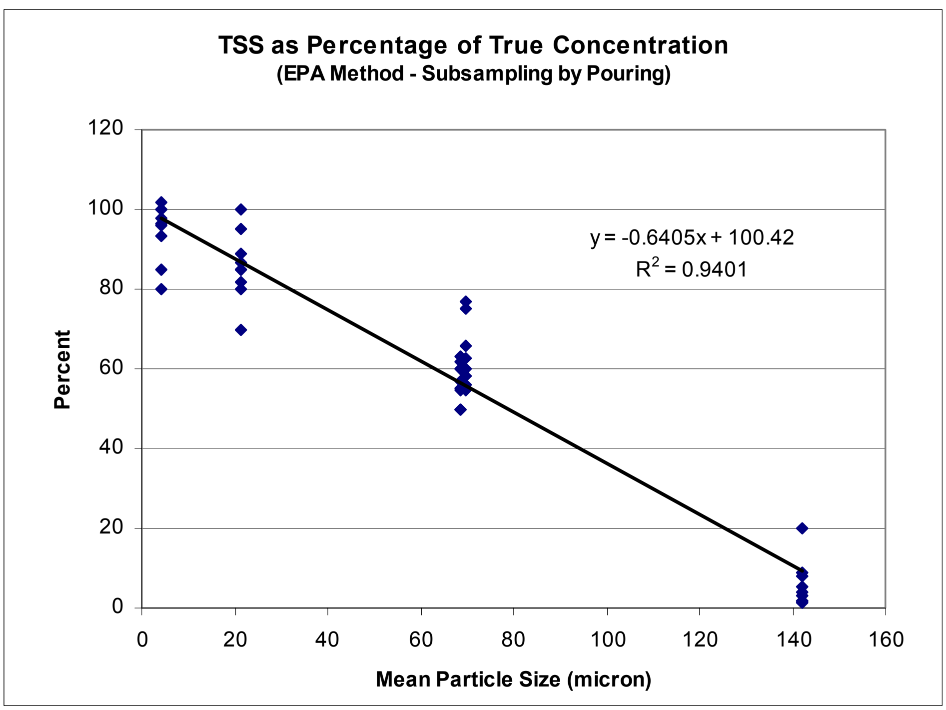

Figure 9. Correlation between the TSS-EPA Concentration and True Concentration Difference and the Mean Particle Size with All the Lab Data Combined

Data from all the nine tested solids concentrations and the five different mean particle sizes are combined in Figure 9. The following linear regression line is obtained:

TSS-EPA as Percentage of True Concentration (%)

= 100.42 - 0.6405 x Mean Particle Size (microns)

Extending this linear regression line yields the zero TSS-EPA reading when the mean particle size is 157 microns. That is, if the mean particle size of a water sample is larger than 157 microns, there will be no TSS-EPA reading.

The above linear regression relationship could be used to predict the TSS concentration (using the EPA sub-sample pouring procedure) from the known true solids concentration and the known mean particle size.

Correlation between the TSS-SSC Concentration Difference and the Mean Particle Size

The correlation between the TSS-SSC concentration difference and the mean particle size was also analyzed. Since the SSC concentration was very close to the true concentration, all the correlations were similar to the correlation between the TSS-true concentration difference and the mean particle size. The results of the correlation analysis are shown from Figures 10 to 13.

The linear regression line for the three solids concentrations (100 mg/L, 200 mg/L, and 300 mg/L) combined (Figure 12) can be expressed as:

TSS-EPA as Percentage of SSC Concentration (%)

= 102.97 - 0.6619 x Mean Particle Size (microns)

The 95% confidence intervals of the above linear regression were additionally calculated. The 95% confidence interval for the intercept is from 98.36% to 107.57%, and that for the slope is from –0.7212 to -0.6027. The calculated lower and upper 95% confidence limits are also included in Figure 12.

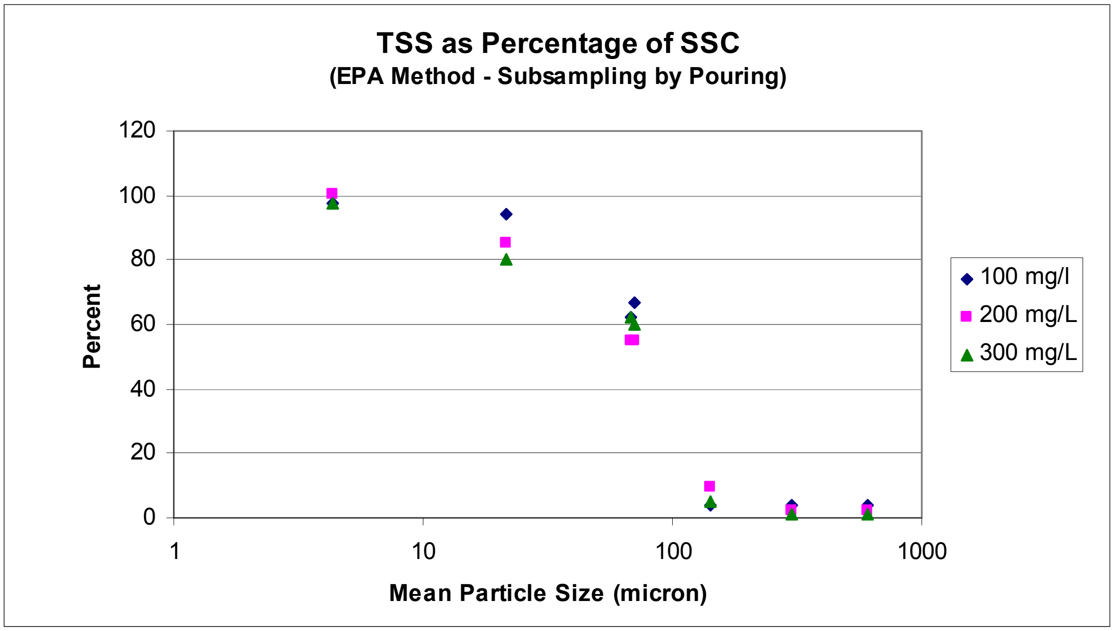

Figure 10. Difference between TSS-EPA Concentration and SSC Concentration at Different Mean Particle Sizes

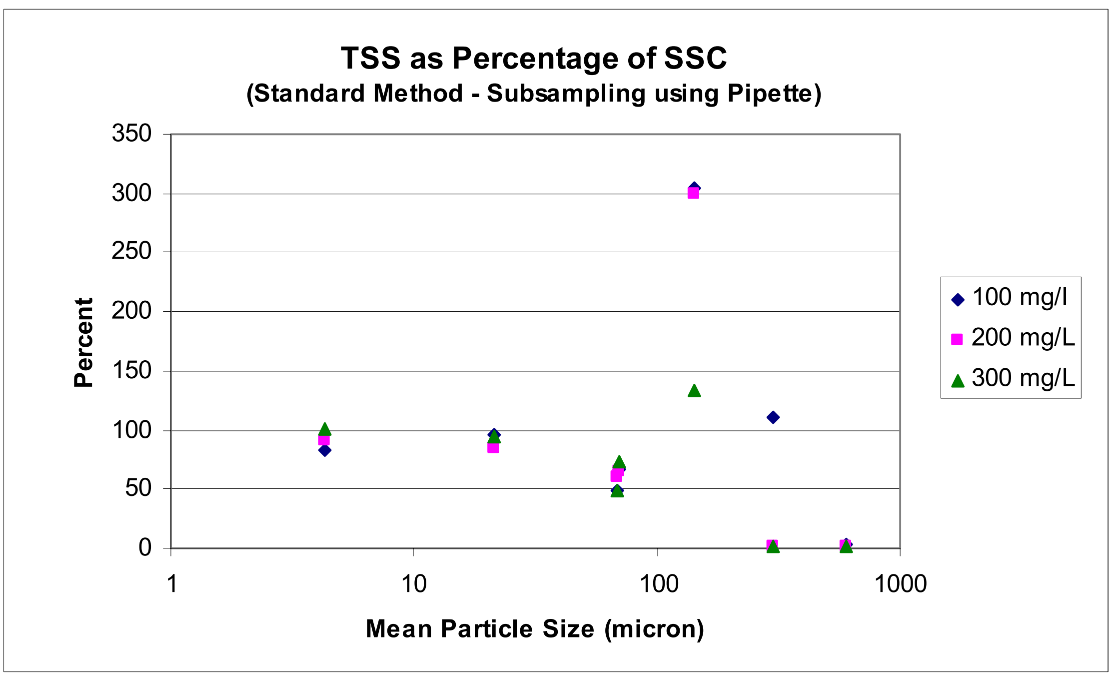

Figure 11. Difference between TSS-SM Concentration and SSC Concentration at Different Mean Particle Sizes

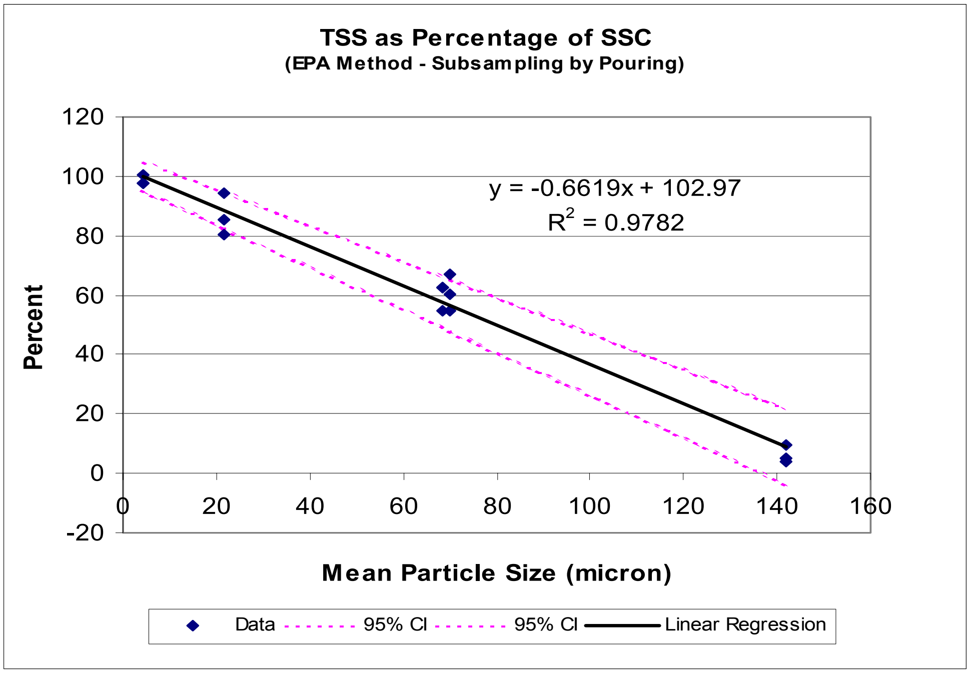

Figure 12. Correlation between the TSS-EPA Concentration and SSC Concentration Difference and the Mean Particle Size with Three Different Solids Concentrations Combined and Blend Materials Included

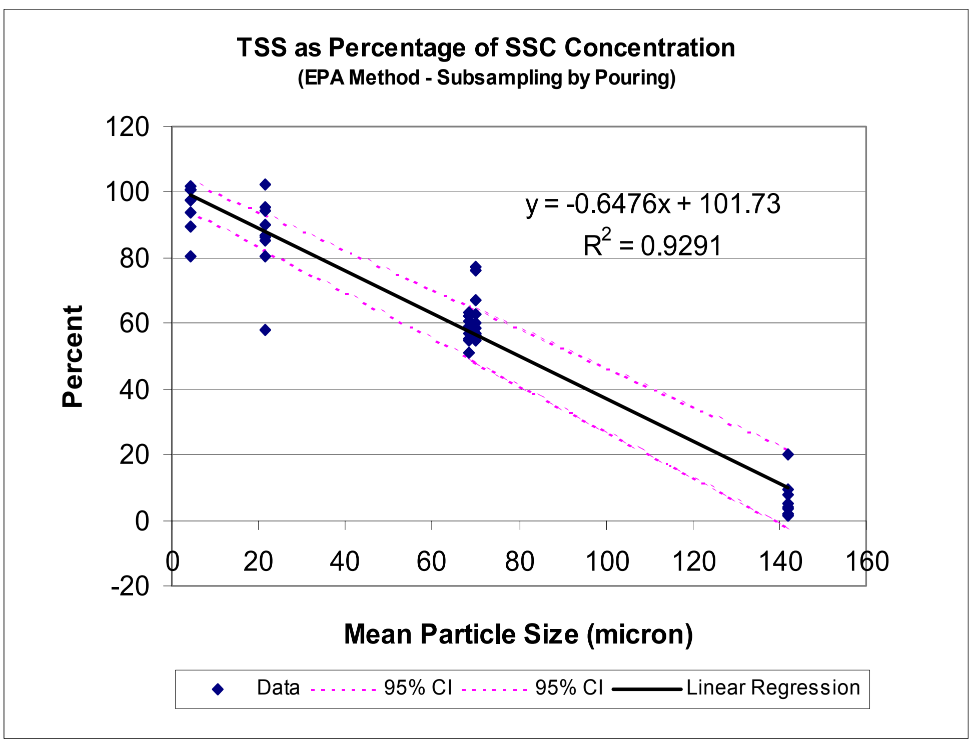

Figure 13. Correlation between the TSS-EPA Concentration and SSC Concentration Difference and the Mean Particle Size with All the Lab Data Combined

The linear regression line for all nine solids concentrations (20 mg/L, 50 mg/L, 100 mg/L, 150 mg/L, 200 mg/L, 300 mg/L, 400 mg/L, 500 mg/L, 600 mg/L, and 1000 mg/L) combined (Figure 13) can be expressed as:

TSS-EPA as Percentage of SSC Concentration (%)

= 101.73 - 0.6476 x Mean Particle Size (microns)

Extending this linear regression line yields the zero TSS-EPA reading when the mean particle size is 157 microns. That is, if the mean particle size of a water sample is larger than 157 microns, there will be no TSS-EPA reading.

The above linear regression relationship could be used to predict the TSS concentration (using the EPA sub-sample pouring procedure) from the measured SSC concentration and the known mean particle size.

The 95% confidence intervals of the above linear regression were additionally calculated. The 95% confidence interval for the intercept is from 97.45% to 106.01%, and that for the slope is from –0.7026 to -0.5926. The lower and upper 95% confidence limits are also included in Figure 13.

In addition to studying direct correlation between the measured TSS and SSC concentrations of the stream water samples, USGS (Gray et al. 2000) also studied the impacts of particle size distribution (PSD) on differences between TSS and SSC concentrations. Stormwater Management Inc. (SMI 2004) did a similar PSD impacts study using manufactured solids as well as stormwater-born solids. They both used a fraction of sand to represent the particle size distribution, rather than the mean size used in this project. USGS used the Standard Method to analyze the TSS concentration, whereas SMI used the EPA Method to analyze the TSS concentration. Both of their results show that the difference between TSS and SSC became smaller as the solids material became finer, consistent with the findings from this research project. Although a complete comparison is difficult to do, the regression results from SMI (2004) appear to be close to the regression results obtained from this research project. The same EPA Method was used to analyze TSS in SMI (2004) and this research project, but two different outside, certified laboratories were utilized.

TSS and SSC Data from the Field

A literature search was conducted on the specific method that was used to quantify the amount of solids removed during past quantification of the BMPs TSS removal performance. The focus was placed on the two performance databases, the American Society of Civil Engineers (ASCE)'s National BMP Database and the Center for Watershed Protection (CWP)'s database, that were used in developing the NJ stormwater technical manuals.

Both ASCE database (http://www.bmpdatabase.org) and CWP database (http://www.cwp.org) were accessed and reviewed. The development and management personnel for the ASCE database were contacted for understanding the database, especially the laboratory analytical methods that were used in quantifying the various reported solid concentrations. A hard copy of the CWP database report (Winer 2000) was purchased and reviewed. The literature search was also conducted for other databases, reports, papers, et al. for additional TSS and SSC measurements and BMP solids removal efficiencies.

Unfortunately, no simultaneous measurements of TSS and SSC were found from the past field studies. Therefore, no field results can be reported and an analysis of the TSS-SSC correlation cannot be conducted from the field data either.

Fortunately, the Technology Acceptance and Reciprocity Partnership (TARP) field monitoring protocol (TARP, 2003) and its amendments by NJDEP (2006) require measurements of both TSS and SSC. Implementation of the protocol will lead to a rich database for TSS and SSC. However, no reports of the TARP field studies were completed and released before end of this project (August 2006).

Potential Impacts of Research Results on BMP Performance Certification

Potential Impacts on Certification Based on Laboratory Testing Data

The NJDEP lab testing protocol (NJDEP 2003) specified that particles with a density of 2,650 kg/m^3 should be used, and influent concentrations of 100 mg/L, 200 mg/L, and 300 mg/L should be used. Therefore, the obtained correlation between the TSS (EPA)-SSC difference and the particle diameter for the three concentrations combined (Figure 12) could be directly used. Adjusting the regression line to have the intercept of 100% yields the following correlation relationship (Figure 14):

TSS-EPA as Percentage of SSC Concentration (%)

= 100 - 0.6319 x Mean Particle Size (microns)

The 95% confidence interval of the above linear regression with the fixed intercept of 100% was additionally calculated. The 95% confidence interval for the slope is from -0.6693 to –0.5944. The lower and upper 95% confidence limits are also included in Figure 14.

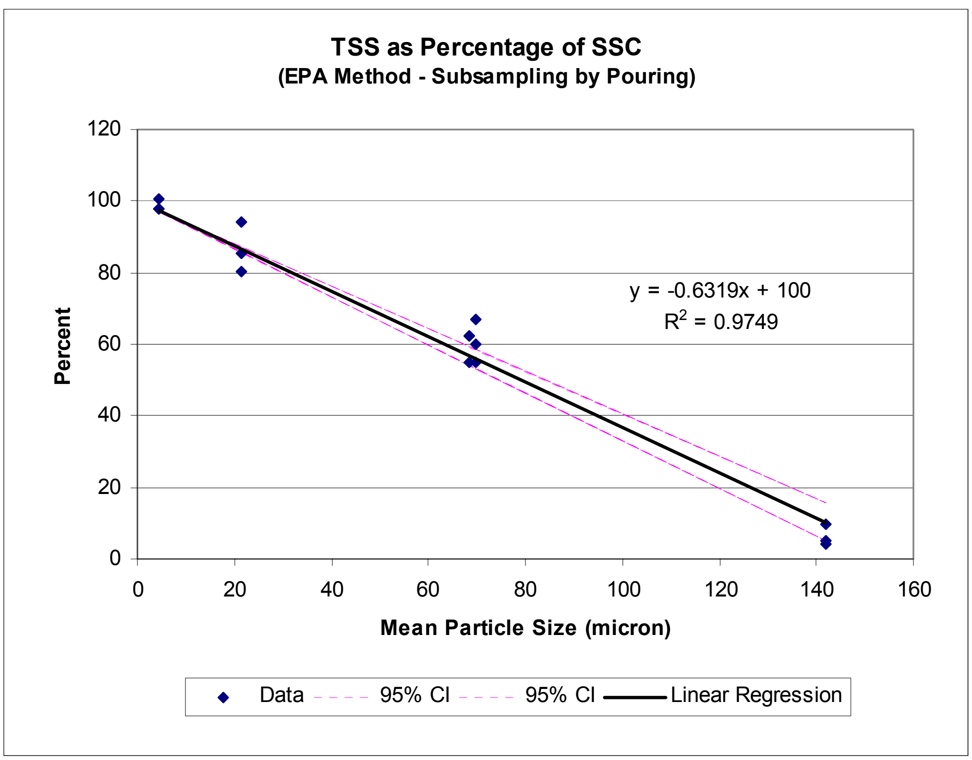

Figure 14. Correlation between TSS-EPA as Percentage of SSC and Mean Particle Size with Intercept of 100 percent

The above regression relationship can be converted into a direct relationship between TSS and SSC as follows:

$$\mathbf{TSS = SSC\ (1 - 0.0063\ d_{50})}$$

where TSS is the concentration of total suspended solids in mg/L, SSC is the suspended sediment concentration in mg/L, and d_{50} is the mean particle size in microns. Correspondingly, the 95% confidence interval of the coefficient -0.0063 is from -0.0067 to -0.0059.

An example of potential application of the obtained regression relationship to adjusting the lab- tested solids removal performance is given below:

Measured Influent SSC = 200 mg/L
Measured Influent d_{50} = 67 microns
Measured Effluent SSC = 60 mg/L
Measured Effluent d_{50} = 30 microns

Measured SSC Removal Efficiency = 70 %

Predicted Influent TSS = 116 mg/L
(with the 95% confidence interval from 110 to 121 mg/L)
Predicted Effluent TSS = 48.7 mg/L
(with the 95% confidence interval from 47.9 to 49.4 mg/L)

Predicted TSS Removal Efficiency = 58 %
(with the 95% confidence interval from 56.5 to 59.2%)

In the above example, the measured SSC removal efficiency of 70% has been adjusted down to TSS removal efficiency of 58% (or 57 to 59%).

Potential Impacts on Certification Based on Field Monitoring Data

Since density of particles in the actual runoff would most likely differ from the density of the particles used in the laboratory tests, the regression relationship obtained from this research project based on the measured particle size alone cannot be directly applied to predict the field TSS from the field-measured SSC. However, the "equivalent" particle size (diameter) could be used to predict the field TSS from the field-measured SSC. The equivalent particle diameter is defined as the diameter of a sphere that has the same density and the same settling velocity in any given fluid as the particle in question. In order to determine the equivalent particle size, the particle settling velocity has to be quantified beforehand. The particle settling velocity could be measured directly from the collected water samples. It could also be calculated from the measured particle size, density, and fluid temperature by using the Stokes' law for fine particles or using other equations for coarse particles (see, e.g., Yang 1996).

An example of potential application of the obtained regression relationship to adjusting the field- monitored solids removal performance is given below:

Measured Influent SSC = 200 mg/L
Measured Influent Particle Settling Velocity = 0.17 cm/s
(Alternatively, Measured Influent d50 = 100 microns, Measured Influent Mean Particle Density = 1,500 kg/m3, Measured Water Temperature = 4^{o}C)
Calculated Influent Equivalent d50 = 55 microns

Measured Effluent SSC = 30 mg/L
Measured Effluent Particle Settling Velocity = 0.0035 cm/s
(Alternatively, Measured Effluent d50 = 10 microns, Measured Effluent Mean Particle Density = 2,000 kg/m3, Measured Water Temperature = 4^{o}C)
Calculated Effluent Equivalent d50 = 8 microns

Measured SSC Removal Efficiency = 85 %

Predicted Influent TSS = 131 mg/L
(with the 95% confidence interval from 126 to 135 mg/L)
Predicted Effluent TSS = 28.5 mg/L
(with the 95% confidence interval from 28.4 to 28.6 mg/L)

Predicted TSS Removal Efficiency = 78.2%
(with the 95% confidence interval from 77.5 to 78.8%)

In the above example, the measured SSC removal efficiency of 85% has been adjusted down to the TSS removal efficiency of 78% (or 78 to 79%).

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Appendix A. Particle Size Distribution of Manufactured Solids

A-1. Results of Sieve Analysis

PTI POWDER TECHNOLOGY INC.

Classification, Pulverization, Blending, Screening and Particle Modification Services

SIEVE ANALYSIS DATA SHEET

Customer: Rutgers University **Date:** 10 January 2006 **Material: QUARTZ**

Operator: Kyle **Lab Numbers:** 90094 **Sieve Equipment:** Ro-Tap

Material: Quartz Blend
Analysis No: 90094L
Sample Weight: 100 grams
Sieve time: 10 min

Screen		On Screen Material	
Mesh	**Micron**	**Weight**	**%**
18	1000	0.0	0.0
35	500	5.5	5.5
60	250	5.4	5.4
140	106	30.2	30.2
270	53	21.9	21.9
PAN	-53	37.0	37.0

Material: Quartz Blend
Analysis No: 90094L
Sample Weight: 100 grams
Sieve time: 10 min

Screen		On Screen Material	
Mesh	**Micron**	**Weight**	**%**
18	1000	0.0	0.0
35	500	5.3	5.3
60	250	5.6	5.6
140	106	30.1	30.1
270	53	22.2	22.2
PAN	-53	36.8	36.8

Material: Quartz Blend
Analysis No: 90094L
Sample Weight: 100 grams
Sieve time: 10 min

Screen		On Screen Material	
Mesh	**Micron**	**Weight**	**%**
18	1000	0.0	0.0
35	500	5.6	5.6
60	250	5.1	5.1
140	106	30.4	30.4
270	53	21.7	21.7
PAN	-53	37.2	37.2

Material
Analysis No.
Sample Weight
Sieve Time:

Screen		On Screen Material	
Mesh	**Micron**	**Weight**	**%**

ISO 9001:2000 Certified

14331 Ewing Ave S • Burnsville, Minnesota 55306 • Phone: 952-894-8737 • Fax: 952-894-0734
Web: www.powdertechnologyinc.com

SIEVE ANALYSIS DATA SHEET

Customer: Rutgers **Date:** 12/14/05 **Material:** Quartz

Operator: CCP **Lab Numbers:** 90094 **Sieve Equipment:** Ro-Tap

Material: Nominal 53-106 micron quartz
Material No: 90094C
Sample Weight: 100 grams
Sieve Time: 10 minutes

Sieve Screen size

Mesh	Micron	% Retained
140	106	3.0
170	88	17.9
200	75	44.4
230	62	29.9
270	53	4.8
Pan	-53	0.0

Material: Nominal 106-250 micron quartz
Material No: 90094F
Sample Weight: 100 grams
Sieve Time: 10 minutes

Sieve Screen size

Mesh	Micron	% Retained
60	250	1.8
70	210	13.7
80	177	26.9
100	150	26.0
120	125	18.8
140	106	9.8
Pan	-1065	3.0

Material: Nominal 250-500 micron quartz
Material No: 90049G
Sample Weight: 100 grams
Sieve Time: 10 minutes

Sieve Screen size

Mesh	Micron	% Retained
35	500	0.0
40	425	8.1
45	355	46.5
50	300	32.2
60	250	8.7
Pan	-250	4.5

Material: Nominal 500-1000 micron quartz
Material No: 90094J
Sample Weight: 100 grams
Sieve Time: 10 minutes

Sieve Screen size

Mesh	Micron	% Retained
18	1000	0.0
20	850	9.0
25	710	46.8
30	600	35.5
35	500	6.8
Pan	-500	1.9

A-2 Results of Coulter Counter Analysis

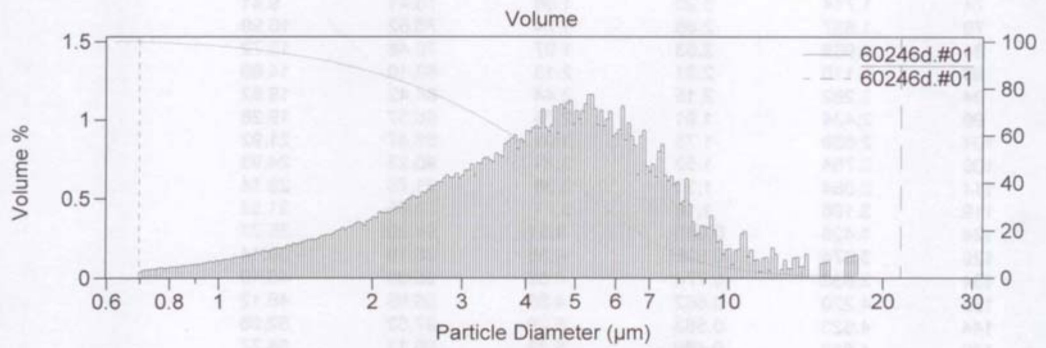
COULTER® MULTISIZER AccuComp® 1.19

12 Jul 2006

POWDER TECHNOLOGY, INC.

PTI Powder Technology Inc.
14331 Ewing Avenue South Burnsville, Minnesota 55306
Phone: 952-894-8737

Filename:	60246d.#01	Sample Number:	111
Group ID:	60246D		
Sample ID:	RUN 4		
Comment:	NOMINAL 0-8 MICRON QUARTZ		
Operator:	LHA		
Electrolyte:	ISOTON II		
Dispersant:	TYPE IC		
Aperture Size:	30 µm	Aperture Current:	800 uA
Channels:	256	Kd:	319.27
Full Data, Log Diameter		Gain:	4
Control Method:	200.0 sec Elapsed Time		
Elapsed Time:	200.0 Seconds		
Raw Count:	333664		
Acquired:	23:43 28 Jun 2004		
Serial Number:	8308970		
Edited size data			



LC= 0.696 µm UC= 21.67 µm {100.00%}

Volume Statistics (Geometric) 60246d.#01

Calculations from 0.696 µm to 21.67 µm

Volume	$1.981e6\ \mu m^3$		
Mean:	4.020 µm	S.D.:	3.23 µm
Median:	4.331 µm	Variance:	$10.5\ \mu m^2$
Mean/Median Ratio:	0.928		
Mode:	5.379 µm		
Spec. surf. area:	$1.801\ m^2/ml$		

% >	10	25	50	75	90
Size µm	7.903	6.064	4.331	2.788	1.760

COULTER® MULTISIZER AccuComp® 1.19

12 Jul 2006

POWDER TECHNOLOGY, INC.

60246d.#01

Channel Number	Particle Diameter µm	Diff Number %	Diff Volume %	Cum < Number %	Cum < Volume %
9	0.696	7.38	0.245	0	0
14	0.746	7.52	0.306	7.38	0.245
19	0.800	7.09	0.355	14.90	0.551
24	0.857	6.75	0.417	21.99	0.907
29	0.918	6.43	0.488	28.74	1.32
34	0.984	6.11	0.571	35.17	1.81
39	1.055	5.69	0.655	41.27	2.38
44	1.131	5.35	0.759	46.97	3.04
49	1.212	5.00	0.872	52.32	3.80
54	1.299	4.56	0.979	57.32	4.67
59	1.392	4.22	1.12	61.88	5.65
64	1.492	3.83	1.25	66.10	6.77
69	1.599	3.49	1.40	69.93	8.01
74	1.714	3.20	1.58	73.41	9.41
79	1.837	2.86	1.74	76.62	10.99
84	1.969	2.63	1.97	79.48	12.72
89	2.110	2.31	2.13	82.10	14.69
94	2.262	2.15	2.44	84.42	16.82
99	2.424	1.91	2.66	86.57	19.26
104	2.598	1.75	3.01	88.47	21.92
109	2.784	1.52	3.21	90.23	24.93
114	2.984	1.30	3.38	91.75	28.14
119	3.198	1.16	3.71	93.05	31.52
124	3.428	0.990	3.91	94.20	35.23
129	3.674	0.896	4.35	95.19	39.14
134	3.938	0.774	4.63	96.09	43.49
139	4.220	0.662	4.86	96.86	48.12
144	4.523	0.583	5.29	97.52	52.98
149	4.848	0.469	5.22	98.11	58.27
154	5.196	0.400	5.47	98.58	63.50
159	5.569	0.296	4.98	98.98	68.97
164	5.968	0.230	4.79	99.27	73.95
169	6.397	0.165	4.22	99.50	78.75
174	6.856	0.112	3.53	99.67	82.97
179	7.348	0.087	3.35	99.78	86.50
184	7.875	0.056	2.65	99.87	89.85
189	8.441	0.027	1.57	99.92	92.50
194	9.046	0.021	1.48	99.95	94.07
199	9.696	0.009	0.772	99.97	95.55
204	10.39	0.010	1.08	99.98	96.32
209	11.14	0.004	0.528	99.99	97.40
214	11.94	0.003	0.441	99.99	97.93
219	12.79	0.002	0.495	99.99	98.37
224	13.71	0.001	0.293	100.00	98.86
229	14.70	0.001	0.291	100.00	99.16
234	15.75	0	0	100.00	99.45
239	16.88	0.001	0.553	100.00	99.45
244	18.09	0	0	100.00	100.00
249	19.39	0	0	100.00	100.00

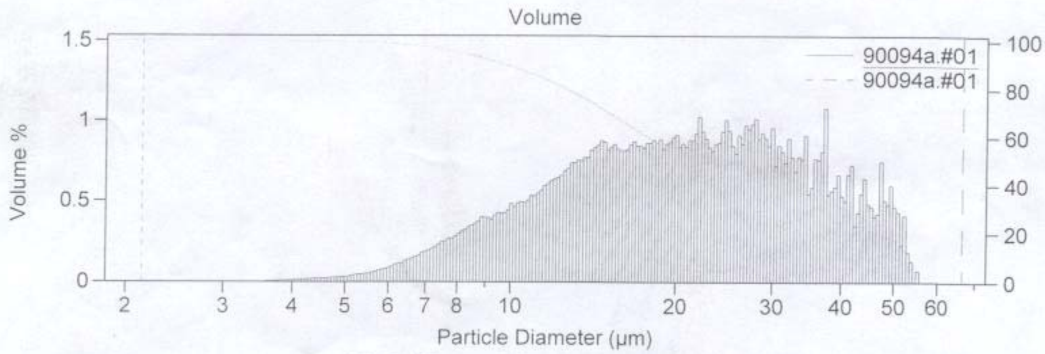
COULTER® MULTISIZER AccuComp® 1.19

12 Dec 2005

POWDER TECHNOLOGY, INC.

PTI Powder Technology Inc.
14331 Ewing Avenue South Burnsville, Minnesota 55306
Phone: 952-894-8737

Filename:	90094a.#01	Sample Number:	200
Group ID:	90094A		
Sample ID:	RUN 1 DRUM 1		
Comment:	NOMINAL 8-53 MICRON QUARTZ		
Operator:	CP		
Electrolyte:	ISOTON II		
Dispersant:	TYPE 1C		
Aperture Size:	100 µm	Aperture Current:	1600 uA
Channels:	256	Kd:	981.22
Full Data, Log Diameter		Gain:	2
Control Method:	Manual		
Elapsed Time:	226.5 Seconds		
Raw Count:	131027		
Acquired:	13:50 9 Dec 2005		
Serial Number:	8308970		
Edited size data			



LC= 2.139 µm UC= 66.59 µm {100.00%}

Volume Statistics (Geometric) 90094a.#01

Calculations from 7.984 µm to 53.34 µm

Volume	120.6e6 μm^3		
Mean:	21.22 µm	S.D.:	13 µm
Median:	21.46 µm	Variance:	169 μm^2
Mean/Median Ratio:	0.989		
Mode:	37.46 µm		
Spec. surf. area:	0.345 m^2/ml		

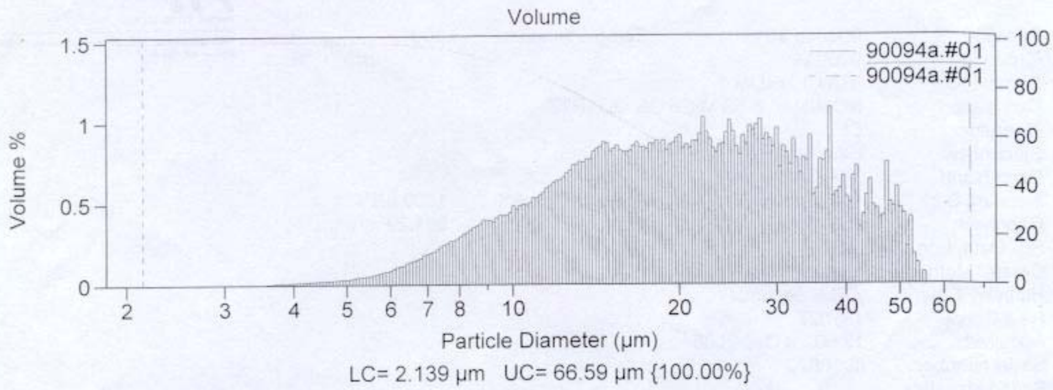
8-53

% >	10	25	50	75	90
Size µm	40.63	30.92	21.46	14.59	10.98

COULTER® MULTISIZER AccuComp® 1.19

12 Dec 2005

POWDER TECHNOLOGY, INC.



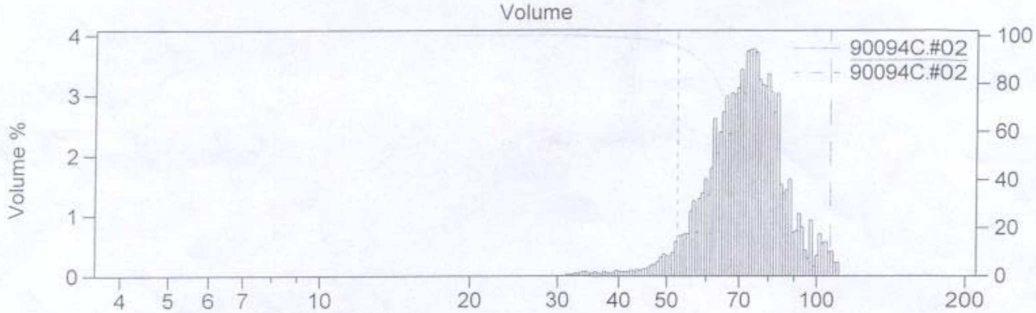
COULTER®　　MULTISIZER AccuComp® 1.19

9 Dec 2005

POWDER TECHNOLOGY, INC.

PTI POWDER TECHNOLOGY INC. 14331 Ewing Avenue South Burnsville, Minnesota 55306 Phone: 952-894-8737

Filename:	90094C.#02	Sample Number:	200
Group ID:	90094C		
Sample ID:	RUN 3 DRUM 1		
Comment:	NOMINAL 53-106 MICRON		
Operator:	CCP		
Electrolyte:	ISOTON II		
Dispersant:	TYPE IC		
Aperture Size:	200 µm	Aperture Current:	1600 uA
Channels:	256	Kd:	1905.6
Full Data, Log Diameter		Gain:	2
Control Method:	Manual		
Elapsed Time:	203.7 Seconds		
Raw Count:	12984		
Acquired:	15:32 9 Dec 2005		
Serial Number:	8308970		
Edited size data			



LC= 52.52 µm UC= 106.5 µm {94.30%}

Volume Statistics (Geometric)　　90094C.#02

Calculations from 52.52 µm to 106.5 µm

53-106

Volume	295.3e6 μm^3		
Mean:	72.87 µm	S.D.:	11.4 µm
Median:	73.11 µm	Variance:	130 μm^2
Mean/Median Ratio:	0.997		
Mode:	74.79 µm		
Spec. surf. area:	0.0854 m^2/ml		

% >	10	25	50	75	90
Size µm	87.60	80.33	73.11	65.74	59.99

COULTER® MULTISIZER AccuComp® 1.19

9 Dec 2005

POWDER TECHNOLOGY, INC.

90094C.#02

Channel Number	Particle Diameter µm	Diff Number %	Diff Volume %	Cum < Number %	Cum < Volume %
192	52.52	7.26	3.82	17.36	4.85
197	56.29	9.69	6.27	24.63	8.67
202	60.33	12.78	10.18	34.31	14.93
207	64.66	14.48	14.09	47.09	25.12
212	69.30	14.22	17.08	61.57	39.21
217	74.27	11.64	17.07	75.79	56.29
222	79.60	7.62	13.68	87.43	73.36
227	85.32	2.68	5.90	95.05	87.04
232	91.44	1.29	3.51	97.73	92.94
237	98.00	0.670	2.31	99.02	96.44
242	105.0	0.103	0.396	99.69	98.75

A-3. Results of Laser Counter Analysis

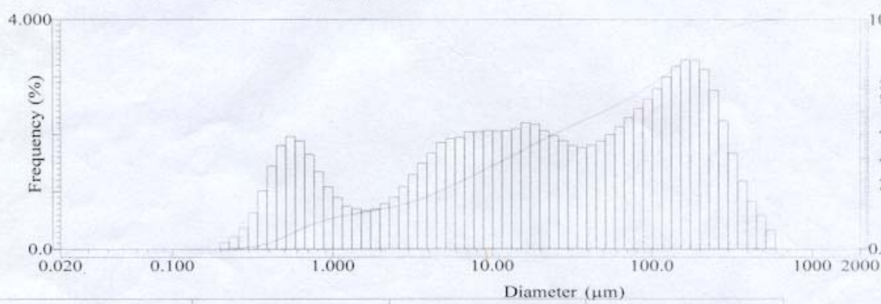
PTI
POWDER TECHNOLOGY INC.
14331 Ewing Ave S
Burnsville, MN 55306
Ph: 952-894-8737
Fax: 952-894-0734

Filename	:90094L CUSTOM BLEND	Dispersant	:ISOTON II
Circulation Speed	:2	Fluid used	:WATER
Ultra sonic	:01:00 (2)	Run #	:
Laser T%	: 76.0(%)	Drum or Sack #	:12/14/05
Lamp T%	: 76.6(%)		
Form of Distribution	:Standard		
Distribution Base	:Volume		
R.R.Index	:109a001i		
Customer	:RUTGERS		
Material	:PRODUCT #1		
Lot #	:		
PTI Analysis #	:90094L		
Operator	:CCP		

Median : 24.3047(µm)

Diameter on % :(1)5.000 (%)- 0.4872(µm)
(2)10.00 (%)- 0.6995(µm)
(3)20.00 (%)- 2.9573(µm)
(4)30.00 (%)- 6.6031(µm)
(5)40.00 (%)- 12.7924(µm)
(6)60.00 (%)- 50.7334(µm)
(7)70.00 (%)- 92.9659(µm)
(8)80.00 (%)- 148.2006(µm)
(9)90.00 (%)- 225.3401(µm)
(10)95.00 (%)- 293.6905(µm)

% on Diameter :2.000 (µm)- 17.312(%)
4.000 (µm)- 23.153(%)
8.000 (µm)- 32.879(%)
53.00 (µm)- 60.632(%)
106.0 (µm)- 72.587(%)
250.0 (µm)- 92.158(%)
500.0 (µm)- 99.522(%)
1000 (µm)- 100.000(%)



No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %
1	0.022	0.000	0.000	23	0.445	1.448	3.798	45	8.816	2.048	34.344	67	174.616	3.295	83.959
2	0.026	0.000	0.000	24	0.510	1.805	5.603	46	10.097	2.068	36.412	68	200.000	3.293	87.251
3	0.029	0.000	0.000	25	0.584	1.961	7.564	47	11.565	2.053	38.465	69	229.075	3.128	90.379
4	0.034	0.000	0.000	26	0.669	1.889	9.453	48	13.246	2.065	40.530	70	262.376	2.762	93.141
5	0.039	0.000	0.000	27	0.766	1.652	11.105	49	15.172	2.096	42.626	71	300.518	2.238	95.379
6	0.044	0.000	0.000	28	0.877	1.350	12.455	50	17.377	2.205	44.831	72	344.206	1.673	97.052
7	0.051	0.000	0.000	29	1.005	1.084	13.539	51	19.904	2.175	47.007	73	394.244	1.189	98.241
8	0.058	0.000	0.000	30	1.151	0.895	14.434	52	22.797	2.060	49.067	74	451.556	0.836	99.077
9	0.067	0.000	0.000	31	1.318	0.747	15.181	53	26.111	1.978	51.045	75	517.200	0.593	99.670
10	0.076	0.000	0.000	32	1.510	0.706	15.887	54	29.907	1.890	52.935	76	592.387	0.330	100.000
11	0.087	0.000	0.000	33	1.729	0.668	16.555	55	34.255	1.803	54.737	77	678.504	0.000	100.000
12	0.100	0.000	0.000	34	1.981	0.701	17.255	56	39.234	1.771	56.508	78	777.141	0.000	100.000
13	0.115	0.000	0.000	35	2.269	0.795	18.050	57	44.938	1.807	58.315	79	890.116	0.000	100.000
14	0.131	0.000	0.000	36	2.599	0.910	18.960	58	51.471	1.885	60.200	80	1019.515	0.000	100.000
15	0.150	0.000	0.000	37	2.976	1.091	20.051	59	58.953	1.999	62.199	81	1167.725	0.000	100.000
16	0.172	0.000	0.000	38	3.409	1.303	21.354	60	67.523	2.137	64.336	82	1337.481	0.000	100.000
17	0.197	0.000	0.000	39	3.905	1.502	22.856	61	77.339	2.287	66.623	83	1531.914	0.000	100.000
18	0.226	0.112	0.112	40	4.472	1.669	24.524	62	88.583	2.447	69.070	84	1754.613	0.000	100.000
19	0.259	0.211	0.323	41	5.122	1.857	26.381	63	101.460	2.615	71.684	85	2000.000	0.000	100.000
20	0.296	0.373	0.696	42	5.867	1.918	28.299	64	116.210	2.799	74.484				
21	0.339	0.639	1.335	43	6.720	1.953	30.252	65	133.103	2.998	77.481				
22	0.389	1.015	2.350	44	7.697	2.044	32.296	66	152.453	3.182	80.663				

PTI

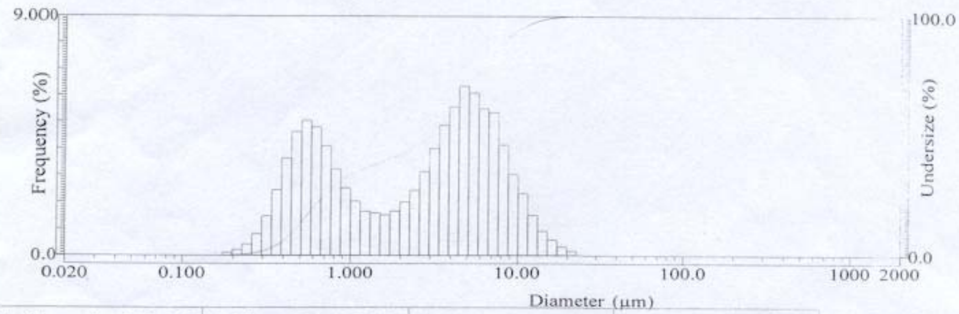
POWDER TECHNOLOGY INC.
14331 Ewing Ave S
Burnsville, MN 55306
Ph: 952-894-8737
Fax: 952-894-0734

Filename	:60246D-0-8 UM	Dispersant	:ISOTON II
Circulation Speed	:2	Fluid used	:WATER
Ultra sonic	:01:00 (1)	Run #	:
Laser T%	: 78.3(%)	Drum or Sack #	:
Lamp T%	: 77.7(%)		
Form of Distribution	:Standard		
Distribution Base	:Volume		
R.R.Index	:109a001i		
Customer	:RUTGERS		
Material	:QUARTZ		
Lot #	:		
PTI Analysis #	:60246D		
Operator	:CCP		

Median : 3.0439(μm)

Diameter on % :(1)5.000 (%)- 0.3795(μm)
(2)10.00 (%)- 0.4576(μm)
(3)20.00 (%)- 0.6052(μm)
(4)30.00 (%)- 0.8467(μm)
(5)40.00 (%)- 1.7103(μm)
(6)60.00 (%)- 4.0776(μm)
(7)70.00 (%)- 5.1076(μm)
(8)80.00 (%)- 6.4407(μm)
(9)90.00 (%)- 8.4769(μm)
(10)95.00 (%)- 10.5617(μm)

% on Diameter :1.000 (μm)- 33.267(%)
2.000 (μm)- 41.921(%)
3.000 (μm)- 49.571(%)
4.000 (μm)- 59.212(%)
5.000 (μm)- 69.005(%)
6.000 (μm)- 77.134(%)
7.000 (μm)- 83.323(%)
8.000 (μm)- 88.235(%)



No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %
1	0.022	0.000	0.000	23	0.445	3.628	9.053	45	8.816	4.137	91.194	67	174.616	0.000	100.000
2	0.026	0.000	0.000	24	0.510	4.628	13.681	46	10.097	3.041	94.234	68	200.000	0.000	100.000
3	0.029	0.000	0.000	25	0.584	5.048	18.728	47	11.565	2.310	96.544	69	229.075	0.000	100.000
4	0.034	0.000	0.000	26	0.669	4.800	23.528	48	13.246	1.506	98.050	70	262.376	0.000	100.000
5	0.039	0.000	0.000	27	0.766	4.089	27.617	49	15.172	0.916	98.967	71	300.518	0.000	100.000
6	0.044	0.000	0.000	28	0.877	3.227	30.844	50	17.377	0.576	99.543	72	344.206	0.000	100.000
7	0.051	0.000	0.000	29	1.005	2.513	33.356	51	19.904	0.311	99.854	73	394.244	0.000	100.000
8	0.058	0.000	0.000	30	1.151	2.023	35.380	52	22.797	0.146	100.000	74	451.556	0.000	100.000
9	0.067	0.000	0.000	31	1.318	1.651	37.031	53	26.111	0.000	100.000	75	517.200	0.000	100.000
10	0.076	0.000	0.000	32	1.510	1.578	38.609	54	29.907	0.000	100.000	76	592.387	0.000	100.000
11	0.087	0.000	0.000	33	1.729	1.515	40.124	55	34.255	0.000	100.000	77	678.504	0.000	100.000
12	0.100	0.000	0.000	34	1.981	1.655	41.779	56	39.234	0.000	100.000	78	777.141	0.000	100.000
13	0.115	0.000	0.000	35	2.269	1.993	43.772	57	44.938	0.000	100.000	79	890.116	0.000	100.000
14	0.131	0.000	0.000	36	2.599	2.429	46.201	58	51.471	0.000	100.000	80	1019.515	0.000	100.000
15	0.150	0.000	0.000	37	2.976	3.135	49.336	59	58.953	0.000	100.000	81	1167.725	0.000	100.000
16	0.172	0.000	0.000	38	3.409	4.011	53.347	60	67.523	0.000	100.000	82	1337.481	0.000	100.000
17	0.197	0.104	0.104	39	3.905	4.874	58.221	61	77.339	0.000	100.000	83	1531.914	0.000	100.000
18	0.226	0.206	0.310	40	4.472	5.568	63.789	62	88.583	0.000	100.000	84	1754.613	0.000	100.000
19	0.259	0.420	0.730	41	5.122	6.346	70.134	63	101.460	0.000	100.000	85	2000.000	0.000	100.000
20	0.296	0.796	1.526	42	5.867	6.093	76.227	64	116.210	0.000	100.000				
21	0.339	1.457	2.983	43	6.720	5.488	81.715	65	133.103	0.000	100.000				
22	0.389	2.441	5.425	44	7.697	5.342	87.057	66	152.453	0.000	100.000				

POWDER TECHNOLOGY INC.
14331 Ewing Ave S
Burnsville, MN 55306
Ph: 952-894-8737
Fax: 952-894-0734

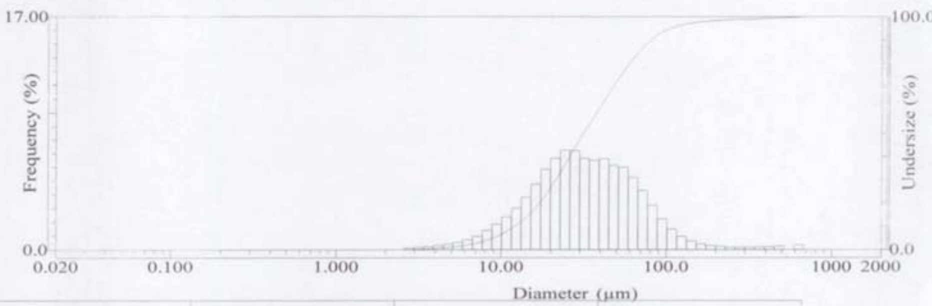
Filename :5346B 8-53 UM
Circulation Speed :2
Ultra sonic :01:00 (2)
Laser T% : 82.0(%)
Lamp T% : 87.7(%)
Form of Distribution :Standard
Distribution Base :Volume
R.R.Index :120a000I
Customer :RUTGERS
Material :QUARTZ
Lot # :
PTI Analysis # :5346B 8-53UM
Operator :CCP

Dispersant :ISOTON II
Fluid used :WATER
Run # :
Drum or Sack # :

POWDER TECHNOLOGY INC.
14331 Ewing Avenue South Burnsville, Minnesota 55306
Phone: 952-894-8737

Median : 31.4364(μm)
Diameter on % :(1)5.000 (%)- 8.9989(μm)
(2)10.00 (%)- 12.1336(μm)
(3)20.00 (%)- 17.1167(μm)
(4)30.00 (%)- 21.4251(μm)
(5)40.00 (%)- 25.9583(μm)
(6)60.00 (%)- 38.6261(μm)
(7)70.00 (%)- 47.6282(μm)
(8)80.00 (%)- 59.7187(μm)
(9)90.00 (%)- 80.5091(μm)
(10)95.00 (%)- 106.2783(μm)

% on Diameter :8.000 (μm)- 3.727(%)
53.00 (μm)- 74.797(%)



No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %
1	0.022	0.000	0.000	23	0.445	0.000	0.000	45	8.816	1.390	4.722	67	174.616	0.419	97.977
2	0.026	0.000	0.000	24	0.510	0.000	0.000	46	10.097	1.836	6.557	68	200.000	0.298	98.275
3	0.029	0.000	0.000	25	0.584	0.000	0.000	47	11.565	2.377	8.935	69	229.075	0.228	98.503
4	0.034	0.000	0.000	26	0.669	0.000	0.000	48	13.246	3.012	11.947	70	262.376	0.190	98.693
5	0.039	0.000	0.000	27	0.766	0.000	0.000	49	15.172	3.812	15.759	71	300.518	0.171	98.864
6	0.044	0.000	0.000	28	0.877	0.000	0.000	50	17.377	4.772	20.531	72	344.206	0.168	99.032
7	0.051	0.000	0.000	29	1.005	0.000	0.000	51	19.904	5.855	26.386	73	394.244	0.180	99.212
8	0.058	0.000	0.000	30	1.151	0.000	0.000	52	22.797	6.659	33.045	74	451.556	0.207	99.419
9	0.067	0.000	0.000	31	1.318	0.000	0.000	53	26.111	7.269	40.314	75	517.200	0.248	99.667
10	0.076	0.000	0.000	32	1.510	0.000	0.000	54	29.907	7.236	47.551	76	592.387	0.000	99.667
11	0.087	0.000	0.000	33	1.729	0.000	0.000	55	34.255	6.666	54.217	77	678.504	0.333	100.000
12	0.100	0.000	0.000	34	1.981	0.000	0.000	56	39.234	6.536	60.752	78	777.141	0.000	100.000
13	0.115	0.000	0.000	35	2.269	0.000	0.000	57	44.938	6.622	67.375	79	890.116	0.000	100.000
14	0.131	0.000	0.000	36	2.599	0.000	0.000	58	51.471	6.129	73.504	80	1019.515	0.000	100.000
15	0.150	0.000	0.000	37	2.976	0.112	0.112	59	58.953	5.997	79.501	81	1167.725	0.000	100.000
16	0.172	0.000	0.000	38	3.409	0.154	0.265	60	67.523	5.249	84.750	82	1337.481	0.000	100.000
17	0.197	0.000	0.000	39	3.905	0.209	0.474	61	77.339	4.294	89.044	83	1531.914	0.000	100.000
18	0.226	0.000	0.000	40	4.472	0.283	0.757	62	88.583	3.231	92.275	84	1754.613	0.000	100.000
19	0.259	0.000	0.000	41	5.122	0.385	1.143	63	101.460	2.220	94.495	85	2000.000	0.000	100.000
20	0.296	0.000	0.000	42	5.867	0.522	1.664	64	116.210	1.479	95.973				
21	0.339	0.000	0.000	43	6.720	0.709	2.373	65	133.103	0.959	96.933				
22	0.389	0.000	0.000	44	7.697	0.958	3.331	66	152.453	0.625	97.557				

PTI
POWDER TECHNOLOGY INC.
14331 Ewing Ave S
Burnsville, MN 55306
Ph: 952-894-8737
Fax: 952-894-0734

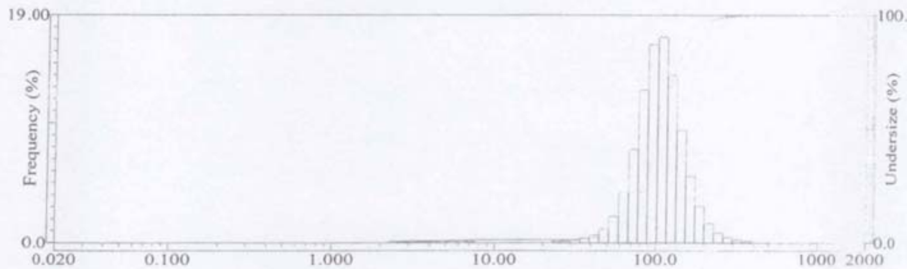
Filename	:	Dispersant	:ISOTON II
Circulation Speed	:2	Fluid used	:WATER
Ultra sonic	:01:00 (2)	Run #	:
Laser T%	: 83.0(%)	Drum or Sack #	:
Lamp T%	: 85.5(%)		
Form of Distribution	:Standard		
Distribution Base	:Volume		
R.R.Index	:120a000I		
Customer	:RUTGERS		
Material	:QUARTZ		
Lot #	:		
PTI Analysis #	:90094C 53-106UM		
Operator	:CCP		

PTI
POWDER TECHNOLOGY INC.
14331 Ewing Avenue South Burnsville, Minnesota 55306
Phone: 952-894-8737

Median : 103.4795(μm)

% on Diameter :53.00 (μm)- 4.374(%)
106.0 (μm)- 53.046(%)

Diameter on % :(1)5.000 (%)- 55.0658(μm)
(2)10.00 (%)- 66.7403(μm)
(3)20.00 (%)- 78.8383(μm)
(4)30.00 (%)- 87.6889(μm)
(5)40.00 (%)- 95.4038(μm)
(6)60.00 (%)- 111.9880(μm)
(7)70.00 (%)- 122.3649(μm)
(8)80.00 (%)- 135.6893(μm)
(9)90.00 (%)- 159.7776(μm)
(10)95.00 (%)- 185.4705(μm)



No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %
1	0.022	0.000	0.000	23	0.445	0.000	0.000	45	8.816	0.000	1.252	67	174.616	5.563	93.640
2	0.026	0.000	0.000	24	0.510	0.000	0.000	46	10.097	0.000	1.252	68	200.000	3.062	96.701
3	0.029	0.000	0.000	25	0.584	0.000	0.000	47	11.565	0.000	1.252	69	229.075	1.611	98.313
4	0.034	0.000	0.000	26	0.669	0.000	0.000	48	13.246	0.000	1.252	70	262.376	0.846	99.159
5	0.039	0.000	0.000	27	0.766	0.000	0.000	49	15.172	0.000	1.252	71	300.518	0.450	99.609
6	0.044	0.000	0.000	28	0.877	0.000	0.000	50	17.377	0.000	1.252	72	344.206	0.248	99.856
7	0.051	0.000	0.000	29	1.005	0.000	0.000	51	19.904	0.000	1.252	73	394.244	0.144	100.000
8	0.058	0.000	0.000	30	1.151	0.000	0.000	52	22.797	0.000	1.252	74	451.556	0.000	100.000
9	0.067	0.000	0.000	31	1.318	0.000	0.000	53	26.111	0.112	1.364	75	517.200	0.000	100.000
10	0.076	0.000	0.000	32	1.510	0.000	0.000	54	29.907	0.153	1.517	76	592.387	0.000	100.000
11	0.087	0.000	0.000	33	1.729	0.000	0.000	55	34.255	0.228	1.745	77	678.504	0.000	100.000
12	0.100	0.000	0.000	34	1.981	0.000	0.000	56	39.234	0.366	2.110	78	777.141	0.000	100.000
13	0.115	0.000	0.000	35	2.269	0.000	0.000	57	44.938	0.643	2.754	79	890.116	0.000	100.000
14	0.131	0.000	0.000	36	2.599	0.116	0.116	58	51.471	1.141	3.894	80	1019.515	0.000	100.000
15	0.150	0.000	0.000	37	2.976	0.134	0.250	59	58.953	2.223	6.117	81	1167.725	0.000	100.000
16	0.172	0.000	0.000	38	3.409	0.150	0.400	60	67.523	4.248	10.365	82	1337.481	0.000	100.000
17	0.197	0.000	0.000	39	3.905	0.158	0.558	61	77.339	7.831	18.196	83	1531.914	0.000	100.000
18	0.226	0.000	0.000	40	4.472	0.159	0.717	62	88.583	12.757	30.953	84	1754.613	0.000	100.000
19	0.259	0.000	0.000	41	5.122	0.155	0.872	63	101.460	16.553	47.506	85	2000.000	0.000	100.000
20	0.296	0.000	0.000	42	5.867	0.142	1.013	64	116.210	17.177	64.683				
21	0.339	0.000	0.000	43	6.720	0.127	1.141	65	133.103	13.983	78.666				
22	0.389	0.000	0.000	44	7.697	0.112	1.252	66	152.453	9.411	88.077				

PTI
POWDER TECHNOLOGY INC.
14331 Ewing Ave S
Burnsville, MN 55306
Ph: 952-894-8737
Fax: 952-894-0734

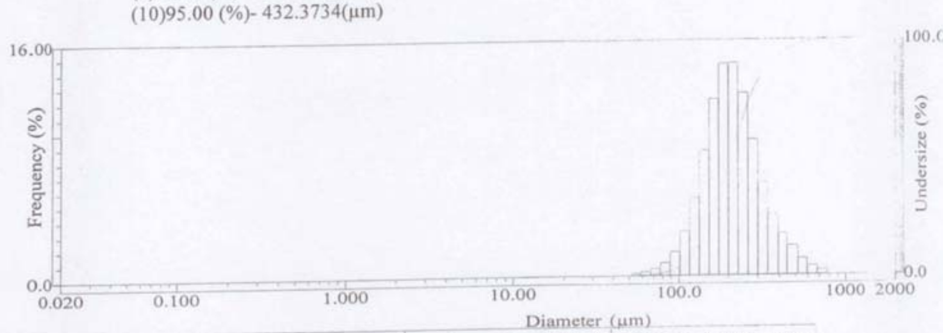
Filename	:90094F 106-250UM
Circulation Speed	:2
Ultra sonic	:01:00 (2)
Laser T%	: 82.5(%)
Lamp T%	: 87.7(%)
Form of Distribution	:Standard
Distribution Base	:Volume
R.R.Index	:120a000I
Customer	:RUTGERS
Material	:QUARTZ
Lot #	:
PTI Analysis #	:90094F 106-250UM
Operator	:CCP

Dispersant	:ISOTON II
Fluid used	:WATER
Run #	:
Drum or Sack #	:

PTI
POWDER TECHNOLOGY INC.
14331 Ewing Avenue South Burnsville, Minnesota 55306
Phone: 952-894-8737

Median : 206.5539(μm)
Diameter on % :(1)5.000 (%)- 109.0838(μm)
(2)10.00 (%)- 127.3716(μm)
(3)20.00 (%)- 151.8368(μm)
(4)30.00 (%)- 170.2782(μm)
(5)40.00 (%)- 187.9489(μm)
(6)60.00 (%)- 226.9347(μm)
(7)70.00 (%)- 252.8389(μm)
(8)80.00 (%)- 289.1458(μm)
(9)90.00 (%)- 356.4565(μm)
(10)95.00 (%)- 432.3734(μm)

% on Diameter :106.0 (μm)- 4.364(%)
250.0 (μm)- 68.970(%)



No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %
1	0.022	0.000	0.000	23	0.445	0.000	0.000	45	8.816	0.000	0.000	67	174.616	11.962	32.217
2	0.026	0.000	0.000	24	0.510	0.000	0.000	46	10.097	0.000	0.000	68	200.000	14.357	46.573
3	0.029	0.000	0.000	25	0.584	0.000	0.000	47	11.565	0.000	0.000	69	229.075	14.424	60.997
4	0.034	0.000	0.000	26	0.669	0.000	0.000	48	13.246	0.000	0.000	70	262.376	12.380	73.377
5	0.039	0.000	0.000	27	0.766	0.000	0.000	49	15.172	0.000	0.000	71	300.518	9.253	82.630
6	0.044	0.000	0.000	28	0.877	0.000	0.000	50	17.377	0.000	0.000	72	344.206	6.303	88.933
7	0.051	0.000	0.000	29	1.005	0.000	0.000	51	19.904	0.000	0.000	73	394.244	4.140	93.074
8	0.058	0.000	0.000	30	1.151	0.000	0.000	52	22.797	0.000	0.000	74	451.556	2.832	95.906
9	0.067	0.000	0.000	31	1.318	0.000	0.000	53	26.111	0.000	0.000	75	517.200	2.011	97.917
10	0.076	0.000	0.000	32	1.510	0.000	0.000	54	29.907	0.000	0.000	76	592.387	1.117	99.034
11	0.087	0.000	0.000	33	1.729	0.000	0.000	55	34.255	0.000	0.000	77	678.504	0.621	99.655
12	0.100	0.000	0.000	34	1.981	0.000	0.000	56	39.234	0.000	0.000	78	777.141	0.345	100.000
13	0.115	0.000	0.000	35	2.269	0.000	0.000	57	44.938	0.000	0.000	79	890.116	0.000	100.000
14	0.131	0.000	0.000	36	2.599	0.000	0.000	58	51.471	0.000	0.000	80	1019.515	0.000	100.000
15	0.150	0.000	0.000	37	2.976	0.000	0.000	59	58.953	0.154	0.154	81	1167.725	0.000	100.000
16	0.172	0.000	0.000	38	3.409	0.000	0.000	60	67.523	0.264	0.418	82	1337.481	0.000	100.000
17	0.197	0.000	0.000	39	3.905	0.000	0.000	61	77.339	0.474	0.892	83	1531.914	0.000	100.000
18	0.226	0.000	0.000	40	4.472	0.000	0.000	62	88.583	0.877	1.769	84	1754.613	0.000	100.000
19	0.259	0.000	0.000	41	5.122	0.000	0.000	63	101.460	1.624	3.393	85	2000.000	0.000	100.000
20	0.296	0.000	0.000	42	5.867	0.000	0.000	64	116.210	3.011	6.404				
21	0.339	0.000	0.000	43	6.720	0.000	0.000	65	133.103	5.322	11.726				
22	0.389	0.000	0.000	44	7.697	0.000	0.000	66	152.453	8.529	20.254				

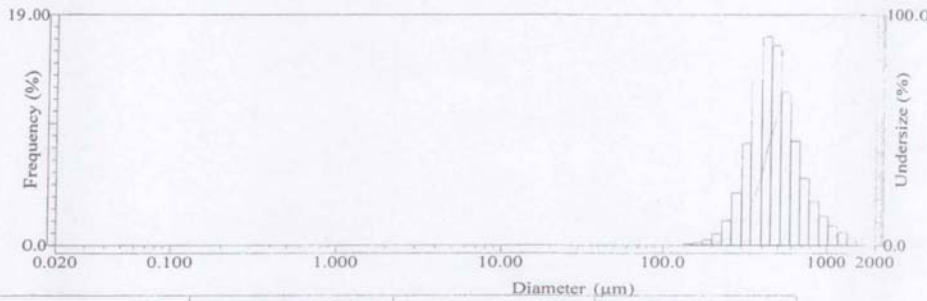
PTI
POWDER TECHNOLOGY INC.
14331 Ewing Ave S
Burnsville, MN 55306
Ph : 952-894-8737
Fax: 952-894-0734

Filename	:90094G 250-500UM	Dispersant	:ISOTON II
Circulation Speed	:2	Fluid used	:WATER
Ultra sonic	:01:00 (2)	Run #	:
Laser T%	: 82.2(%)	Drum or Sack #	:
Lamp T%	: 82.8(%)		
Form of Distribution	:Standard		
Distribution Base	:Volume		
R.R.Index	:120a0001		
Customer	:RUTGERS		
Material	:QUARTZ		
Lot #	:		
PTI Analysis #	:90094G 250-500 UM		
Operator	:CCP		

PTI
POWDER TECHNOLOGY INC.
14331 Ewing Avenue South Burnsville, Minnesota 55306
Phone: 952-894-8737

Median : 462.1523(μm)
Diameter on % :(1)5.000 (%)- 272.6331(μm)
(2)10.00 (%)- 309.8767(μm)
(3)20.00 (%)- 356.5395(μm)
(4)30.00 (%)- 394.1298(μm)
(5)40.00 (%)- 426.5839(μm)
(6)60.00 (%)- 501.9949(μm)
(7)70.00 (%)- 554.0500(μm)
(8)80.00 (%)- 628.9833(μm)
(9)90.00 (%)- 771.0157(μm)
(10)95.00 (%)- 945.3498(μm)

% on Diameter :250.0 (μm)- 3.049(%)
500.0 (μm)- 59.518(%)



No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %
1	0.022	0.000	0.000	23	0.445	0.000	0.000	45	8.816	0.000	0.000	67	174.616	0.222	0.341
2	0.026	0.000	0.000	24	0.510	0.000	0.000	46	10.097	0.000	0.000	68	200.000	0.447	0.788
3	0.029	0.000	0.000	25	0.584	0.000	0.000	47	11.565	0.000	0.000	69	229.075	0.945	1.733
4	0.034	0.000	0.000	26	0.669	0.000	0.000	48	13.246	0.000	0.000	70	262.376	2.044	3.777
5	0.039	0.000	0.000	27	0.766	0.000	0.000	49	15.172	0.000	0.000	71	300.518	4.330	8.106
6	0.044	0.000	0.000	28	0.877	0.000	0.000	50	17.377	0.000	0.000	72	344.206	8.381	16.488
7	0.051	0.000	0.000	29	1.005	0.000	0.000	51	19.904	0.000	0.000	73	394.244	13.541	30.029
8	0.058	0.000	0.000	30	1.151	0.000	0.000	52	22.797	0.000	0.000	74	451.556	17.166	47.195
9	0.067	0.000	0.000	31	1.318	0.000	0.000	53	26.111	0.000	0.000	75	517.200	16.413	63.608
10	0.076	0.000	0.000	32	1.510	0.000	0.000	54	29.907	0.000	0.000	76	592.387	12.605	76.213
11	0.087	0.000	0.000	33	1.729	0.000	0.000	55	34.255	0.000	0.000	77	678.504	8.574	84.787
12	0.100	0.000	0.000	34	1.981	0.000	0.000	56	39.234	0.000	0.000	78	777.141	5.535	90.323
13	0.115	0.000	0.000	35	2.269	0.000	0.000	57	44.938	0.000	0.000	79	890.116	3.614	93.937
14	0.131	0.000	0.000	36	2.599	0.000	0.000	58	51.471	0.000	0.000	80	1019.515	2.397	96.334
15	0.150	0.000	0.000	37	2.976	0.000	0.000	59	58.953	0.000	0.000	81	1167.725	1.629	97.962
16	0.172	0.000	0.000	38	3.409	0.000	0.000	60	67.523	0.000	0.000	82	1337.481	1.093	99.055
17	0.197	0.000	0.000	39	3.905	0.000	0.000	61	77.339	0.000	0.000	83	1531.914	0.607	99.663
18	0.226	0.000	0.000	40	4.472	0.000	0.000	62	88.583	0.000	0.000	84	1754.613	0.337	100.000
19	0.259	0.000	0.000	41	5.122	0.000	0.000	63	101.460	0.000	0.000	85	2000.000	0.000	100.000
20	0.296	0.000	0.000	42	5.867	0.000	0.000	64	116.210	0.000	0.000				
21	0.339	0.000	0.000	43	6.720	0.000	0.000	65	133.103	0.000	0.000				
22	0.389	0.000	0.000	44	7.697	0.000	0.000	66	152.453	0.118	0.118				

PTI
POWDER TECHNOLOGY INC.

14331 Ewing Ave S
Burnsville, MN 55306
Ph: 952-894-8737
Fax: 952-894-0734

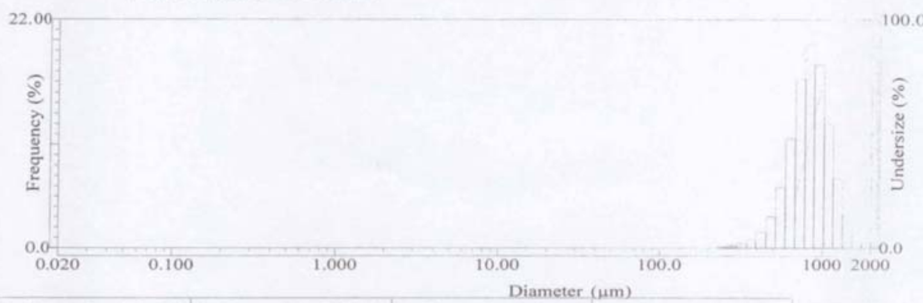
Filename	:90094J 500-1000UM
Circulation Speed	:2
Ultra sonic	:00:05 (2)
Laser T%	: 82.6(%)
Lamp T%	: 86.5(%)
Form of Distribution	:Standard
Distribution Base	:Volume
R.R.Index	:109a001i
Customer	:RUTGERS
Material	:QUARTZ
Lot #	:
PTI Analysis #	:90094J 500-1000UM
Operator	:CCP

Dispersant	:ISOTON II
Fluid used	:WATER
Run #	:
Drum or Sack #	:

PTI
POWDER TECHNOLOGY INC.
14331 Ewing Avenue South Burnsville, Minnesota 55306
Phone: 952-894-8737

Median : 839.3464(μm)
Diameter on % :(1)5.000 (%)- 490.6761(μm)
(2)10.00 (%)- 565.1368(μm)
(3)20.00 (%)- 656.2512(μm)
(4)30.00 (%)- 721.7298(μm)
(5)40.00 (%)- 783.2452(μm)
(6)60.00 (%)- 900.5356(μm)
(7)70.00 (%)- 972.6622(μm)
(8)80.00 (%)-1065.3271(μm)
(9)90.00 (%)-1212.5546(μm)
(10)95.00 (%)-1344.9473(μm)

% on Diameter :500.0 (μm)- 5.420(%)
1000 (μm)- 73.598(%)



No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %	No.	Diameter	Freq. %	Under %
1	0.022	0.000	0.000	23	0.445	0.000	0.000	45	8.816	0.000	0.000	67	174.616	0.000	0.000
2	0.026	0.000	0.000	24	0.510	0.000	0.000	46	10.097	0.000	0.000	68	200.000	0.000	0.000
3	0.029	0.000	0.000	25	0.584	0.000	0.000	47	11.565	0.000	0.000	69	229.075	0.000	0.000
4	0.034	0.000	0.000	26	0.669	0.000	0.000	48	13.246	0.000	0.000	70	262.376	0.117	0.117
5	0.039	0.000	0.000	27	0.766	0.000	0.000	49	15.172	0.000	0.000	71	300.518	0.227	0.344
6	0.044	0.000	0.000	28	0.877	0.000	0.000	50	17.377	0.000	0.000	72	344.206	0.432	0.775
7	0.051	0.000	0.000	29	1.005	0.000	0.000	51	19.904	0.000	0.000	73	394.244	0.816	1.592
8	0.058	0.000	0.000	30	1.151	0.000	0.000	52	22.797	0.000	0.000	74	451.556	1.555	3.147
9	0.067	0.000	0.000	31	1.318	0.000	0.000	53	26.111	0.000	0.000	75	517.200	3.027	6.174
10	0.076	0.000	0.000	32	1.510	0.000	0.000	54	29.907	0.000	0.000	76	592.387	5.858	12.033
11	0.087	0.000	0.000	33	1.729	0.000	0.000	55	34.255	0.000	0.000	77	678.504	10.562	22.595
12	0.100	0.000	0.000	34	1.981	0.000	0.000	56	39.234	0.000	0.000	78	777.141	16.274	38.869
13	0.115	0.000	0.000	35	2.269	0.000	0.000	57	44.938	0.000	0.000	79	890.116	19.621	58.489
14	0.131	0.000	0.000	36	2.599	0.000	0.000	58	51.471	0.000	0.000	80	1019.515	17.617	76.106
15	0.150	0.000	0.000	37	2.976	0.000	0.000	59	58.953	0.000	0.000	81	1167.725	12.024	88.130
16	0.172	0.000	0.000	38	3.409	0.000	0.000	60	67.523	0.000	0.000	82	1337.481	6.736	94.867
17	0.197	0.000	0.000	39	3.905	0.000	0.000	61	77.339	0.000	0.000	83	1531.914	3.253	98.120
18	0.226	0.000	0.000	40	4.472	0.000	0.000	62	88.583	0.000	0.000	84	1754.613	1.359	99.478
19	0.259	0.000	0.000	41	5.122	0.000	0.000	63	101.460	0.000	0.000	85	2000.000	0.522	100.000
20	0.296	0.000	0.000	42	5.867	0.000	0.000	64	116.210	0.000	0.000				
21	0.339	0.000	0.000	43	6.720	0.000	0.000	65	133.103	0.000	0.000				
22	0.389	0.000	0.000	44	7.697	0.000	0.000	66	152.453	0.000	0.000				

Appendix B. List of Prepared Water Samples

The First Batch of Water Samples

Sample ID	Particle Size Distrib. ID	Analytical Method	Targeted Conc. (*mg/l*)	Date (mon.,day)	Time (min,sec)	Water Temp. (deg C)	Mass on paper (*mg*)	Mass in bottle (*mg*)	Water Tank Number
M-A-20	M	A	20	316	1420	24	20.4	19.9	2
M-B-20	M	B	20	316	1500	24	20.2	19.9	2
M-C-20	M	C	20	316	1530	24	20.2	20.1	1
M-A-50	M	A	50	314	1750	23	50.4	50.1	1
M-B-50	M	B	50	314	1810	23	50.1	49.7	1
M-C-50	M	C	50	314	1845	23	50.1	49.5	1
M-A-100	M	A	100	315	1110	24	100.5	99.9	1
M-B-100	M	B	100	315	1120	24	99.9	99.5	1
M-C-100	M	C	100	315	1145	24	100.3	99.8	1
M-A-150	M	A	150	316	1100	24	150.1	149.6	1
M-B-150	M	B	150	316	1130	24	150.3	149.8	1
M-C-150	M	C	150	316	1250	23.3	150.4	150.7	2
M-A-200	M	A	200	315	1200	24	200.1	199.3	1
M-B-200	M	B	200	315	1215	24	200.3	199.4	1
M-C-200	M	C	200	315	1250	24.3	200.7	200.4	1
M-A-300	M	A	300	315	1315	24.3	301	300.1	1
M-B-300	M	B	300	315	1330	24.3	300.6	300.2	1
M-C-300	M	C	300	315	1500	24.3	300.7	299.9	1
M-A-400	M	A	400	316	1310	24	400.1	399.8	2
M-B-400	M	B	400	316	1330	24	400.6	400.9	2
M-C-400	M	C	400	316	1345	24	400.5	400.7	2
M-A-600	M	A	600	316	1600	24	600.8	598.4	2
M-B-600	M	B	600	316	1614	24	601.8	600.7	2
M-C-600	M	C	600	316	1625	24	601.2	599.2	2
M-A-1000	M	A	1000	316	1635	24	1004.2	1002	2
M-B-1000	M	B	1000	316	1638	24	1003.8	1001.3	2
M-C-1000	M	C	1000	316	1650	24	1001.9	998.9	2
106-A-20	106	A	20	316	1915	24	20.1	20.4	3
106-B-20	106	B	20	316	1950	24	20.2	20.1	3
106-C-20	106	C	20	316	2010	24	20.3	19.7	3
106-A-50	106	A	50	316	2030	24	50.4	49.8	3
106-B-50	106	B	50	316	2040	24	50.6	50.3	3
106-C-50	106	C	50	316	2120	24	50.5	50.7	3
106-A-100	106	A	100	316	2240	23	101.1	100.5	3
106-B-100	106	B	100	316	2300	23	101.9	100	3
106-C-100	106	C	100	316	2310	23	100.3	100.1	3
106-A-150	106	A	150	316	2340	23	150.9	151.3	3
106-B-150	106	B	150	316	2355	23	150.8	150.9	3
106-C-150	106	C	150	317	10	23	150.3	149	3
106-A-200	106	A	200	317	20	23	201.3	198.6	3
106-B-200	106	B	200	317	35	23	201.2	201	3
106-C-200	106	C	200	317	42	23	201.8	200.2	3
106-A-300	106	A	300	317	230	23	300.2	298.9	3
106-B-300	106	B	300	317	245	23	301.1	301.7	3
106-C-300	106	C	300	317	305	23	301.2	299	3
106-A-400	106	A	400	317	1020	22.3	401.5	398.6	4
106-B-400	106	B	400	317	1030	22.3	402	402.7	4
106-C-400	106	C	400	317	1040	22.3	401.7	400.4	4
106-A-600	106	A	600	317	1100	22.3	600.4	598.2	4
106-B-600	106	B	600	317	1107	22.3	600.6	596.8	4
106-C-600	106	C	600	317	1120	22.3	601.8	602.3	4
106-A-1000	106	A	1000	317	1132	22.3	1005.1	1004	4
106-B-1000	106	B	1000	317	1140	22.3	1001	1000.2	4
106-C-1000	106	C	1000	317	1147	22.3	1000.7	1001.6	4
Water-A-1	Water	A	0						
Water-B-1	water	B	0						
Water-C-1	Water	C	0						

The Second Batch of Water Samples

Sample ID	Particle Size ID	Analytical Method	Targeted Conc. (*mg/l*)	Date (mon.,day)	Time (min,sec)	Water Temp. (deg C)	Mass on paper (*mg*)	Mass in bottle (*mg*)	Water Tank Number
8-A-20	8	A	20	320	1515	24	20.1	20.4	3
8-B-20	8	B	20	320	1521	24	20.4	20.2	3
8-C-20	8	C	20	320	1530	24	20.2	20.4	3
8-A-50	8	A	50	320	1545	24	50.2	50.7	3
8-B-50	8	B	50	320	1610	24	50.7	50.4	3
8-C-50	8	C	50	320	1631	24	50.4	50.9	3
8-A-100	8	A	100	320	1645	24	101	101.5	3
8-B-100	8	B	100	320	1720	24	100	100.7	3
8-C-100	8	C	100	320	1733	24	100.2	99.9	3
8-A-150	8	A	150	321	2200	23	150.1	149.6	4
8-B-150	8	B	150	321	2210	23	150.9	151.8	4
8-C-150	8	C	150	321	2218	23	150.5	150.6	4
8-A-200	8	A	200	321	2300	23	202.2	201.1	4
8-B-200	8	B	200	321	2319	23	202	201.3	4
8-C-200	8	C	200	321	2328	23	202.4	201.5	4
8-A-300	8	A	300	321	2340	23	301.2	301.4	4
8-B-300	8	B	300	321	2348	23	303.1	302	4
8-C-300	8	C	300	321	2356	23	301.1	299	4
8-A-400	8	A	400	322	10	23	401.4	400.2	4
8-B-400	8	B	400	322	17	23	403.3	402	4
8-C-400	8	C	400	322	24	23	402.7	401.2	4
8-A-600	8	A	600	322	1100	23	600.4	600.2	4
8-B-600	8	B	600	322	1110	23	600.5	597.3	4
8-C-600	8	C	600	322	1120	23	604.2	602.3	4
8-A-1000	8	A	1000	322	1140	23	1003	1000.6	4
8-B-1000	8	B	1000	322	1145	23	1005.2	1007	4
8-C-1000	8	C	1000	322	1155	23	1004.1	1001.4	4
53-A-20	53	A	20	322	1520	22	20.2	20.1	5
53-B-20	53	B	20	322	1530	22	20.4	19.8	5
53-C-20	53	C	20	322	1545	22	20.4	20.3	5
53-A-50	53	A	50	322	1600	22	50.3	50.1	5
53-B-50	53	B	50	322	1608	22	50.4	49.6	5
53-C-50	53	C	50	322	1620	22	50.8	50.5	5
53-A-100	53	A	100	322	2000	23	100.5	99.5	5
53-B-100	53	B	100	322	2010	23	100.2	99.3	5
53-C-100	53	C	100	322	2020	23	100.9	100.1	5
53-A-150	53	A	150	322	2030	23	151.5	149.1	5
53-B-150	53	B	150	322	2045	23	150.8	149.9	5
53-C-150	53	C	150	322	2055	23	152.2	151.3	5
53-A-200	53	A	200	322	2115	23	201.9	200.1	5
53-B-200	53	B	200	322	2130	23	201.1	199.6	5
53-C-200	53	C	200	322	2145	23	202.5	202.3	5
53-A-300	53	A	300	323	1020	23	300.2	298.2	5
53-B-300	53	B	300	323	1040	23	303	301.5	5
53-C-300	53	C	300	323	1050	23	302.2	301	5
53-A-400	53	A	400	323	1100	23	400.8	399.3	5
53-B-400	53	B	400	323	1110	23	400.7	399.6	5
53-C-400	53	C	400	323	1125	23	401	401.3	5
53-A-600	53	A	600	324	1400	24	601.6	599.5	6
53-B-600	53	B	600	324	1405	24	602	599	6
53-C-600	53	C	600	324	1412	24	605.2	604.4	6
53-A-1000	53	A	1000	324	1440	24	1001.3	1001	6
53-B-1000	53	B	1000	324	1446	24	1003.8	1002	6
53-C-1000	53	C	1000	324	1458	24	1003.7	1001.7	6
M-B-20R	M	B	20	530	2230	19	20.4	19.8	7
M-B-50R	M	B	50	530	2240	19	50.6	50.2	7
M-B-100R	M	B	100	530	2255	19	100.6	101.8	7
M-B-150R	M	B	150	530	2310	19	151.2	152.6	7
M-B-200R	M	B	200	530	2320	19	201.4	198.6	7
M-B-300R	M	B	300	530	2330	19	301.5	300.7	7
M-B-400R	M	B	400	530	2340	19	4004.1	403.6	7
M-B-600R	M	B	600	531	930	17	601.3	602.2	7
M-B-1000R	M	B	1000	531	945	17	1001.6	1002.3	7
106-B-20R	106	B	20	531	1000	18	20.1	20.4	7
106-B-50R	106	B	50	531	1010	18	50.2	49.9	7
106-B-100R	106	B	100	531	1020	18	100.9	101.3	7
106-B-150R	106	B	150	531	1030	18	150.7	150.5	7

The Third Batch of Water Samples

Sample ID	Particle Size Distrib. ID	Analytical Method	Targeted Conc. (*mg/l*)	Date (mon.,day)	Time (min,sec)	Water Temp. (deg C)	Mass on paper (*mg*)	Mass in bottle (*mg*)	Water Tank Number
250-A-20	250	A	20	606	1500	22	20.3	20.2	8
250-B-20	250	B	20	606	1510	22	20.1	20.4	8
250-C-20	250	C	20	606	1520	22	20	19.7	8
250-A-50	250	A	50	606	1540	22	50.5	50.1	8
250-B-50	250	B	50	606	1545	22	50.7	50.3	8
250-C-50	250	C	50	606	1550	22	50.4	50.7	8
250-A-100	250	A	100	606	1600	22	101.6	101.3	8
250-B-100	250	B	100	606	1610	22	101.6	101.4	8
250-C-100	250	C	100	606	1620	22	101	100.3	8
250-A-150	250	A	150	606	1820	22	150.3	150.2	8
250-B-150	250	B	150	606	1840	22	150.6	150.3	8
250-C-150	250	C	150	606	1900	22	151	150.3	8
250-A-200	250	A	200	607	1400	20	200.6	199.8	8
250-B-200	250	B	200	607	1420	20	200.8	200.6	8
250-C-200	250	C	200	607	1430	20	200.6	200.2	8
250-A-300	250	A	300	607	1450	20	300.5	300.7	8
250-B-300	250	B	300	607	1500	20	301.5	301.1	8
250-C-300	250	C	300	607	1520	20	301	299.8	8
250-A-400	250	A	400	608	1000	21	401.3	400.4	9
250-B-400	250	B	400	608	1010	21	401.5	401.4	9
250-C-400	250	C	400	608	1020	21	401.8	401.4	9
250-A-600	250	A	600	608	1030	21	601	600.6	9
250-B-600	250	B	600	608	1050	21	601.3	601	9
250-C-600	250	C	600	608	1100	21	601.8	601.9	9
250-A-1000	250	A	1000	608	1110	21	1000.4	999.5	9
250-B-1000	250	B	1000	608	1120	21	1000.5	1000.7	9
250-C-1000	250	C	1000	608	1130	21	1001.7	1001.5	9
500-A-20	500	A	20	608	1540	21	19.6	19.8	9
500-B-20	500	B	20	608	1600	21	20.2	20.4	9
500-C-20	500	C	20	608	1610	21	20.4	20.1	9
500-A-50	500	A	50	608	1620	21	50.4	49.9	9
500-B-50	500	B	50	608	1630	21	50.8	50.7	9
500-C-50	500	C	50	608	1700	21	50.6	50.9	9
500-A-100	500	A	100	608	1710	21	101.5	101.1	9
500-B-100	500	B	100	608	1730	21	100.2	100.6	9
500-C-100	500	C	100	608	1750	21	100.4	99.9	9
500-A-150	500	A	150	611	2000	17	150.8	150.2	10
500-B-150	500	B	150	611	2010	17	151.4	150.4	10
500-C-150	500	C	150	611	2030	17	151.7	150.9	10
500-A-200	500	A	200	611	2040	17	201.1	200.9	10
500-B-200	500	B	200	611	2100	17	200.6	200.3	10
500-C-200	500	C	200	611	2120	17	200.6	201.2	10
500-A-300	500	A	300	611	2130	17	300.3	300.3	10
500-B-300	500	B	300	611	2140	17	300.2	299.4	10
500-C-300	500	C	300	611	2155	17	301.3	300.8	10
500-A-400	500	A	400	611	2210	17	401.4	400.8	10
500-B-400	500	B	400	611	2230	17	401.9	401.4	10
500-C-400	500	C	400	611	2300	17	401.5	401.4	10
500-A-600	500	A	600	612	1430	18	601.9	601.2	10
500-B-600	500	B	600	612	1500	18	600.8	600.5	10
500-C-600	500	C	600	612	1510	18	602.8	602.5	10
500-A-1000	500	A	1000	612	1520	18	1000.8	999.7	10
500-B-1000	500	B	1000	612	1540	18	1003.1	1002.9	10
500-C-1000	500	C	1000	612	1600	18	1001.6	1000.3	10
1000-A-20	1000	A	20	613	1000	22	20.2	20.4	11
1000-B-20	1000	B	20	613	1020	22	20.4	20.4	11
1000-C-20	1000	C	20	613	1040	22	20.2	20.1	11
1000-A-50	1000	A	50	613	1100	22	51	50.5	11
1000-B-50	1000	B	50	613	1110	22	50	50.2	11
1000-C-50	1000	C	50	613	1120	22	50.6	50.5	11
1000-A-100	1000	A	100	613	1140	22	100	99.7	11
1000-B-100	1000	B	100	613	1150	22	100.9	100.4	11
1000-C-100	1000	C	100	613	1430	22	100.1	100.2	11
1000-A-150	1000	A	150	613	1450	22	150.6	150.5	11
1000-B-150	1000	B	150	613	1500	22	150.5	150.3	11
1000-C-150	1000	C	150	613	1510	22	150.1	149.7	11
1000-A-200	1000	A	200	613	1520	22	201.6	201.5	11

The Fourth Batch of Water Samples

Sample ID	Particle Size Distrib. ID	Analytical Method	Targeted Conc. (*mg/l*)	Date (mon. /day)	Time (min:sec)	Water Temp. (deg C)	Mass on paper (*mg*)	Mass in bottle (*mg*)	Water Tank Number
M-A-20R	M	A	20	7/12	18:00	21	20.2	20.4	13
M-A-50R	M	A	50	7/12	18:10	21	50.6	49.8	13
M-A-100R	M	A	100	7/12	18:30	21	100.2	100.1	13
M-A-150R	M	A	150	7/12	18:50	21	150.7	151.3	13
M-A-200R	M	A	200	7/12	19:05	21	200.2	201.8	13
M-A-300R	M	A	300	7/12	19:20	21	302.3	301.9	13
M-A-400R	M	A	400	7/12	19:40	21	400.6	399.6	13
M-A-600R	M	A	600	7/13	18:10	21	603.9	605.0	13
M-A-1000R	M	A	1000	7/13	18:30	21	1001.3	1001.6	14
106-A-20R	106	A	20	7/14	9:50	18	20.3	20.4	14
106-B-50R	106	A	50	7/14	10:05	18	49.8	49.6	14
106-B-100R	106	A	100	7/14	10:20	18	99.6	99.1	14
106-B-150R	106	A	150	7/14	10:30	18	150.4	151.0	14
106-B-200R	106	A	200	7/14	10:50	18	200.4	200.7	14
106-B-300R	106	A	300	7/14	11:05	18	301.0	300.5	14
106-B-400R	106	A	400	7/14	11:20	18	400.9	400.2	14
106-B-600R	106	A	600	7/14	11:40	18	601.0	601.2	14
106-B-1000R	106	A	1000	7/14	12:10	18	1004.2	1005.5	14
M-C-20R	M	C	20	7/13	18:50	21	20.1	19.7	13
M-C-50R	M	C	50	7/13	19:05	21	50.9	50.5	13
M-C-100R	M	C	100	7/13	19:20	21	101.7	101.5	13
M-C-150R	M	C	150	7/13	19:35	21	150.9	141.9	13
M-C-200R	M	C	200	7/13	19:50	21	202.3	201.7	13
M-C-300R	M	C	300	7/13	20:10	21	302.5	302.8	13
M-C-400R	M	C	400	7/13	20:30	21	403.8	403.2	13
M-C-600R	M	C	600	7/14	8:50	18	601.4	601.0	14
M-C-1000R	M	C	1000	7/14	9:20	18	1003.5	1003.7	14
Water-A-4	Water	A	0						
Water-C-4	Water	C	0						

Notes:

* Particle Size
- M - Mixture $(0\sim1000\mu m)$
- 106 - 53~106 (μm)

* Method
- A - TSS EPA Method
- C - SSC ASTM Method

The Fifth Batch of Water Samples

Sample ID	Particle Size Distrib. ID	Analytical Method	Targeted Conc. (*mg/l*)	Date (mon/day)	Time (min:sec)	Water Temp. (deg C)	Mass on paper (*mg*)	Mass in bottle (*mg*)	Water Tank Number
106-C-20R	106	C	20 R	8/8	10:20	20	20.1	19.4	15
106-C-50R	106	C	50 R	8/8	10:50	20	50.3	49.9	15
106-C-100R	106	C	100 R	8/8	11:10	20	100.4	99.8	15
106-C-150R	106	C	150 R	8/8	11:30	20	150.1	148.8	15
106-C-200R	106	C	200 R	8/8	11:50	20	200.9	200.3	15
106-C-300R	106	C	300 R	8/8	14:00	20	300.1	299.3	15
106-C-400R	106	C	400 R	8/8	14:20	20	400.8	399.9	15
106-C-600R	106	C	600 R	8/8	14:30	20	602.3	601.7	15
106-C-1000R	106	C	1000 R	8/8	14:50	20	1001.5	1001.1	15
Water-C-5	Water	C	0						

Notes:

* Particle Size
- 106 - 53~106 (μm)

* Method
- C - SSC ASTM Method

Appendix C. Measured Solids Concentration of Prepared Water Samples

Measured Concentrations for the First Batch of Water Samples

Particle Size Distrib. ID	Targeted Conc. (*mg/l*)	Method A	Method B*	Method C
M	20	9	10	10.1
M	50	11	10	35.6
M	100	37	10	75.3
M	150	52	10	89.1
M	200	72	10	104
M	300	120	10	173
M	400	170	10	324
M	600	200	10	368
M	1000	300	10	579
106	20	4	10	19.6
106	50	9	10	50.2
106	100	16	10	98.6
106	150	23	10	149
106	200	47	10	278
106	300	58	10	292
106	400	150	10	394
106	600	46	10	584
106	1000	180	10	944
WATER 1	0	4	10	5

* Concentration of Total Volatile Solids (TVS) was mesaured instead.
The Standard Method 2540E was used, with the minimim reporting level of 10 mg/L.

Measured Concentrations for the Second Batch of Water Samples

Particle Size Distrib. ID	Targeted Conc. (*mg/l*)	Method A	Method B	Method C
8	20	17	24	19
8	50	40	45	49.8
8	100	96	82	98.2
8	150	140	130	149
8	200	200	180	199
8	300	290	300	297
8	400	400	380	398
8	600	610	570	599
8	1000	980	990	971
53	20	14	13	24.2
53	50	41	40	45.4
53	100	89	90	94.5
53	150	130	120	150
53	200	170	170	199
53	300	240	280	299
53	400	380	350	399
53	600	510	520	592
53	1000	1000	900	976
M(R)	20		13	
M(R)	50		24	
M(R)	100		50	
M(R)	150		85	
M(R)	200		120	
M(R)	300		140	
M(R)	400		260	
M(R)	600		400	
M(R)	1000		670	
106(R)	20		17	
106(R)	50		20	
106(R)	100		65	
106(R)	150		85	
106(R)	200		130	
106(R)	300		220	
106(R)	400		290	
106(R)	600		400	
106(R)	1000		610	
WATER 2	0	4	4	5

Measured Concentrations for the Third Batch of Water Samples

Particle Size Distrib. ID	Targeted Conc. (*mg/l*)	Method A	Method B	Method C
250	20	4	4	20
250	50	4	160	50.7
250	100	4	300	98.4
250	150	5	460	144
250	200	18	570	190
250	300	16	410	306
250	400	7	600	394
250	600	9	580	600
250	1000	18	1200	978
500	20	4	15	23.2
500	50	4	47	51.9
500	100	4	110	99.5
500	150	4	85	150
500	200	4	4	200
500	300	4	4	292
500	400	4	4	405
500	600	4	5	599
500	1000	4	300	997
1000	20	4	4	20
1000	50	4	4	49.7
1000	100	4	4	100
1000	150	4	4	144
1000	200	4	4	201
1000	300	4	4	301
1000	400	4	4	364
1000	600	4	4	533
1000	1000	4	4	971
WATER 3	0	4	4	5

Measured Concentrations for the Fourth Batch of Water Samples

Particle Size Distrib. ID	Targeted Conc. (*mg/l*)	Method A	Method B	Method C
M(R)	20	10		18.1
M(R)	50	31		48.9
M(R)	100	63		101
M(R)	150	82		144
M(R)	200	110		200
M(R)	300	180		288
M(R)	400	200		390
M(R)	600	360		593
M(R)	1000	570		963
106(R)	20	15		
106(R)	50	28		
106(R)	100	66		
106(R)	150	82		
106(R)	200	110		
106(R)	300	180		
106(R)	400	250		
106(R)	600	350		
106(R)	1000	770		
WATER 4	0	4		5

Measured Concentrations for the Fifth Batch of Water Samples

Particle Size Distrib. ID	Targeted Conc. (*mg/l*)	Method A	Method B	Method C
106(R)	20			19.7
106(R)	50			49
106(R)	100			98.5
106(R)	150			146
106(R)	200			200
106(R)	300			299
106(R)	400			398
106(R)	600			598
106(R)	1000			995
WATER 5	0			5