

# Modeling Liquid Solid Separation in a Coalescing Plate Oil Water Separator

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**Research Methods Final Project** 

# Modeling Liquid Solid Separation in a Coalescing Plate Oil Water Separator

A report on the background, experimental methods and regression analysis used to assess a stormwater best management practice

By Jacob Gorski



#### Introduction

When precipitation occurs in undeveloped areas a number of abstractions catch and absorb the precipitation. Abstractions include plants and trees, which catch a portion of the water, pervious soils that infiltrate stormwater until saturated and natural changes in topography where stormwater accumulates. During more intense, longer storm evens the abstraction limit in a watershed can be reached and runoff occurs. In the process of developing areas for cities, towns, industrial sites and transportation the watershed characteristics of that area are changed and the quantity of abstraction in the developed area is reduced. Pervious soils are replaced with impervious surfaces and plants that abstract, absorb and release moisture through evapotranspiration are removed. As a result a significantly larger quantity of surface runoff is generated in these areas. There are a number of methods used to manage the quantity of runoff. Two popular options are the combined sewer system and the separate sewer system. The combined sewer system conveys stormwater runoff and sanitary sewage from households to a wastewater treatment plant. After treatment water is released into a receiving body and the quality of the effluent is monitored to comply with water quality regulations in general, or for water quality regulations at a particular receiving body of water. The separate sewer system, also known as the municipal separate storm sewer system (MS4) conveys stormwater separate from sanitary waste. The MS4 generally discharges stormwater to a receiving body of water through a system of outfalls while sanitary sewage is conveyed to a wastewater treatment plant. Because stormwater picks up and transports pollutants deposited in urban areas, and is then discharged to a receiving body, or treated along with sanitary waste it is necessary reduce pollutants and/or reduce quantity of runoff for water quality and economic reasons. Within stormwater management methods that reduce runoff volume and or runoff pollution are called best management practices (BMP).

Early examples of stormwater management and conveyance systems can be found throughout history; The Incas utilized decentralized disconnected infiltration systems at Machu Picchu (Wright et al. 1999) similar to modern low impact development (LID) BMPs, and the ancient cities of Ur and Babylon had effective drainage systems for stormwater (Burian and Edwards 2004). The first urban drainage systems in North America were constructed in New England during the colonial era. Many early civilizations had methods to manage stormwater and sanitary waste quantity; however they were understandably unaware of water quality criteria such as waterborne disease which was, and remains in some parts of the world, a serious problem. The correlation between disease and contaminated water was made in 1854 by Dr. John Snow marked and both a turning point in both engineering and science. Interestingly Snow's work was not immediately well received by his peers despite the fact that Snow's study showed overwhelming scientific evidence. For a while after Snow's publication it was still believed that diseases, like cholera were spread by miasma, a poisonous vapor which entered the body through the nose or mouth that was produced by warm air, moisture and decaying animal and vegetable matter (Rees 1996).

Despite not being completely aware of the dangers associated with wastewater the first modern day centralized water-carriage sewer system was constructed in Hamburg Germany in 1842.(Seeger 1999)The successful implementation of this centralized system paved the way for other sewer systems and by the late 1850s combined systems were being constructed in Chicago and Brooklyn. This installation of sewer systems throughout American cities and towns marked a turning point in how stormwater and sanitary sewage was managed. Imaginably, sewers increased the quality of life for urban residence, however, the sewers also made it easier for industry to dispose of waste chemicals and environmental regulation did not yet exist.

In 1899 the United States passed its first federal environmental regulation to protect waterways, the Refuse Act (RA). This early legislation made unauthorized depositing, discharging and all other means of evacuating waste and garbage material into navigable waters and tributaries of navigable waters illegal. Compared to modern environmental regulations the RA was simple and unfortunately ineffective. Advances in Industry coupled by the economic boom the United States experienced post World War II resulted in a new type of pollution problem. Sewage treatment plants were common practice by this point in time; however these plasticizers, inorganic pesticides and legacy pollutants that were being dumped into water sources had different effects than waterborne disease that previously plagued the industrialized world. Not only did this pollution affect human health, but it harmed aquatic ecosystems and it bioaccumulated. In response to this new pollution the federal government enacted the Water Pollution Control Act in 1948. The EPA did not yet exist so water quality standards, effluent limitations and the enforcement that would come with subsequent environmental legislation was not yet present.

Amendments to the Water Pollution Control came about in 1956 which brought about minimal enforcement of interstate pollution and provided a percentage of Federal dollars for the construction of waste water treatment plants.

In 1965 the Water Quality Act (WQA) was enacted which established quality standards. The WQA was difficult to implement as it required a link between individual polluters and water quality. Industrial pollution continued and numerous water quality incidents sparked demand for more effective regulations. In 1972 the Clean Water Act (CWA) was passed. The CWA intended to eliminate contaminated effluent discharge into navigable waters by 1985 by focusing on using technology. Nonpoint pollution was still considered a local responsibility, but federal grants were provided for nonpoint pollution programs and the National Pollutant Discharge Elimination System (NPDES) was introduced. Further amendments to the CWA came about in 1977 and 1987.

The CWA improved the Nation's waters dramatically. However, the National Water Quality Inventory of 2000 showed that 40 percent of the surveyed water bodies did not meet water quality standards, of those 13 percent of impaired rivers, 18 percent of impaired lakes and 32 percent of impaired estuaries were affected by urban/suburban stormwater runoff (Agency 2005). Prior to this, in 1990 Phase I of the EPA's stormwater program was enacted and in 1999 Phase II of the stormwater program was published further expanding on the requirements for stormwater best management practices. The stormwater program was designed to reduce negative impacts to water bodies caused by certain unregulated stormwater discharges. Increasing regulations and demand for sustainable infrastructure drive the technological, engineering and planning innovations that keep the field of stormwater management ever changing.

This report summarizes experiments that have been done to assess and model suspended solids removal capability of BMP technology in order to ascertain if the device can be effectively used to treat stormwater.

#### BMPs & Stormwater Runoff

A number of pollutants are present in stormwater runoff. A 1992 study by the EPA on the environmental impacts of stormwater discharge showed stormwater runoff and wastewater treatment plant (WWTP) effluent being discharged into impaired rivers to contribute pollutants seen in figure 1.



Figure 1(b). Comparison of pollutants impacting use support in rivers. (see inset previous page for pollutant categories) \*305(b) pollutants may overlap as cause of impairment for a given waterbody, accounting for total pie percentage of 187%.

As seen in the figure a large variety pollutants that can harm human health such as pesticides, pathogens and metals are present in runoff. It can also be seen that a variety of oxygen demanding substances and other negative impacts such as thermal modification, salinity and changes in PH, all of which can affect the aquatic ecosystem are also due to stormwater runoff. Suspended solids are also seen in figure 1 which negatively affects a number of water quality parameters. There are negative consequences associated with the physical presence of suspended solids in water (TSS), however TSS also correlates with other chemical pollutants. Copper, chromium, lead, phosphorus and zinc have been shown to attach to urban particulate matter as well (Thomson et al. 1997). As such TSS is commonly used as a water quality parameter in assessing discharge from stormwater outfalls.

Figure 1: Pollutants discharged to impaired rivers, measured at stormwater outfalls and WWTP effluent points (Agency 1992).

There are a variety of BMP types that can be used for different purposes. Broadly BMPs can be categorized as structural, or non-structural. Non-structural BMPs include educational programs, maintenance requirements such as sweeping and specifications on where certain items may be stored. Structural BMPs are organized into the following categories by the International Stormwater BMP database (database): Grass strip, bioretention, bioswale, composite, detention basin, green roof, manufactured device, media filter, porous pavement, retention pond, wetland basin and wetland channel (Consultants et al. 2012a). These BMPs reduce runoff quantity, decrease runoff pollutants or do combination of the two. Generally runoff quantity is reduced with a disconnected decentralized system of BMPs that mimicking the pre-development hydrology of an area. BMPs such as porous pavements and green roofs are prime examples of such BMPs and are considered low impact development (LID) BMPs. LID BMPs can also reduce pollutant concentrations and restore groundwater levels. Other BMPs such as retention ponds, bioretention and media filter are primarily used to remove common stormwater pollutants. Figure 2 (Consultants et al. 2012a) demonstrates influent and effluent concentrations of TSS for different BMP types. As seen effluent quality varies suggesting certain BMP types a will be better at removing TSS than others.



Figure 2: TSS influent and effluent concentrations for a variety of BMPs(Consultants et al. 2012a)

The BMP tested in the paper is a manufactured device type BMP. Manufactured device BMPs encompass a wide variety of design components which can accomplish various treatments processes. Manufactured BMP components are designed to provide treatment by filtration, sedimentation, skimming, sorption, straining and even disinfection. The BMP database (Consultants et al. 2012b) categorizes the performance of these devices by the process in which they treat stormwater. Treatment categories are filtration, inlet insert, multi process, physical manufactured device, oil/grit separators and baffle boxes, biological filtration and physical with volume control type. Physical manufactured devices use gravitational settling as the treatment process. Biological filtration uses a filtration device that supports plant, bacterial and, or biofilms. The physical with volume control manufactured devices category uses detention vaults, other structures that allow infiltration, or pipes to reduce stormwater pollution. The filtration, inlet insert, baffle box and oil/grit separator subcategories are self explanatory in respect to treatment mechanism.

As expected each subcategory within manufactured devices performs differently depending on the pollutant considered however general removal trends were observed for manufactured devices. All manufactured devices were shown to significantly reduce TSS, especially biological filtration, filtration, multi-process and physical with volume control subcategories. None of the manufactured devices were shown to significantly reduce dissolved copper, dissolved lead and dissolved zinc while total copper, lead and zinc were reduced best with the multi-process subcategory. All manufactured device BMPs reduced total phosphorous significantly, except oil/grit separators and baffle boxes. As with dissolved heavy metals, manufactured devices did not significantly reduce dissolved phosphorus. Certain subcategories were shown to significantly reduce TKN and NOx, however the majority of manufactured devices were ineffective at removing TKN and NOx (Consultants et al. 2012b).

From performance data for manufactured devices it seen that this BMP type is constrained in that no significant reduction in dissolved heavy metals or dissolved phosphorous is provided. Additionally the majority of manufactured devices were ineffective at removing TKN and NOx; if oxygen demanding substances or dissolved heavy metals in runoff requires treatment a manufactured device will likely be ineffective. Manufactured devices provide excellent treatment for certain pollutants and have a comparatively small footprint. Additionally conditions such as lack of space, high ground water level and poor soil infiltration can make a manufactured device the best option. Also certain industrial applications may require that a manufactured device like an oil/grit chamber be used.

According to the BMP database manufactured devices have been used in California, Texas, Washington, Florida, Alabama, New Jersey, Oregon and in other parts of America. As this BMP type is well suited for particular applications when alternative BMPs are not an option due to constraints.

The manufactured BMP tested was designed by Mohr Separation Research and is an enhanced gravity separator that utilizes a system of multiple angle plates to slow the flow of water, minimize turbulence, reduce rise/settling distance, provide solid/oil removal paths and enhance coalescing of oil droplets. Influent to the MSR unit first enters a disengaging chamber where larger solids can settle and bulk oil rises to the surface. From the disengaging chamber water enters the inlet chamber where the flow is distributed by a baffle before entering the coalescing plate system where liquid solid separation is increased. Within the coalescing system light non aqueous phase liquids (LNAPL) merge and rise along paths through perforations in the plates. LNAPLs are subsequently collected in a chamber while solids are directed along paths to the bottom of the unit. After flowing through the coalescing plates water passes over an adjustable weir and exits the system (Gorski and Fish 2012).

#### Experimental Testing Procedure

A variety of protocols are referred to when assessing TSS concentrations and loads entering and exiting a BMP. Protocol selection depends on the regulatory agency overseeing environmental compliance, the type of device, if TSS concentrations will be measured during actual events, or if synthetic events will be created. The International Stormwater BMP Database previously mentioned has extensive information using storm events available. Information includes influent and effluent BMP pollutant data, watershed properties, hydrological data, BMP costs, BMP design parameters and more. Additionally, the database project publishes reports which summarizes data and provide guidelines for statistical analysis. The (Consultants et al. 2011) report provides background information on causes of contaminated stormwater runoff, removal mechanisms, recommendations on BMP selection and design and regulatory context. Ongoing data collection and analysis from the database is expected to increase our understanding of BMP performance and stormwater pollution. As our understanding of stormwater pollution and BMP performance increases new methods and technologies are made available that need to be tested. Much analysis can be done using the database, for example figure 3, which shows the pairing influent and effluent TSS event mean concentrations (EMC) with events, for manufactured BMPs using the same primary treatment process, sedimentation, as the BMP tested in this experiment. From the figure it is observed that the coalescing plate separator will likely be effective at removing solids in the laboratory experiment and that effluent quality from BMPs using this treatment process is likely to depend on influent concentration. Further statistical analysis regarding influent effluent TSS relationship for this primary treatment process is necessary.



Figure 3: Paired influent/effluent event mean concentrations of TSS for manufactured devices with a primary treatment of processes of density/gravity/inertial separation and sedimentation

Full scale manufactured device type BMPs are well suited for laboratory testing. Many regulatory agencies such as the State of Washington Department of Ecology (Protocol 2011) provide protocol for full scale laboratory testing of manufactured BMPs. Additionally full scale manufactured BMPs have been tested at universities, (Schwarz and Wells 1999) (Wilson et al. 2007) which provide guidance on conducing BMP experiments using synthetic storm events. Experiments done to model and assess TSS removal performance of the MSR-11P were completed in two stages. The first stage involved collection of effluent samples from the unit in a laboratory setting and analyzing effluent samples for TSS according to EPA method 160.2 (Agency 1971). A complete report on the first stage of the experiment was completed in December, 2012 for the Jensen Precast Company by William Fish and Jacob Gorski; the following 2 figures and 5 paragraphs are from that report in order to put the second stage of the experiment in context.

The MSR separator unit was installed in the Hydraulics Laboratory in the Portland State University Engineering Building. The setup is shown in the photograph in figure 4. To supply required flow rates a water supply tank was connected to a centrifugal pump was used (Dayton model #5k476C). The pump feeds into the system via a gate valve and inline flow meter which allowed for variable influent flow rates. Solids were introduced at the crown of the influent pipe in the form of a well-mixed slurry using a peristaltic pump (Pulsafeeder model # VSP-20) to provide a consistent delivery rate. The desired influent concentrations of solids were achieved by adjusting the solids/water ratio of the slurry. The slurry was mixed and maintained as a uniform suspension using a mounted electric drill with mixer attachment. Influent with a specified solids concentration was introduced to the MSR unit using a 1.5" PVC pipe and exited the unit under free fall conditions into a trough located below the unit. Preliminary tests were conducted to ensure accurate and consistent flow rates and solids influent rates. TSS removal of the MSR unit was tested at three influent TSS concentrations (50, 100 and 200 mg/L) and three different flow rates (5, 10 and 15 GPM) for a total of nine operational conditions.



Figure 4: Photograph, first phase of the experiment

To achieve consistent and reproducible results we used SCS, a commercially available ground silica product as the source of influent solids. SCS is manufactured by U.S. Silica and has a median particle size of 20  $\mu$ m, with a particle size distribution (PSD) shown in figure 4. SCS is 99.8% pure silica and has a specific gravity of 2.65. Regulatory agencies such as the Washington State Dept. of Ecology (Protocol 2011) require SCS to be used as the testing solids for assessing TSS removal of a stormwater treatment device in the laboratory. Use of this commercially available testing media facilitates performance comparisons of different technologies and ensures the experiment can be reproduced. It also has a consistent and known proportion of the very fine particles that are often of greatest concern in stormwater management.

Four effluent grab samples were taken at different times for each one of the specified influent and flow rate conditions, a total of 36 grab samples were analyzed. The unit was allowed to cycle a minimum of three volumes (100 gallons) before samples were collected. On average samples were collected every 25 gallons for the 50 mg/L run, every 31 gallons for the 100 mg/L run, and every 32 gallons for the 200 mg/L run. Samples were analyzed according to EPA method 106.2 (Agency 1971). Each Whatman Glass Microfiber Grade GF/C Filter was placed in a 47mm Pall Magnetic Filter Funnel and suction flask with vacuum attachment, then washed with three successive 20 mL aliquots of distilled water while vacuum was applied. After washing, filters were placed in a drying oven at 105°C for one hour. After drying, filters were placed in a desiccator. After cooling, the weight of each filter was taken to ensure a constant mass was obtained. Filters were stored in a desiccator at room temperature until immediately before use. Immediately before being placed in the suction apparatus for analysis masses were taken of each filter. Each filter was then placed in the 47mm Pall Magnetic Filter Funnel with suction flask and vacuum attachment. An aliquot of 200 ml for each well mixed effluent sample was measured using a graduated cylinder and run through the filter while vacuum was applied. The filter funnel and graduated cylinder were then rinsed with a small amount of distilled water to ensure all effluent solids had been captured by the filter. The vacuum was then turned off and the filter was removed and placed into a drying oven for one hour at 105°C, after drying filters were cooled in a desiccator and weighed. Effluent concentrations were calculated as follows:

Effluent Concentration 
$$\left(\frac{mg}{L}\right) = \frac{A-B}{D}(1000)$$

Where:

A=Weight of filter and captured solids (mg) B=Weight of filter (mg)

D=Sample volume (mL)

In observing figure 5 we see that we see that removal efficiency decreases with increasing flow rate, which is as expected as increasing flow rates lead to higher turbulence, this trend was present for all influent concentrations tested. It was also tested if the influent concentration would have a statistically significant outcome on removal efficiency of the unit. The P values seen in table 1 indicate that differences in removal efficiencies measured at different influent concentrations are not statistically significant. However, it is important to keep in mind that there is consensus among the research community that lower influent pollutant concentrations have a lower percentage of pollution reduction upon outflow from a BMP that higher pollutant concentration influent (Protocol 2011).



Figure 5: Box plots for showing % TSS removed over various flow rates and an influent concentration=100 (mg/L)

Table 1: P values from 2 tailed, paired T-test showing influent concentration to not have a statistically significant impact on % removal in this test

Flow Rate (GPM)	P Value			
5	0.654			
10	0.398			
15	0.735			

The second phase of the experiment involved analyzing the particle size distribution of effluent samples and at influent concentrations using a liquid particle counter (HIAC 9703), which uses laser diffraction to determine the number of particle counts that fall within a specified range. Data for this experiment may be found in the appendix. As seen in figure x, PSDs ranged from  $5\mu$  to  $60 \mu$ , exact increments and size counts for this test can be seen in the appendix. Differences between influent particle counts and effluent particle counts were used to determine the removal efficiency.

A 2005 publication in the Journal of Environmental Engineering titled, Particle Size Distribution in Highway Runoff (Li et al. 2005), which includes extensive information on typical PSDs found in urban runoff, sorption of metals and polynuclear aromatic hydrocarbons to particles, PSD sampling methods, PSD sampling protocol and change in PSD and particle loading in runoff over storm duration. An extensive literature review of article and articles referenced will be included in the master's thesis version of this paper which will also include a comparison of PSD data measured at actual BMPs sites outside of the lab and compare that to the PSD used for this test. Additionally PSD testing protocol established in (Li et al. 2005) will be compared with PSD testing protocol used in the experiment. A literature reviews on particle size distribution and pollutant concentrations will also be included; correlations between smaller PSDs in urban particulate and higher pollutant concentrations have been shown. Smaller particles have more surface are per mass and pollutants tend to sorb to these particles. Table 2, taken form (Wang et al. 2006) shows the general trend of increasing heavy metal and nutrient presence at decreasing particle sizes in lake sediment.

Sediments	TOC (%)	CEC (meq (100) <sup>-1</sup> )	TN (mg kg <sup>-1)</sup>	${\rm TP}({\rm mg}{\rm kg}^{-1})$	Al (%)	Fe (%)	Ca (%)	Clay (%)	Silt (%)	Sand (%)
East Taihu Lake	0.90	13.33	932	441	6.16	3.61	0.98	6.35	74.60	19.05
360-480 mesh	1.45	17.31	1231	872	8.32	5.36	0.79	6.01	78.42	15.57
240-360 mesh	0.95	14.53	902	606	7.56	4.26	0.84	5.46	81.02	13.52
60-240 mesh	0.78	12.32	821	472	5.74	3.01	1.03	6.89	70.63	22.48
1860 mesh	0.71	11.45	631	336	5.12	2.67	1.12	7.12	63.78	29.10
Yue Lake	6.23	30.12	5213	1640	8.51	6.02	3.71	6.28	81.81	11.91
360-480 mesh	6.50	40.87	6342	2275	10.35	8.53	3.02	5.89	84.32	9.79
240-360 mesh	6.33	36.52	6123	1856	9.43	7.51	3.31	5.23	87.73	7.04
60-240 mesh	6.29	29.42	5832	1763	8.02	5.38	4.15	6.75	76.98	16.27
1860 mesh	6.03	27.31	5124	1374	7.24	4.89	4.36	7.04	72.16	20.8
Wuli Lake	1.67	22.15	1923	819	6.55	3.44	0.69	7.95	71.00	21.05
360–480 mesh	2.32	26.75	2451	1294	9.32	5.42	0.46	6.75	79.42	13.83
240–360 mesh	1.94	24.63	2013	1037	8.43	4.76	0.53	6.23	83.15	10.62
60–240 mesh	1.69	20.12	2314	892	6.31	4.02	0.74	8.34	68.45	23.21
1860 mesh	1.68	18.42	1905	608	5.46	3.86	0.93	8.78	65.36	25.86

Table 2: Chemical and physical observations of lake sediment according to particle size (Wang et al. 2006)

#### Data Analysis on PSD, Flow Rate and Percent Removal

When removal efficiency is plotted against particle count, as in figure 6, it is observed that PSDs from  $0\mu$  to  $20\mu$  are less likely to be removed; the  $0\mu$  to  $20\mu$  particle size range account for approximately 75 percent of particles not captured.



Figure 6: Percent of TSS removed by the MSR-11P unit, by count, at various to particle sizes

In observing the histogram of counts by percent removal, figure 7, we see that effluent particle counts do not occur in a normally distributed manner. From the percent removed

by particle size figure we see that removal occurrences generally occur more frequently above 75% and particularly at 100% when particles are larger than 30µ which enforces the skewed removal cont seen in the histogram. A number of transforms were applied which did not yield a normal distribution. As such it was judged that a non-parametric approach, which will be discussed in further detail later, would be best suited to empirically model removal of various particle sizes by the separator.



Figure 7: Count of removal frequencies observed

As demonstrated in the first experiment that used EPA method 106.2 TSS removal percent, by mass decreased with increasing flow rate. The same trend is present when observing percentage of particle removal by count with increasing flow rate, as seen in figure 8.



Figure 8: Percent of TSS removed by the MSR-11P unit, by count, at various flow rates

Additive non-parametric regression with R was used to predict TSS effluent concentration, or removal efficiency, given particle size ranges and design storm flow rate. There are two non-parametric regression options in R, which are as follows: non-parametric multiple regression model, which is like the polynomial approach but extended, and the additive non-parametric regression model. The additive non-parametric model fits a simple-regression smother to a partial regression function (Fox 2002) using the gam function which is part of the MGCV library. Results of regression may be observed in table 3. To obtain the best fitting and most statistically significant model the smoothing function was applied to the particle size variable while flow rate was left as a parametric. As seen the model fits data well with and adjusted R-sq. value of .873 and p values well below .005. Funding to run PSD analysis was approved for all 38 samples on 3/15/13 which will provide a total of 567 data points instead of the current 45 data points used. It is expected that more data will reduce R-sq. value of the regression and increase P values. The addition of data will however increase the confidence in regressions prediction of effluent quality.

Table 3: Results of additive non-parametric regression using particle size and flow rate to predict TSS removal

Figure 9 shows the data and a regression plotted in 3 dimensions. Upon visual inspection a comparatively small number of outliers are present that will be addressed when all data is collected. As expected the figure shows removal increasing with at decreasing flow rates and at smaller particle size.



Figure 9: Data plotted showing relationship between percent removal, particle size and flow rate

PSD data is still being collected which will allow regression models to be established for each size increment according flow rate to predict removal of specified range. With more data exploration of the statistical significance between influent concentration and removal by particle size can be performed, and non-removable particle size ranges for coalescing plate separators can be identified.

#### Conclusion

Human development changes the quantity of water a watershed infiltrates, as less water is infiltrated in urbanized watersheds, surface runoff increases and must be managed. It has been determined that the best practices be used to manage runoff in order to decrease pollution concentrations to receiving waters, reduce treatment costs and minimize other negative hydrologic impacts on watersheds. As new methods and technologies become available it is necessary to assess how well they function as a stormwater BMP for a particular application. This paper described experiments and data analysis to assess how well a coalescing plate oil water separator removes TSS using additive non-parametric regression considering particle size and flow rate. It was found that the model fit data well with statistically significant correlations and an R-sq. value of .87.

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# Appendix A: PSD Data

4850 6.335 5 7881.5   1413 10.17 5 3693.5   450 14.005 5 1872.2   120 17.84 5 812   42 21.675 5 343.5   18 25.51 5 162.2   7 29.345 5 90   0 33.18 5 48   0 37.015 5 22.2   0 40.85 5 13.5   0 44.685 5 7.2   0 44.685 5 7.2   0 48.52 5 3   0 56.19 5 1.5   0 56.19 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
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18 25.51 5 162.2   7 29.345 5 90   0 33.18 5 48   0 37.015 5 22.2   0 40.85 5 13.5   0 44.685 5 7.2   0 48.52 5 3   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
7 29.345 5 90   0 33.18 5 48   0 37.015 5 22.2   0 40.85 5 13.5   0 44.685 5 7.2   0 44.685 5 7.2   0 48.52 5 3   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 33.18 5 48   0 37.015 5 22.2   0 40.85 5 13.5   0 40.85 5 7.2   0 44.685 5 7.2   0 48.52 5 3   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 37.015 5 22.2   0 40.85 5 13.5   0 40.85 5 7.2   0 44.685 5 7.2   0 48.52 5 3   0 52.355 5 1.5   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 40.85 5 13.5   0 40.85 5 7.2   0 44.685 5 7.2   0 48.52 5 3   0 52.355 5 1.5   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 44.685 5 7.2   0 48.52 5 3   0 52.355 5 1.5   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 48.52 5 3   0 52.355 5 1.5   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 52.355 5 1.5   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 56.19 5 1.8   0 56.19 5 1.8   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5
0 60125 5 110   0 60.025 5 3.5   6279 6.335 10 7881.5   2168 10.17 10 3693.5   749 14.005 10 1877.3
6279 6.335 10 7881.5   2168 10.17 10 3693.5   749 14.005 10 1873.3
2168 10.17 10 3693.5   749 14.005 10 1973.3
7/19 1/ 005 10 1073 3
(47 14.00) 10 18/2.2
214 17.84 10 812
56 21.675 10 343.5
24 25.51 10 162.2
10 29.345 10 90
5 33.18 10 48
3 37.015 10 22.2
1 40.85 10 13.5
0 44.685 10 7.2
0 48.52 10 3
0 52.355 10 1.5
0 56.19 10 1.8
0 60.025 10 3.5
6681.8 6.335 15 7881.5
2549.2 10.17 15 3693.5
967 14.005 15 1872.2
300 17.84 15 812
93 21.675 15 343.5
32 25.51 15 162.2
17 29.345 15 90
8 33.18 15 48
4 37.015 15 22.2
1 40.85 15 13.5
1 44.685 15 7.2
0 48.52 15 3
0 52.355 15 1.5
1 56.19 15 1.8
1 60.025 15 3.5

# **Appendix B: Grab Sample Data**

Date:	12/16/2012	Date:	12/16/2012	Date:	12/16/2012
Run Start Time	7:46	Run Start Time	5:01	Run Start Time	1:50
Flow Rate (GPM)	5	Flow Rate (GPM)	10	Flow Bate (GPM)	15
Target Influent Concentration (mg/l)	50	Target Influent Concentration (mg/L)	50	Target Influent Concentration (mg/L)	50
Slume Details	50	Slurge Details	50	Slurp Dotails	50
			105		204
Mass of solids added (g)	66	Mass of solids added (g)	135	Mass of solids added (g)	204
Volume of water used (L)	1.8	Volume of water used (L)	1.8	Volume of water used (L)	1.8
-					
Temperature at grab (C)	11.4	Temperature at grab (C)	11.6	Temperature at grab (C)	12.3
Time at grab	8:12	Time at grab	5:11	Time at grab	1:55
Effluent Grab Sample ID	16.1	Effluent Grab Sample ID	14.1	Effluent Grab Sample ID	12.1
Initial Weight of Filter (mg)	130.9	Initial Weight of Filter (mg)	131.5	Initial Weight of Filter (mg)	133.7
Weight of filter and residue (mg)	134.4	Weight of filter and residue (mg)	135.5	Weight of filter and residue (mg)	138.7
Effluent Concentration (mg/L)	17.5	Effluent Concentration (mg/L)	20.0	Effluent Concentration (mg/L)	25.0
Temperature at grab (C)	11.4	Temperature at grab (C)	11.5	Temperature at grab (C)	12.1
Time at grab	8:17	Time at grab	5:16	Time at grab	2:00
Effluent Grab Sample ID	16.2	Effluent Grab Sample ID	14.2	Effluent Grab Sample ID	12.2
Initial Weight of Filter (mg)	132.4	Initial Weight of Filter (mg)	131.3	Initial Weight of Filter (mg)	132.2
Weight of filter and residue (mg)	135.7	Weight of filter and residue (mg)	135.9	Weight of filter and residue (mg)	137.2
Effluent Concentration (mg/L)	16.5	Effluent Concentration (mg/L)	23.0	Effluent Concentration (mg/L)	25.0
Temperature at grab (C)	11.4	Temperature at grab (C)	11.4	Temperature at grab (C)	12.1
Time at grab	8:18	Time at grab	5:21	Time at grab	2:00
Effluent Grab Sample ID	16.3	Effluent Grab Sample ID	14.3	Effluent Grab Sample ID	12.3
Initial Weight of Filter (mg)	132.6	Initial Weight of Filter (mg)	133.3	Initial Weight of Filter (mg)	133.5
Weight of filter and residue (mg)	135.8	Weight of filter and residue (mg)	137.4	Weight of filter and residue (mg)	138.6
Effluent Concentration (mg/L)	16.0	Effluent Concentration (mg/L)	20.5	Effluent Concentration (mg/L)	25.5
	1010		2010		20.0
Temperature at grab (C)	11.4	Temperature at grab (C)	11.4	Temperature at grab (C)	11.9
Time at grab	0.31	Time at grab	E-21	Time at grab	2.05
Time at grab	0.21	Title at grab	5.21	Time at grab	2.05
Effluent Grab Sample ID	16.4	Effluent Grab Sample ID	14.4	Effluent Grab Sample ID	12.4
Initial Weight of Filter (mg)	133.2	Initial Weight of Filter (mg)	132.7	Initial Weight of Filter (mg)	133.4
Weight of filter and residue (mg)	136.8	Weight of filter and residue (mg)	136.6	Weight of filter and residue (mg)	138.4
Effluent Concentration (mg/L)	18.0	Effluent Concentration (mg/L)	19.5	Effluent Concentration (mg/L)	25.0
Date:	12/16/2012	Date:	12/16/2012	Date:	12/16/201
Run Start Time	11:12	Run Start Time	4:00	Run Start Time	12:2
Flow Rate (GPM)	5	Flow Rate (GPM)	10	Flow Rate (GPM)	1
Target Influent Concentration (mg/L)	100	Target Influent Concentration (mg/L)	100	Target Influent Concentration (mg/L)	10
Slurry Details		Slurry Details		Slurry Details	
Mass of solids added (g)	134	Mass of solids added (g)	277	Mass of solids added (g)	42
Volume of water used (L)	1.8	Volume of water used (L)	1.8	Volume of water used (L)	1.3
Temperature at grab (C)	15.0	Temperature at grab (C)	12.2	Temperature at grab (C)	13.
Time at grab	11:32	Time at grab	4:10	Time at grab	12:3
Effluent Grab Sample ID	10.1	Effluent Grab Sample ID	13.1	Effluent Grab Sample ID	11.
Initial Weight of Filter (mg)	133.7	Initial Weight of Filter (mg)	132.4	Initial Weight of Filter (mg)	133.
Weight of filter and residue (mg)	140.7	Weight of filter and residue (mg)	130.8	Weight of filter and residue (mg)	142
Effluent Concentration (mg/L)	35.0	Effluent Concentration (mg/L)	37.0	Effluent Concentration (mg/L)	142.
	33.0		57.0		
Temperature at grab (C)	15	Temperature at grab (C)	11.0	Temperature at grah (C)	13
Time at grab	11.37	Time at grab	11.7	Time at grab	12:2
	11.57		4.15		12.5
Effluent Grab Sample ID	10.2	Effluent Grab Sample ID	13.2	Effluent Grab Sample ID	11.
Initial Weight of Filter (mg)	132.3	Initial Weight of Filter (mg)	133.0	Initial Weight of Filter (mg)	131.
Weight of filter and residue (mg)	138.9	Weight of filter and residue (mg)	140.8	Weight of filter and residue (mg)	142.
Effluent Concentration (mg/L)	33.0	Effluent Concentration (mg/L)	39.0	Effluent Concentration (mg/L)	52.
Temperature at grab (C)	15	Temperature at grab (C)	11.9	Temperature at grab (C)	1
Time at grab	11:38	Time at grab	4:16	Time at grab	12:4
Effluent Grab Sample ID	10.3	Effluent Grab Sample ID	13.3	Effluent Grab Sample ID	11.
Initial Weight of Filter (mg)	133.0	Initial Weight of Filter (mg)	133.4	Initial Weight of Filter (mg)	132.
Weight of filter and residue (mg)	139.9	Weight of filter and residue (mg)	141.2	Weight of filter and residue (mg)	142.
Effluent Concentration (mg/L)	34.5	Effluent Concentration (mg/L)	39.0	Effluent Concentration (mg/L)	49.
Temperature at grab (C)		Temperature at grab (C)	11.7	Temperature at grab (C)	12.
Time at grab		Time at grab	4.20	Time at grab	12.4
Effluent Grab Sample ID	10.4	Effluent Grab Sample ID	12 /	Effluent Grab Sample ID	11
Initial Weight of Eilter (mg)	122.0		121.4	Initial Woight of Filter (mg)	121.4
Weight of filter and residue (mg)	133.9	Weight of filter and an idea (mg)	131.1	Weight of filter and and due (mg)	151.
weight of filter and residue (mg)	141	stilling to the second residue (mg)	139.6	weight of filter and residue (mg)	140.
Effluent Company that 1 ( )		. TTULOPT / opcontrotion (mg/l)	A.1 E.	. THUGHT / OPCONTRATION (PAG/L)	. 40

# **Appendix B: Grab Sample Data**

Date:	12/14/2012	Date:	12/15/2012	Date:	12/16/2012
Run Start Time	2:27	Run Start Time	12:45	Run Start Time	6:25
Flow Rate (GPM)	5	Flow Rate (GPM)	10	Flow Rate (GPM)	15
Target Influent Concentration (mg/L)	200	Target Influent Concentration (mg/L)	200	Target Influent Concentration (mg/L)	200
Slurry Details		Slurry Details		Slurry Details	
Mass of solids added (g)	276	Mass of solids added (g)	589	Mass of solids added (g)	730
Volume of water used (L)	1.8	Volume of water used (L)	1.8	Volume of water used (L)	1.4
Temperature at grab (C)	18.0	Temperature at grab (C)	18	Temperature at grab (C)	11
Time at grab	2:48	Time at grab	2:48	Time at grab	6:31
Effluent Grab Sample ID	7.1	Effluent Grab Sample ID	8.1	Effluent Grab Sample ID	15.1
Initial Weight of Filter (mg)	132.1	Initial Weight of Filter (mg)	132.5	Initial Weight of Filter (mg)	132.3
Weight of filter and residue (mg)	145.0	Weight of filter and residue (mg)	149.3	Weight of filter and residue (mg)	151.8
Effluent Concentration (mg/L)	64.5	Effluent Concentration (mg/L)	84.0	Effluent Concentration (mg/L)	97.5
Temperature at grab (C)	18.3	Temperature at grab (C)	17.9	Temperature at grab (C)	11
Time at grab	2:53	Time at grab	12:59	Time at grab	6:32
Effluent Grab Sample ID	7.2	Effluent Grab Sample ID	8.2	Effluent Grab Sample ID	15.2
Initial Weight of Filter (mg)	132.7	Initial Weight of Filter (mg)	132.7	Initial Weight of Filter (mg)	131.3
Weight of filter and residue (mg)	145.8	Weight of filter and residue (mg)	150.4	Weight of filter and residue (mg)	150.8
Effluent Concentration (mg/L)	65.5	Effluent Concentration (mg/L)	88.5	Effluent Concentration (mg/L)	97.5
Temperature at grab (C)	18.3	Temperature at grab (C)	17.7	Temperature at grab (C)	10.9
Time at grab	2:54	Time at grab	1:03	Time at grab	6:36
Effluent Grab Sample ID	7.3	Effluent Grab Sample ID	8.3	Effluent Grab Sample ID	15.3
Initial Weight of Filter (mg)	132.3	Initial Weight of Filter (mg)	133.2	Initial Weight of Filter (mg)	132.8
Weight of filter and residue (mg)	145.1	Weight of filter and residue (mg)	151.6	Weight of filter and residue (mg)	154.7
Effluent Concentration (mg/L)	64.0	Effluent Concentration (mg/L)	92.0	Effluent Concentration (mg/L)	109.5
Temperature at grab (C)	18.3	Temperature at grab (C)	17.7	Temperature at grab (C)	10.8
Time at grab	2:58	Time at grab	1:08	Time at grab	6:40
Effluent Grab Sample ID	7.4	Effluent Grab Sample ID	8.4	Effluent Grab Sample ID	15.4
Initial Weight of Filter (mg)	133.2	Initial Weight of Filter (mg)	131.8	Initial Weight of Filter (mg)	133.3
Weight of filter and residue (mg)	146.6	Weight of filter and residue (mg)	151.6	Weight of filter and residue (mg)	155
Effluent Concentration (mg/L)	67.0	Effluent Concentration (mg/L)	99.0	Effluent Concentration (mg/L)	108.5