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COLLEGE OF ENGINEERING

Research Report

LAMELLA SETTLERS: SEDIMENT REMOVAL FROM ROADWAY CONSTRUCTION RUNOFF

Submitted to

The Alabama Department of Transportation

Prepared by

Jose G. Vasconcelos, Carmen D. Chosie,
Holly M. Guest, and Andrew C. Patrick

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16. Abstract
Erosion and Sediment Control (ESC) activities in construction sites are very significant as a means to mitigate environmental impacts on nearby bodies of water. Sediment basins are one technique used to prevent discharge of sediment-laden flows; they operate on the principle of providing quiescent flow conditions that favor sediment settling. Settling conditions can be further improved with the addition of high-rate strategies such as lamella settlers. Such settlers have been used successfully in water purification and wastewater treatment but have not yet been tested or used in the context of ESC applications. This report presents results collected in a laboratory-scale experimental investigation that involved a direct comparison between the effectiveness of traditional and high-rate (lamella) settlers in decreasing the turbidity of sediment-laden flows. The investigation included various repetitions in which inflows with turbidity levels, in the range of 1000 NTU were introduced to a tank that contained both a traditional (control) settler and a high-rate (lamella) settler. Samples collected in the outlets of the settling units indicated turbidity levels 5 to 12 times lower in effluent from the high-rate settler in comparison with the effluent from the traditional (control) settler. The level of total solids (TS) from the high-rate settler was 3.5 times lower than that of the traditional settler. Results from particle-size distribution measurements indicated that the high-rate settler captured a wider range of particles sizes: Whereas the traditional settler captured particles 67 μm and larger, the lamella settler captured particles sizes as small as 22 μm. Such results show the great potential of this technique and point to the need for additional investigations on a larger scale that mimic conditions found on construction sites.

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ABSTRACT

Erosion and Sediment Control (ESC) activities in construction sites are very significant as a means to mitigate environmental impacts on nearby bodies of water. Sediment basins are one technique used to prevent discharge of sediment-laden flows; they operate on the principle of providing quiescent flow conditions that favor sediment settling. Settling conditions can be further improved with the addition of high-rate strategies such as lamella settlers. Such settlers have been used successfully in water purification and wastewater treatment but have not yet been tested or used in the context of ESC applications. This report presents results collected in a laboratory-scale experimental investigation that involved a direct comparison between the effectiveness of traditional and high-rate (lamella) settlers in decreasing the turbidity of sediment-laden flows. The investigation included various repetitions in which inflows with turbidity levels, in the range of 1000 NTU were introduced to a tank that contained both a traditional (control) settler and a high-rate (lamella) settler. Samples collected in the outlets of the settling units indicated turbidity levels 5 to 12 times lower in effluent from the high-rate settler in comparison with the effluent from the traditional (control) settler. The level of total solids (TS) from the high-rate settler was 3.5 times lower than that of the traditional settler. Results from particle-size distribution measurements indicated that the high-rate settler captured a wider range of particles sizes: Whereas the traditional settler captured particles 67 μm and larger, the lamella settler captured particles sizes as small as 22 μm. Such results show the great potential of this technique and point to the need for additional investigations on a larger scale that mimic conditions found on construction sites.

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INTRODUCTION

1.1 IMPORTANCE OF SEDIMENT CONTROL IN CONSTRUCTION SITES

Erosion and Sediment Control (ESC) is a key activity in construction sites, which are among the greatest sources of disturbed soil particles that eventually end up in water bodies and lead to various negative environmental impacts. Construction activities disturb areas, remove vegetative cover, and expose soils to runoff, thus becoming an important source of pollution. Construction sites have measured erosion rates of approximately 20 to 200 tons per acre per year (Pitt et al. 2007). Construction operations may increase sediment yields by as much as 10,000 times in comparison with runoff from natural, undisturbed sites (Haan 1994).

Various natural biological processes may be impacted by high-turbidity, sediment-laden flows. High turbidity levels in water bodies affect habitats, water quality, temperature, and pollutant transport and cause sedimentation in downstream receiving waters (EPA 2009). As consequence, turbidity levels in stormwater runoff discharged from construction sites are regulated by state agencies. Acceptable levels vary across the United States, and the State of Alabama stipulates that "in no case shall turbidity exceed 50 nephelometric turbidity units (NTU) above background. Turbidity levels caused by natural runoff will be included in establishing background levels" (ADEM 2013).

Meeting such turbidity discharge requirements is a challenging task on roadway construction sites. Research has shown that runoff turbidity from such sites can reach levels on the scale of thousands of NTU (Logan 2012). In addition, increased scrutiny by environmental groups provides additional motivation for developing improved sediment control techniques, particularly in sensitive watersheds. Figure 1.1 illustrates the significant impact sediment-laden discharge from a roadway construction site can have on nearby water bodies when sediment control practices are not deployed or are not functioning properly. Such impacts have provided the motivation for the proposed research, which promotes the use of high-rate settlers to enhance the ability of sediment basins to trap sediments, as outlined below.

Figure 1.1 : Sediment plume resulting from road construction runoff (Clark et al. 2012)

1.2 SEDIMENT CONTROL STRATEGIES

One response to the problem of sediment generation in construction sites has been the development of sediment control techniques. The purpose of these techniques is to capture suspended sediment, thereby reducing turbidity levels in runoff, and to control turbidity levels of effluent discharged from construction sites into natural water bodies. These techniques can be divided into the categories of perimeter control techniques and runoff retention techniques, and this research focuses on the latter type.

Various best management practices (BMPs) related to sediment control in construction sites are described in the EPA's National Pollutant Discharge Elimination System (NPDES) documents. Some sediment controls are located at the down-gradient boundaries of the construction site and are commonly referred to as "perimeter controls" (Minnesota PCA 2013). ASWCC (2009) and EPA (2012) provide examples of perimeter control BMPs that include silt fences, brush barriers, compost filter berms/socks, and vegetated buffers, among other technologies.

Runoff retention techniques involve the prevention of sediment-laden flows from leaving construction sites or efforts to reduce the sediment content of flows prior to discharge. Examples include sediment traps and sediment basins. Sediment traps consist of small impoundments, usually installed in drainageways or other points of discharge from disturbed areas, which allow sediment to settle out of construction runoff (EPA 2006). These traps have an effective lifespan of around 24 months and are useful only for drainage areas smaller than 5 acres. Sediment basins are used in drainage areas larger than 5 acres and are designed to slow the velocity of runoff, thus creating enhanced conditions for sedimentation to occur. The overarching idea is to generate quiescent conditions so that sediment particles settle to the bottom of the basins and are not transported in the outflow from the basin. Logan (2012) has presented a comprehensive study on sediment basins. Typically, sediment basins are rectangles with a length 2 to 4 times larger than their width. Depth values range from 2 to 5 feet, with side slopes in the range of 3H:1V to 2H:1V. Over the years, improvements have been made to basin designs that have increased their sediment removal effectiveness. Examples of such improvements include (McLaughlin 2006; McLaughlin and Jarrett 2008; McLaughlin and McCaleb 2010):

- The addition of a forebay/sump at the upstream end to facilitate settling of coarser sediment
- Internal baffles used to calm runoff and create a more even flow distribution
- The use of dewatering techniques based on skimmers that selectively discharge from the upper layers of the flow, which theoretically contain water with the least amount of sediment
- the use of flocculants such as polyacrylamide (PAM) to bind small particles together and enhance the capture of smaller soil particles (silt and clay)

An example of the sediment basin standard employed by the Alabama Department of Transportation (ALDOT), which features all these improvements, is presented in Figure 1.2.

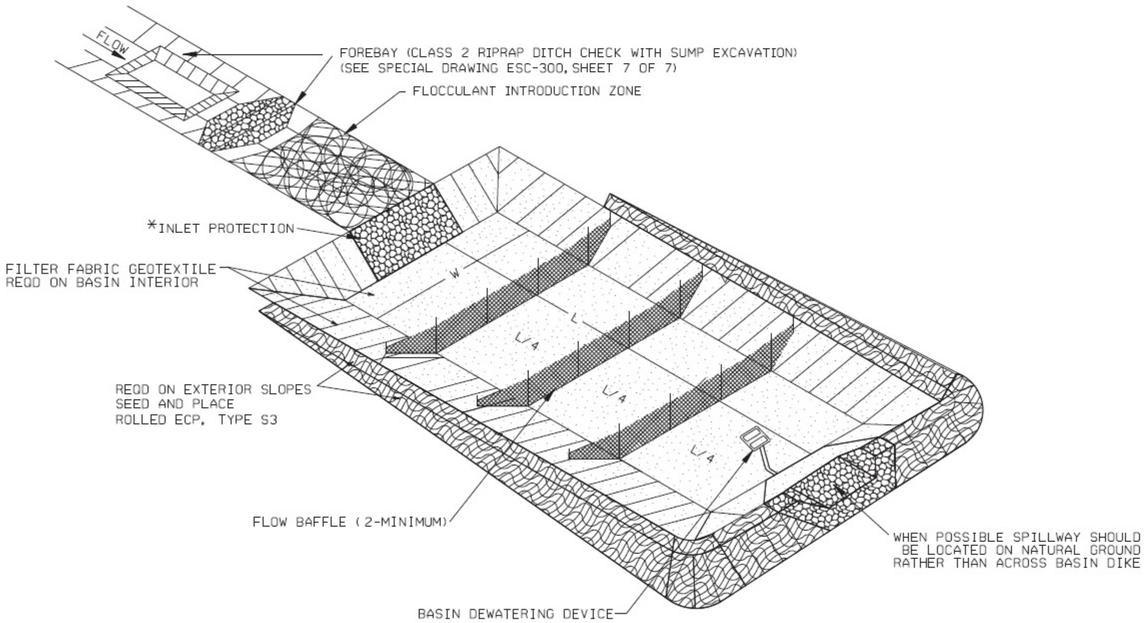

Figure 1.2 : Design characteristics of a sediment basin as specified by ALDOT (2013)

1.3 LIMITATIONS OF SEDIMENT BASINS

Field measurements reported by Logan (2012) indicate that inflows into sediment basins may have turbidity levels in excess of 1,000 NTU, and after some intense rain events may reach levels higher than 25,000 NTU. Measurements taken from sediment basins outflows demonstrated that turbidity levels within the basin dropped, in some cases, to levels in the hundreds of NTU. However, these data indicate that sediment basins are not always completely effective in bringing effluent standards to compliance levels. Difficulties associated with the operation of these basins are diverse and, according to Logan (2012), include:

a) Insufficient storage volumes in sediment basins

b) Issues related to inadequate flocculant selection and application, with flows exceeding the flow-rate limit established by the floc log manufacturer

c) Overtopping of baffles when flow depth is excessive

d) Difficulty in maintaining proper soil stabilization across construction slopes and thus generating very large sediment loads in the inflows within basins

As the main purpose of enhancing water quality through the use of sediment basins centers on the settling of particles, any effort to improve these basins should focus on developing means to improve settling mechanisms. It is of great importance that a range of sediment particles associated with high turbidity reach the bottom of the basin prior to the point where the basin outflow will draw it toward the discharge and into the receiving water body. Therefore, there must be enough time for such particles in the runoff to settle out. The smaller the fraction of fine particles present in the runoff, the more time is required for settling in order to reduce outflow turbidity to acceptable levels. However, in many cases the area available for installation of the sediment basins is very limited, thus preventing ideal conditions for sediment removal.

There are different mechanisms by which the retention of sediment and the reduction of turbidity can be improved in sediment basins:

a) Reduce vertical distance that sediment particles need to travel until they settle
b) Prevent short-circuiting of flows in sediment basins
c) Reduce or prevent flow eddies and vorticity related to turbulence, which have the potential to cause particle re-suspension
d) Deploy flocculant appropriately

Improvements a, b and c can be achieved with the adoption of high-rate settlers, which is the focus of this research work.

Chapter 2

LITERATURE REVIEW

2.1 HIGH-RATE SETTLERS

High-rate settlers offer a means to significantly increase the available settling area in sedimentation units, reduce vertical travel for particles, and create an ordered flow pattern. This process involves the use of parallel surfaces in the tank, often plane panels that are referred to as lamellas.

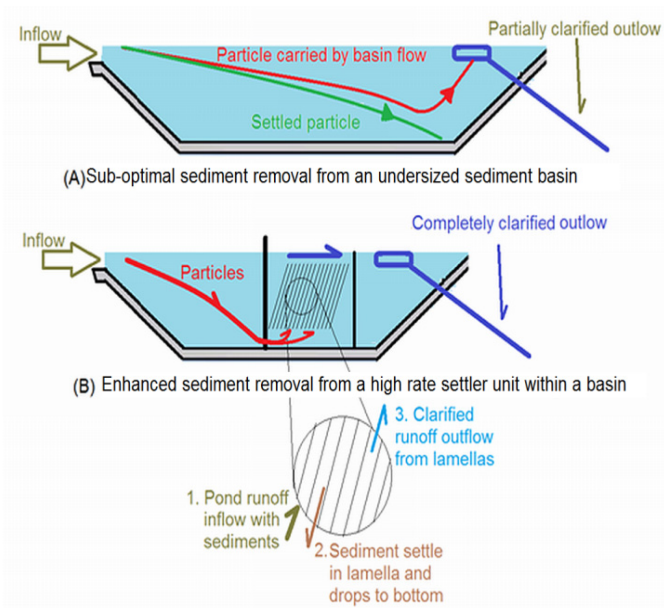

Figure 2.1 : Schematic of traditional settling unit used in a sediment basin and an alternative based on high-rate lamella settlers

These settling surfaces (e.g. parallel plates) are deployed in such a way that inflow flow is oriented along them. The spacing between panels is narrow, thereby reducing the vertical distance (from feet-scale into inch-scale) that a sediment particle must travel before settling. These panels help direct flow orientation in the basin, which in turn reduces the short-circuiting that can contribute to sediment removal failure. Additionally, the narrow spacing between panels that produce the generally low velocity of flow in sediment basins creates laminar flow conditions. Laminar flows do not produce turbulent eddies, and this effect in turn decreases re-suspension of settled particles. A common approach is to position the panels or surfaces at an angle (usually 60 degrees off vertical) to facilitate particles sliding from the plate to the bottom of the basin. Figure 2.1 provides a comparative schematic of sediment particle trajectories in an undersized sediment basin and in a basin that has a high-rate settler deployed within it.

The technology for high-rate settling was first proposed in the 1970s for use in industrial and residential wastewater treatment and in water purification plants. To date, however, this technology has not been used to remove sediment from runoff at construction sites. Several different geometries have been proposed for settlers appropriate to basins on construction sites. As illustrated in Figure 2.2.(A), one version directs inflows along longitudinally oriented plates, with settled sediments being captured at the plate underneath and eventually directed to the settler bottom. Figure 2.2(B) presents another approach in which the flow is directed upward over the plates, with sediment also being captured between plates and sliding to the bottom of the basin.

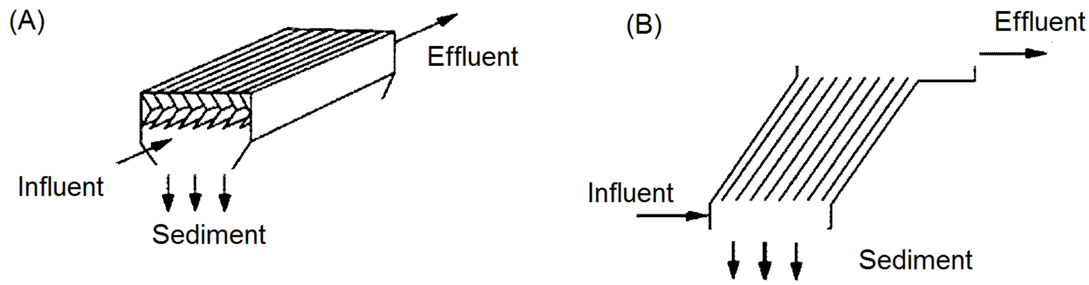

Figure 2.2 : Geometry alternatives for high-rate settlers: (A) longitudinal flow orientation; (B) upward flow orientation

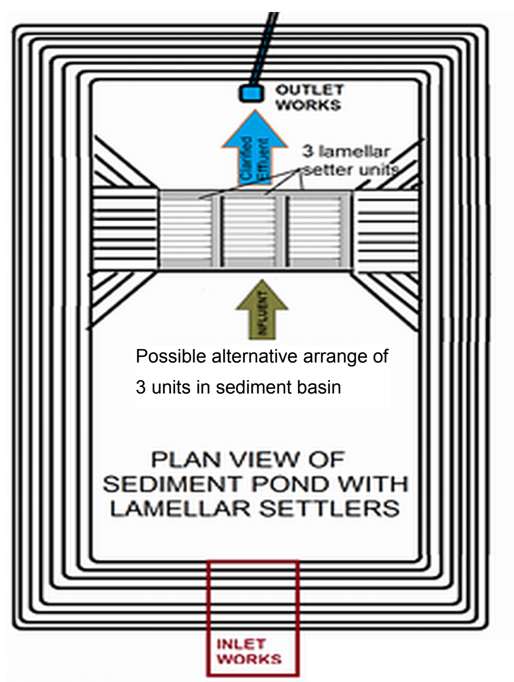

Figure 2.3 : Arrangement of three high-rate lamella settlers in a sediment basin

As pointed out by Montgomery (1985), a lamella-based high-rate settler can remove sediment as effectively as a traditional settler using only one-tenth of the area. This can be a key factor for roadway construction sites with space constraints. The following example illustrates the space-saving arrangement offered by high-rate settlers when compared to traditional sediment ponds. Figure 2.3 illustrates a sediment basin containing three upward-flow lamella settlers (dimensions of 6 x 8 x 10 ft^3), with boards 4.6 ft long and 6 ft wide placed at an angle of 60 degrees and spaced every 2 in. This arrangement could potentially remove silt-sized particles/flocks (0.2 mm and larger) from peak runoff inflows of 1.2 ft^3/s with a required plan area of 180 ft^2. Under identical conditions, a traditional sediment pond design would require an area of 1,450 ft^2 (8 times larger) to settle the same amount of sediments, showing the advantage of high-rate settlers.

2.2 KNOWLEDGE GAP

Although high-rate settling is an established technology in wastewater treatment and water purification, there are some important open questions regarding its use in the context of sediment control in construction sites. These questions may be summarized as follows:

a) What is the effectiveness of high-rate settlers when compared with traditional settlers in reducing the turbidity of sediment-laden flows?
b) How consistent is sediment removal by high-rate settlers (e.g., are results repeatable)?
c) What are the concentration and particle-size distribution of sediments suspended in water flows being discharged from high-rate settlers, and how do these compare with flows discharged from traditional settlers?

Chapter 3

OBJECTIVES

In order to address the identified knowledge gaps, an experimental investigation conducted a direct comparison of the turbidity removal performance between a traditional settler and a high-rate, lamella-based settler. Sediment-laden flows were generated and directed into an experimental apparatus that included the essential features of a sediment basin. A physical model was constructed to allow for a side-by-side evaluation of how much turbidity reduction was attained with each settling approach. Frequent water sampling allowed for the determination of turbidity levels at selected intervals in the apparatus. Samples were used to determine characteristics of the soil in suspension in the sediment-laden flows. These characteristics included measurement of the total solids concentration (mg/L) and determination of the particle-size distribution at selected locations in the apparatus.

Chapter 4

METHODOLOGY

The research objectives of this work were met using an experimental program that involved physical model studies that included the essential features of traditional and high-rate settler units. Turbidity levels in samples collected from the apparatus were measured and compared, with several repetitions being performed to ensure consistency in the results.

Additional non-systematic tests were performed on samples obtained from the high-rate settler that included the use of polyacrylamide. Finally, tests were conducted to characterize the concentration of solids in suspension (Total Solids) and the particle-size distribution at selected points of the apparatus.

4.1 EXPERIMENTAL PROGRAM

The core of the experimental research work was as follows:

1. The construction of an experimental apparatus that would allow a side-by-side evaluation of traditional vs. high-rate settler approaches
2. The systematic testing of turbidity removal in sediment-laden flows directed into the apparatus conducted at selected points in the apparatus during the course of each experimental run

The following subsections detail the development of the experimental apparatus, the experimental procedure and test conditions, and the corresponding data analysis.

4.1.1 Experimental apparatus

The experimental apparatus consisted of an acrylic tank that allowed for observation of the flow and a water-recirculation system comprised of pumps, pipes, tubing, valves, and other hydraulic connections.

Figure 4.1 presents the general layout of the apparatus. A 1.5-in diameter, PVC connection line brought tap water to two identical white tanks, each with a 55-gallon capacity. These tanks were used to store the water that was pumped into the acrylic tanks and were the site at which soils were added to the apparatus. Two pumps were installed in each tank. One pump agitated the water in the tank and thereby kept the added soils in suspension. The second pump discharged the sediment-laden flow into the acrylic tank, with the flow being metered by a differential-pressure flow meter linked to a handheld manometer, as shown in Figure 4.2.

Figure 4.1 : General layout of the experimental apparatus used in this investigation

Figure 4.2 : Pressure-differential flow meter used to measure sediment-laden flows into the acrylic tank

Each tank was constructed with ½-in-thick clear acrylic panels 8-ft long, 4-ft high, and 1-ft wide and was divided into three main compartments. An 11x12-in forebay at the upstream end received the sediment-laden flow from the white tank. The lowest portion of the forebay had two openings, each linking to two 7-ft long, 4-ft high, 5.5-in wide settling tanks. These tanks were separated by a thin acrylic plate and connected to the upstream forebay through manifolds created using 2-in PVC pipes with various ½-in diameter sharp-edged orifices. The manifold distribution for the lamella tank was oriented horizontally, discharging upward at the bottom portion of the tank. The manifold distribution for the traditional settler was vertical, at the upstream end, and discharged horizontally, thereby mimicking the flow supply that would be anticipated in traditional settler inlets. These two settlers discharged outflows at the opposite end of the tank, where a gutter was fitted. Figures 4.3 and 4.4 present a lateral and a longitudinal view of the acrylic tank components. Lamella panels were spaced every 1-in and were placed at an approximate angle of 60 degrees to horizontal. These panels, made of 1/8-in acrylic, were too flexible, so the angle was not uniform, as indicated in Figure 4.3.

The underlying idea behind this apparatus configuration was to represent longitudinal sections of a traditional settler and an upward high-rate, lamella settler. An important feature of this geometry is that it allowed for a direct comparison of the turbidity removal achieved by these settling alternatives. Figure 4.5 shows both tanks discharging flows after settling at the downstream gutter. As shown, the outflows still contain sediment load.

Figure 4.3: Lateral view of the acrylic tank (lamella settler in front). Forebay is located at the right end of the figure, and settled flow discharged at the left end of the system

Figure 4.4: Longitudinal view from the downstream end of the acrylic tank with two settlers (lamella settler is in the right). Forebay is located in the opposite end

Figure 4.5: Tank discharge during typical experimental runs with sediment-laden flows

4.1.2 Experimental procedure and parameters

It is important to note that, because of the innovative nature of these tests, they are not standardized. Thus, the experimental procedures required corrections during the initial stages of the research in order to create test conditions that could be considered representative.

The procedure for comparing the traditional and high-rate settling alternatives was simplified by creating conditions for steady sediment mass intake in the apparatus. An inflow rate of 0.60 L/s was used in all experiments, which corresponds to 0.021 ft^3/s per unit foot of a sediment basin, a value of magnitude comparable to inflow rates measured in a Franklin County sediment basin (Logan, 2012).

Soils used in all tests were obtained from a construction site near Birmingham, Alabama, and were passed through a no. 4 sieve. A mass of 2 kg of soil was added to 265 liters of water volume in the white tanks, producing a soil concentration of around 7,400 mg/L. During the test, sediment was added at a rate of 800 g every 3 minutes to preserve the original sediment concentration in the white tanks during the experimental runs. However, as the TS test results later demonstrated, a large fraction of these sediments (by mass) remained in the bottom region of the white tanks despite the use of recirculation pumps and thus were not pumped into the acrylic tank. Only the finer particles in these soils were eventually pumped to settling units.

The procedure used in the experiments is described below:

1. Following a cleanup to remove sediments, the white tanks were filled to the 265 L mark, with 2 kg of soils added.
2. A recirculation pump was started to keep the soils in these tanks in suspension.
3. Tap water was added to the white tanks at an average flow rate of 0.60 L/s.
4. Immediately following the addition of the tap water, a second pump was started and pumped 0.60 L/s of flow from the white tanks to the forebay of the acrylic tank, which was initially empty. This flow addition marked the start of the clock for each experimental run.
5. Turbidity measurements were performed in samples collected from the white tanks at about every 3 minutes during experiments;
6. The water level gradually increased in the acrylic tank and eventually reached the overflow points of the two settler units (traditional and lamella settlers) at the same time.
7. Samples for the turbidity characterization were collected from the forebay at a frequency of every 60 seconds and at each settler unit every 30 seconds.
8. After about 15 minutes of discharge time in the settling units, tests were concluded and all pumps were stopped.
9. All collected samples were analyzed with a calibrated turbidity meter to assess turbidity variation over time.
10. Experiments were repeated six times under these same conditions to ensure consistency of the results.

4.1.3 Experimental data analysis

All samples collected were analyzed with a LaMotte 2200we turbidity meter, which can measure turbidity values up to 4000 NTU/AU. Two readings per sample were performed and results compared for consistency; when consistent results were averaged, a third reading was performed. Results from all this data collection were entered into a spreadsheet so that the various repetitions could be compared.

4.2 NON-SYSTEMATIC EVALUATIONS

4.2.1 Experiments involving addition of Polyacrylamide

In some of experiments, polyacrylamide (PAM) was added to the apparatus as a means to improve turbidity reduction. Soil and water samples were sent to Applied Polymer Science, Inc. (APS) for analysis. Based on the soil characteristics, APS provided us four floc log blocks (type 706b) that were adequate for promoting the settling of fine particles in the water-soil suspension. Appendix A presents results from APS study on the soils used in this investigation.

In the experiments in which PAM was used, the recirculation line between the two reservoirs was fitted with a wire cage that enclosed the PAM block at the discharging end of the line. This cage held the floc blocs as the pumped water flowed around them, thus ensuring extensive contact between the water-soil suspension and PAM. This soil-water-flocculant mix was then pumped into the acrylic tank and passed through the forebay and the two settling units, essentially following the same procedure outlined before.

4.2.2 Soil characterization studies

As a means of further characterizing the performance of the two settling systems, two additional tests were conducted on the soils present in the samples collected during a typical experimental run:

a) Total solids (TS) tests: Four samples were collected at: 1) the white tanks; 2) the acrylic tank forebay; 3) the outlet of the traditional settler; and 4) the outlet of the lamella settler. TS for these locations were determined by weighing the amount of solids present in a 50 mL sample. The procedure involved weighing a porcelain plate, filling it with the 50-mL sample volume, evaporating the water in an oven and completely drying the residue, and then weighing the plate with the residue. The TS concentration equals the difference between the weight of the plate with the residue and the weight of the plate without it. Procedure details are presented in APHA (1992).
b) Particle size distribution (PSD) of soils in water suspension: The soils used in experiments contained a significant fraction of fine particles that remained in suspension during experimental runs. Particle-size distributions for the suspended soils were obtained by sending the sediment-water samples to the Headwater Resources testing facility in Taylorsville, Georgia. The samples collected at the forebay and at the outlets of the traditional and the high-rate settler units were analyzed by a HORIBA LA-920 particle size analyzer. Using laser diffraction, PSD can be derived using Mie theory. The equipment used is capable of providing PSD characterizations to soil sizes from 0.02 μm to 1 mm (clay to sand sizes).

Chapter 5

EXPERIMENTAL RESULTS

5.1 TURBIDITY RESULTS

The turbidity results in the white tank and forebay were steady in the range of 1000 NTU. This consistency was made possible by the strategy of adding soil gradually, leading to only slight fluctuations of 10 percent to 15 percent turbidity levels during typical experimental runs. The same levels of turbidity were also recorded in the acrylic tank forebay, albeit with smaller fluctuations, as indicated in Figures 5.1 to 5.7.

The turbidity results for the samples collected from the high-rate lamella and traditional settlers presented marked differences. As indicated in Figure 5.1, the turbidity levels measured at the outlet of the lamella tank oscillated from 44 to 117 NTU, with an average of 73 NTU. The traditional settler initially presented similar results, but from the fourth sample (taken at 2 minutes) onward, the results began to oscillate. By the 4.5-minute mark, the results averaged 702 NTU, with a maximum at 765 NTU and minimum of 606 NTU. The results from the traditional settler outlet are labelled “Control Outlet” in the charts and tables that follow.

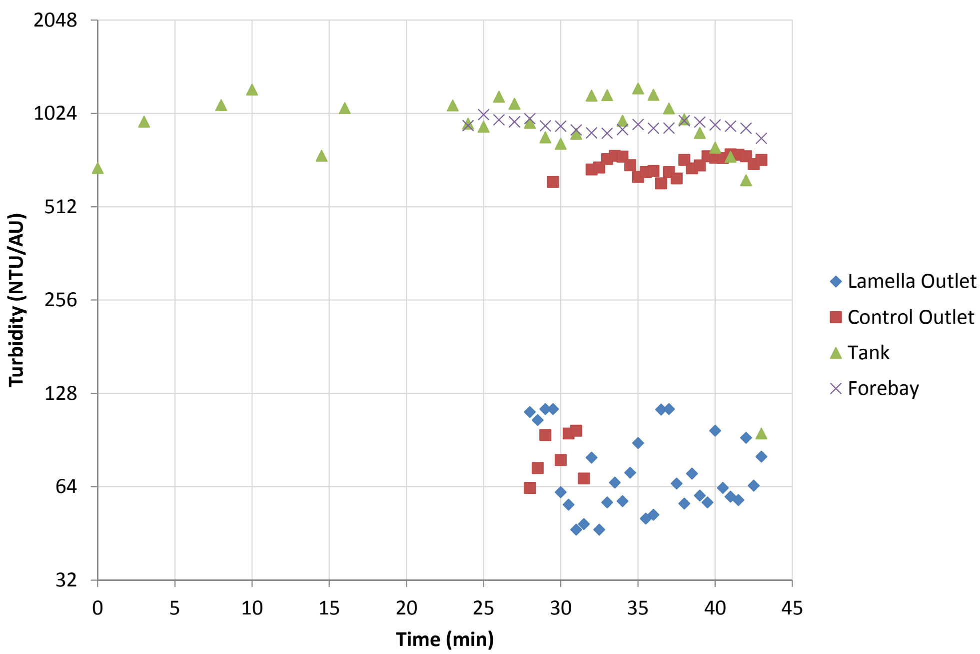

Figure 5.1: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during a typical experimental run, 1st repetition

To assess the consistency of these results, conditions were repeated six times, and the same general trend was observed. The results from repetitions 2 through 7 are presented in Figures 5.2 to 5.7.

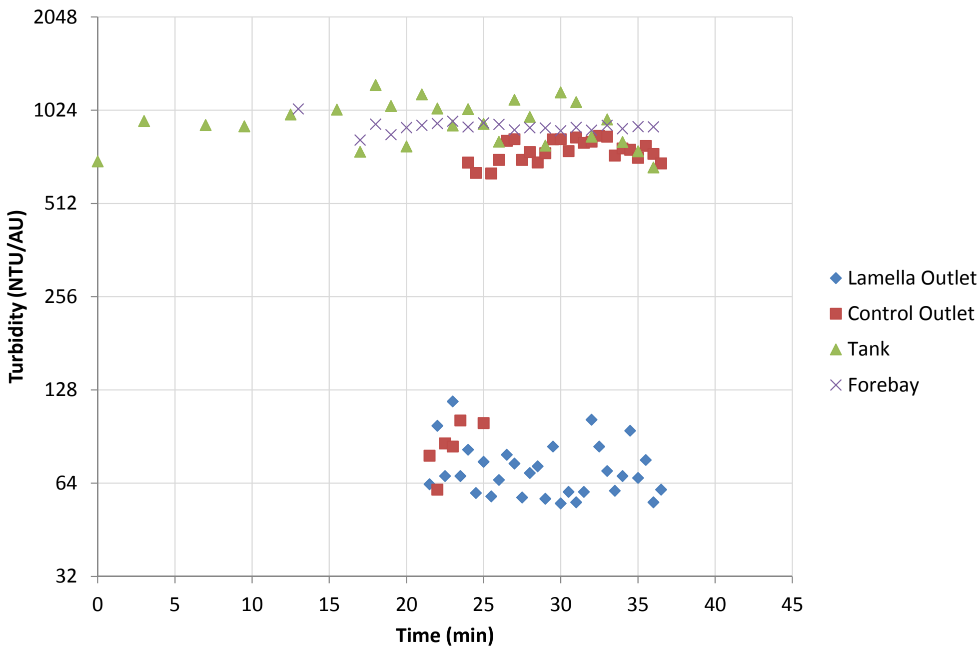

Figure 5.2: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during a typical experimental run, 2nd repetition

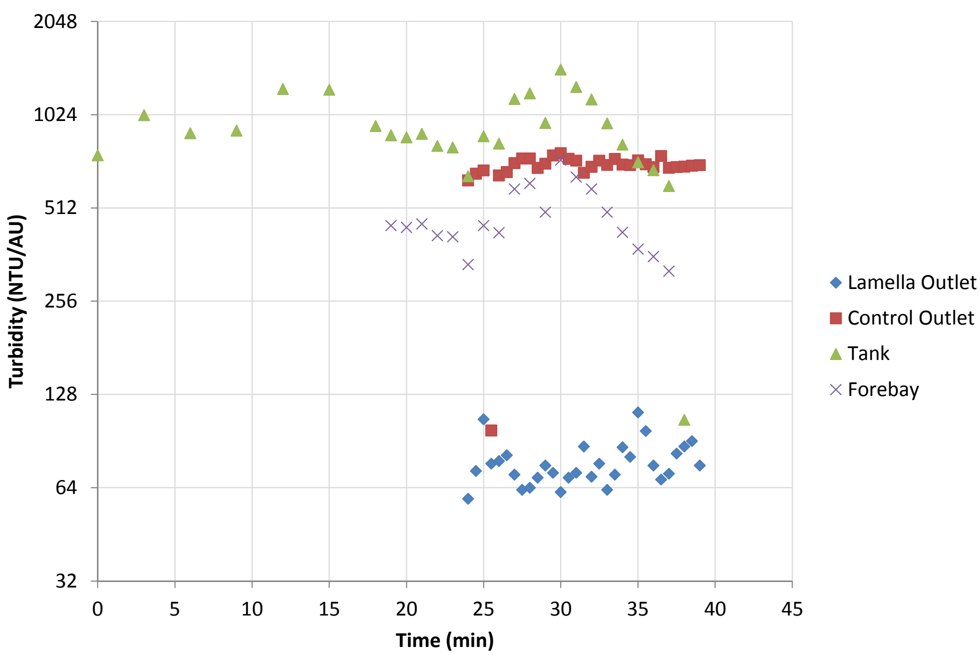

Figure 5.3: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during a typical experimental run, 3rd repetition

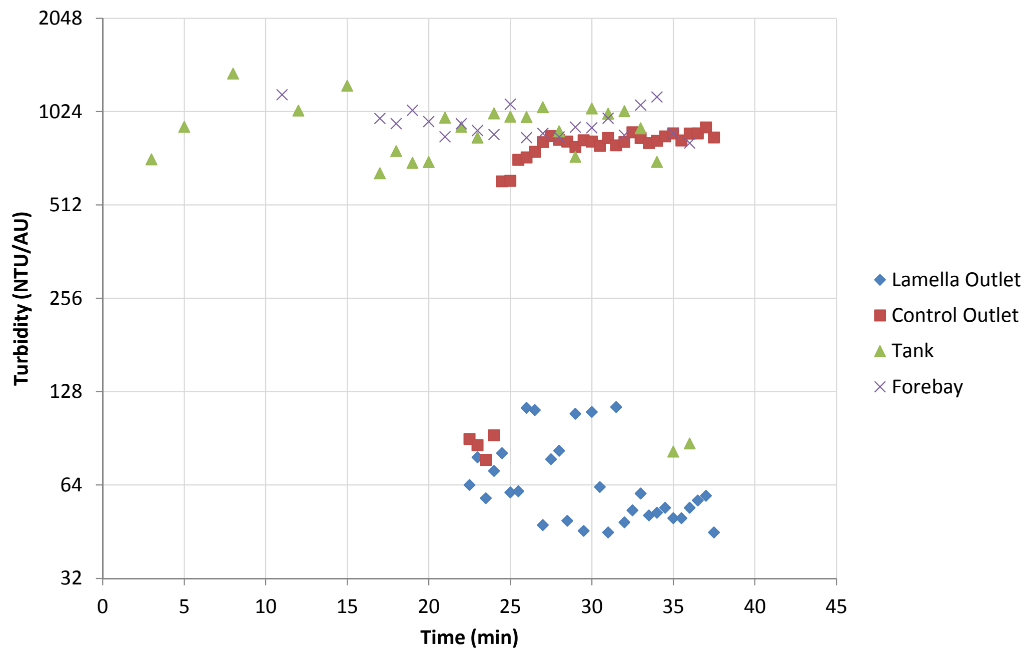

Figure 5.4: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during a typical experimental run, 4th repetition

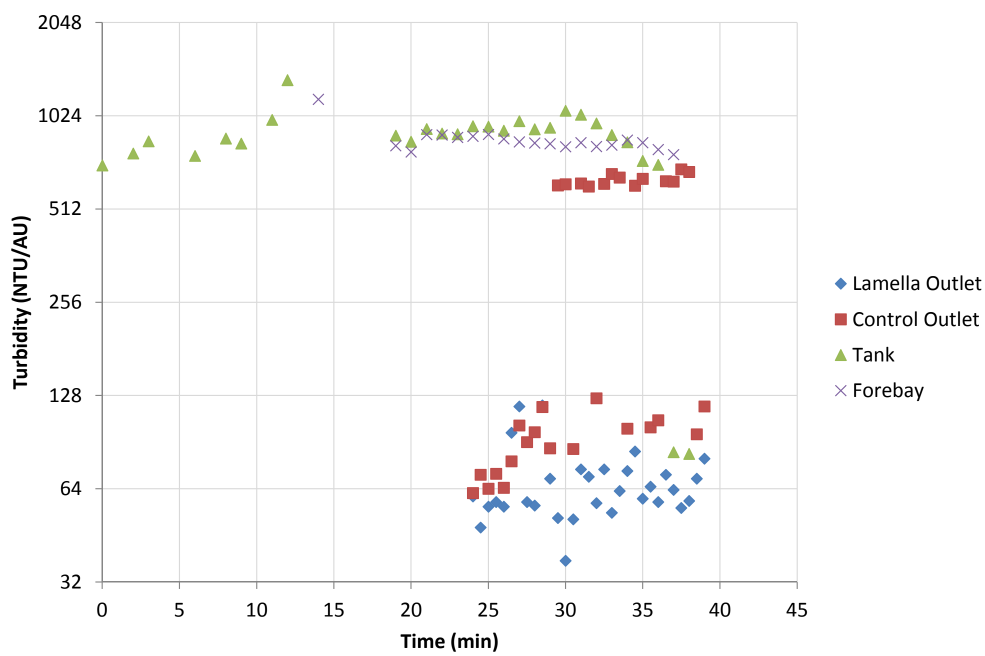

Figure 5.5: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during a typical experimental run, 5th repetition

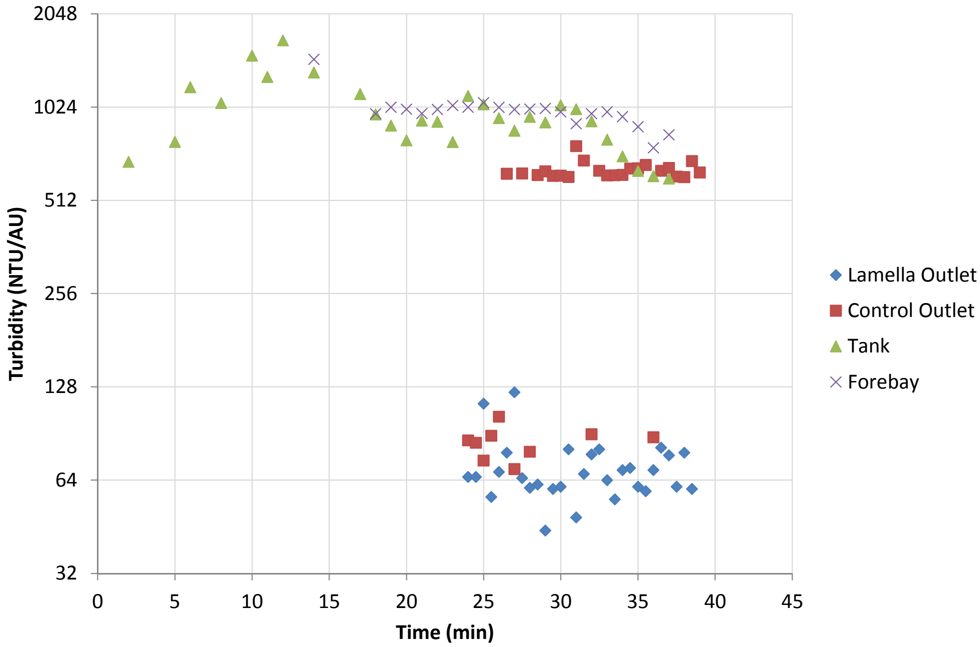

Figure 5.6: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during a typical experimental run, 6th repetition

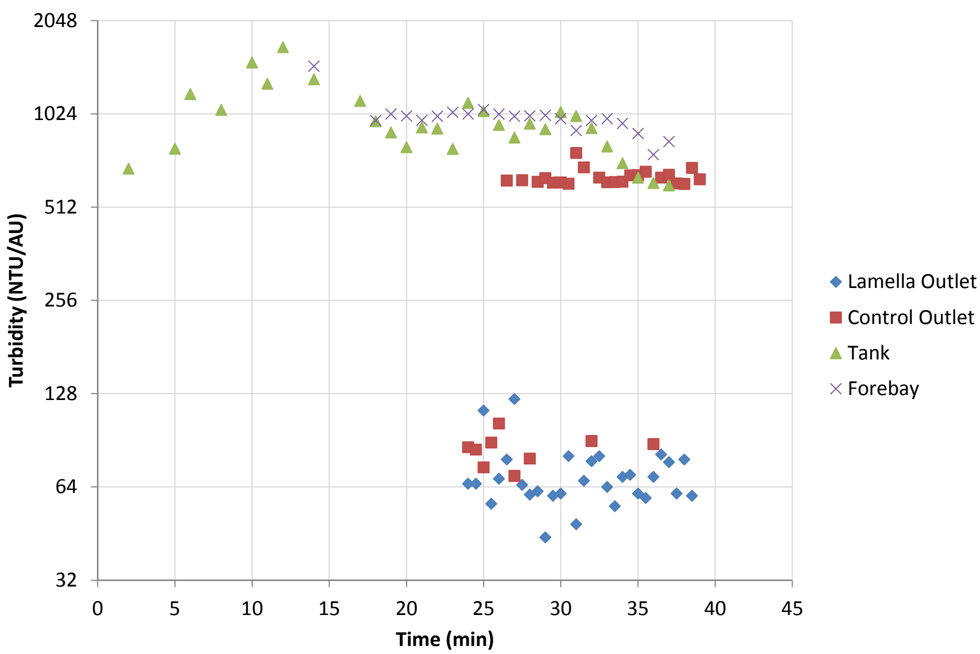

Figure 5.7: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during a typical experimental run, 7th repetition

Average turbidity results from all repetitions are presented in Table 5.1 below, along with the ratio between the turbidity levels measured in the traditional (control) settler unit and in the high-rate lamella settler unit. Turbidity levels were much reduced in the high-rate settler, by a factor ranging from 5 to 12 times.

Table 5-1: Average turbidity results from experiments

Repetition number	Average turbidity white tank (NTU/AU)	Average turbidity at forebay (NTU/AU)	Average turbidity at control outlet (NTU/AU)	Std. deviation of turbidity at control outlet (NTU/AU)	Average turbidity at lamella outlet (NTU/AU)	Std. deviation of turbidity at lamella outlet (NTU/AU)	Control / Lamella turbidity ratio (%)
1	941	933	559	265	73	23	766%
2	935	906	628	276	71	15	885%
3	912	1035	687	114	77	12	892%
4	853	942	715	255	67	22	1067%
5	851	854	351	273	67	18	524%
6	979	995	479	258	69	16	694%
7	740	863	695	165	55	5	1264%

Figure 5.8 presents a photo that shows the differences in the outflow turbidity from both settling units. The lower level of turbidity produced by the lamella settler is readily apparent in the sample on the left.

Figure 5.8: Samples collected at the outflow points of the lamella settling unit (left) and the traditional (control) settling unit.

5.2 TURBIDITY RESULTS – PAM ADDITION

Turbidity results were collected at the same locations in experiments in which PAM blocs were used. As expected, turbidity results were greatly reduced in the whole apparatus because of the addition of the flocculant.

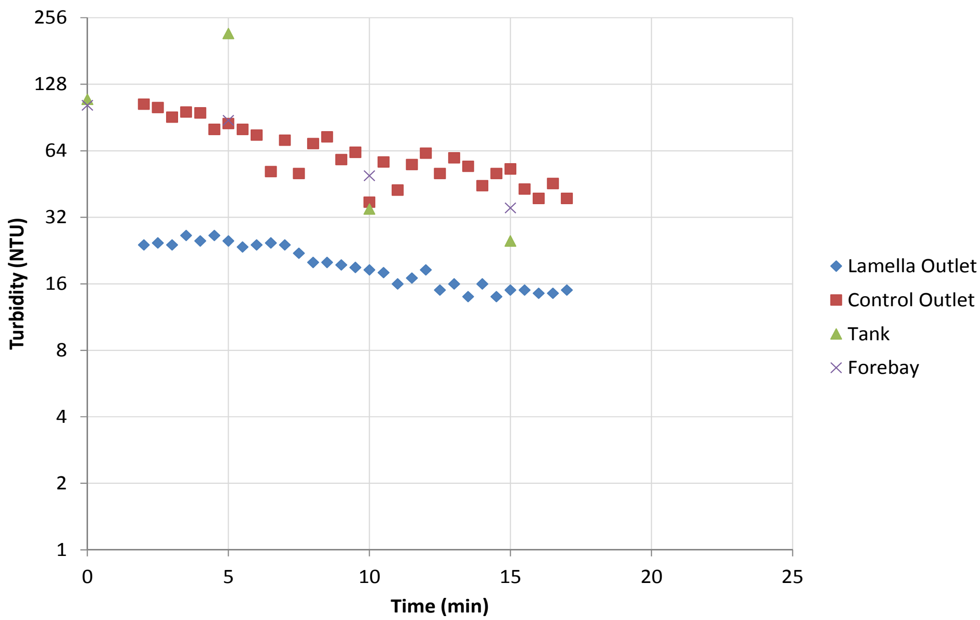

Figure 5.9: Turbidity results from samples collected at the white tank, the forebay, and the two settling unit outlets during an experimental run with PAM

Figures 5.9 presents a typical result for the turbidity levels measured in the apparatus during tests involving the addition of PAM. In this chart, the initial time marks the moment when overflow was detected. Turbidity levels for the white tank were in the range of 25-217 NTU, and between 35 and 103 NTU for the forebay. The results for the traditional settling apparatus ranged from 37 to 107 NTU, with an average of 64 NTU, whereas for the lamella tank the results ranged from 13 to 27 NTU, with an average of 20 NTU. Among those experimental repetitions that included flocculant use, turbidity results were in average 2.1 to 3.3 times smaller for the high-rate lamella settling unit when compared to the traditional (control) settling unit. These results, though, are merely indicative. A more thorough investigation of the PAM high-rate settler is needed to obtain a more precise assessment.

5.3 SOIL CHARACTERIZATION RESULTS

For experimental run number 7 (with no added PAM), samples were taken at the same four points at which turbidity was measured to determine TS and PSD. The measured values for TS were much smaller than the original 7,400 mg/L measurement obtained from the soils originally added to the tanks. This result indicates that a large soil mass remained at the lowest portion of the white tanks. PSD results showed that only soil sizes smaller than 0.15 mm remained in suspension and were responsible for the 1000 NTU turbidity levels measured in the tests. Results for TS are presented in Table 5.2.

Table 5-2: Total solids (TS) results from a sample collected in experimental run 7

Location	Total solids (mg/L)
White tanks	1,694
Forebay	1,148
Control outlet	606
Lamella outlet	170

PSD was determined for three locations: the white tanks and at the outlets of each of the settling units; results are presented in Figure 5.10. The top portion of the figure presents the PSD for the white tanks and shows that the particles sizes ranged from fine sands (d=150 μm) to clay particles (d=0.2 μm), giving an indication of how very fine were the soils used in this investigation.

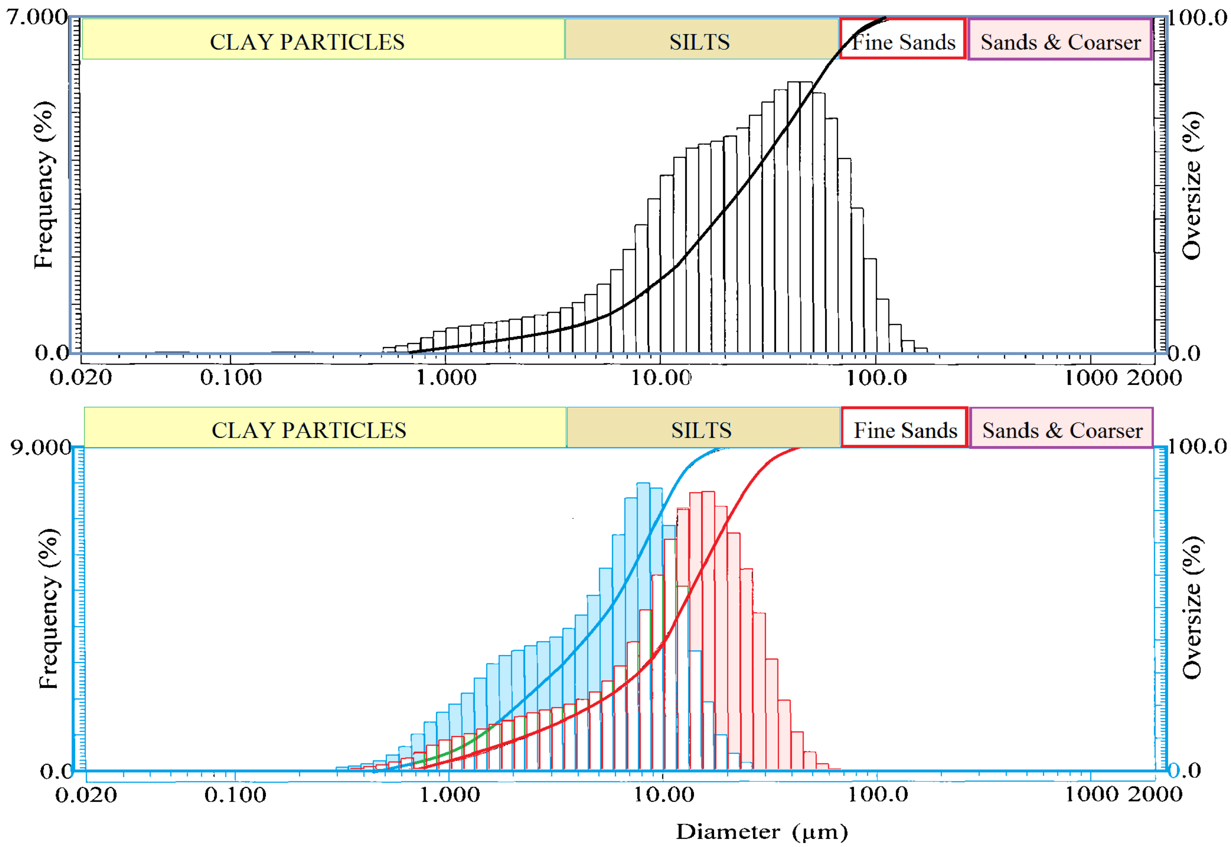

Figure 5.10: Particle size distribution (PSD) for the soils in the samples collected in the white tanks (top chart) and the outlets of the settling units (blue=lamella, red=control).

PSD results for both settler outlets present very interesting insights into the differences between the soils present in the samples. The traditional settler results (PSD red bars) show that this strategy was effective in removing fine sands from the inflow, with particles in the range of 125 μm to 67 μm being captured. This range should be linked to the difference in the TS results measured in the forebay (1,694 mg/L versus 606 mg/L) shown in Table 5.2. However, the full range of silt-sized particles (d=65 μm to 3.8 μm) remained in the sample, accounting for 86 percent of the particles detected by the laser diffraction process. Such silt particles could settle provided conditions were adequate and time was sufficient. Thus, if both the size of the traditional settler unit and time that the suspension spent in it were increased, more silt particles could have been captured and turbidity would be reduced further.

PSD measurements for the lamella settler outlet (blue bars) shows that particles of d=22 μm and larger were fully captured. This result indicates that this method captured a significant fraction of the silt particles present in the water-sediment suspension. The smaller range of particle sizes that remained in sample should be linked with the TS difference found in the traditional settling unit (170 mg/L versus 606 mg/L). Moreover, 37 percent of the particles detected with the laser diffraction process were clay particles, which could not be removed unless a coagulation/flocculation process was added. *The results are a strong indication of the more effective settling produced by the lamella settler, even without the addition of PAM*. These results confirm the better performance of a lamella settler of the same dimension as a traditional settler under the same sediment loading conditions.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

The experimental research achieved its objectives of assessing the ability of a high-rate lamella settler to improve turbidity reduction in sediment basins. This finding is relevant, as it may demonstrate a new alternative for transportation agencies and other developers who are presented with restricted available areas for the implementation of sediment basins. In summary, the investigation indicated that:

1. Turbidity measurements were generally consistent in all selected sampling stations over all experimental repetitions.
2. Turbidity values were comparable between the white tank and forebay but decreased at the settler outlets, as expected.
3. The lamella settler unit decreased the average turbidity values by a factor of 5 to 12 times in comparison with the values produced by the traditional settling unit; in terms of TS measurements the solid discharge from the lamella settler was 3.5 times smaller.
4. PSD measurements showed that a wider range of particle sizes was captured with the lamella settler unit when compared with the traditional settler. This result is consistent with the theory of high-rate settling and is linked with the TS results obtained for the same samples.

Future work should be directed toward investigating the efficiency of lamella settlers at larger scales, mimicking more closely conditions that are anticipated at construction sites. These investigations should consider the benefits of high-rate settlers used in association with other well-established technologies for turbidity reduction, including the use of porous baffles and polyacrylamide.

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APPENDIX A

Floc Log analysis report from Applied Polymer Systems

Alabama Samples
(Silt Stop and Floc Log applications)

Sample	Location (91)	Description	APS Application	Results and Special Instructions
	11-27-12 Analysis by: NAO & KMB	**Soil Type / Sample**	**Floc Log Type**	**Reaction Time / NTU Reading**
	Auburn University			
	238 Harbert Engineering Center	**Soil Sample**	**Floc Log Type**	
	Auburn, AL 36849	pH: 6.15	706b	25-35 seconds / NTUf 15.3
		NTUi: 1077	**Soil Stabilization**	
	Jose Vasconcelos	Hardness : 50 ppm CaCO3	712	dry or spray application
	jqv0001@auburn.edu			

Note : The Polymer Enhanced Best Management Practices (PEBMP) Application Guide contains step by step instructions for using Silt Stop Products for soil stabilization and Floc Logs for water clarification. The guide can be found near the bottom right hand corner at www.siltstop.com.

Floc Logs are designed to work in flowing water conditions. Mixing / reaction times will be very important when using the Floc Log listed above. Mixing must be continuous and in contact with the logs for the time stated to obtain the best results. A mixing ditch, pipe, or flume system may be used with either a pump or gravity flow to meet this requirement. **The dosage rate should be 60-70 GPM flow / each Floc Log placed in a series or in a row. Particulate formed may be captured by filtering through or across a series of jute matting after the mixing and reaction has been completed.** (Please see page 42 of the PEBMP for more on Particle Collection.)

Stabilization of the soil at the source may be obtained by spreading the site-specific Silt Stop powder onto the soil surface (can be mixed with other additives such as seed, fertilizer, etc.), then covering the soil with open-weave jute, coconut matting, mulch, or straw. This will perform as a stabilizer for reducing soil and clay movement into the runoff water, as a tackifier to hold the soil/organic matrix in place, as well as providing a surface area for attachment of flocculated sediment. **For detailed application rates and instructions, please see the Soil Stabilization section beginning on page 5 of the PEBMP.**

Areas where high water velocity may occur (ditch lines, swales, etc.) should be "soft armored" by placing "jute" matting flush to the ground then spreading the dry powder over the jute. This will greatly reduce erosion in these areas. **For detailed application rates and instructions, please see the Soil Stabilization section beginning on page 5 of the PEBMP.**

Applied Polymer Systems, Inc.
519 Industrial Drive
Woodstock, GA 30189
www.siltstop.com

APPENDIX B

PSD results from Headwater Resources HORIBA LA-920 equipment

HEADWATERS RESOURCES

Materials Testing & Research Facility
2650 Hwy 113 SW
Taylorsville, Ga. 30178
Phone 770-684-0102
www.headwaters.com

Filename :2749TS
Sample Name :"White Tank"
Material :Clay @ 1200 NTU
Source :Samual Ginn C of E
Lot Number :2749
Test or Assay. Number :
Sample Preparation :

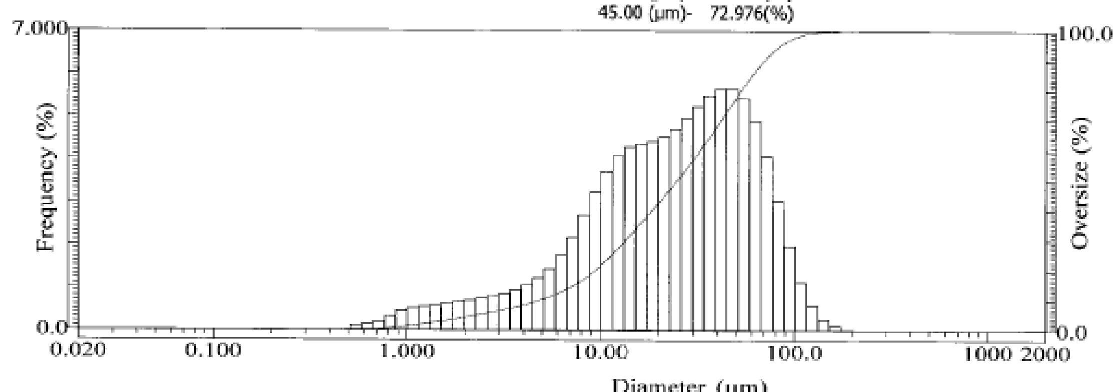
Circulation Speed :3
Ultra sonic :OFF
Laser T% : 90.6(%)
Lamp T% : 96.7(%)
Calc. Level :30
R.R.Index :150a040I
Variance : 714.27(μm²)
S.D. : 26.7259(μm)
CV : 82.7527
Geo. Mean : 20.9388(μm)
Chi-2 : 0.105749

Form of Distribution :Standard
Distribution Base :Volume

Sampling Times :10

S.P. Area : 6011.7(cm² /cm³)
Median : 24.9234(μm)
Mean : 32.2961(μm)
Mode : 47.9620(μm)
Span : 2.6173

:850.0 (μm)- 100.000(%)
300.0 (μm)- 100.000(%)
150.0 (μm)- 99.866(%)
75.00 (μm)- 92.007(%)
45.00 (μm)- 72.976(%)



No.	Diameter		Under %	No.	Diameter		Under %
1	0.022	0.000	0.000	23	0.445	0.000	0.000
2	0.026	0.000	0.000	24	0.510	0.000	0.000
3	0.029	0.000	0.000	25	0.584	0.111	0.111
4	0.034	0.000	0.000	26	0.669	0.147	0.258
5	0.039	0.000	0.000	27	0.766	0.198	0.456
6	0.044	0.000	0.000	28	0.877	0.314	0.770
7	0.051	0.000	0.000	29	1.005	0.443	1.213
8	0.058	0.000	0.000	30	1.151	0.514	1.727
9	0.067	0.000	0.000	31	1.318	0.546	2.273
10	0.076	0.000	0.000	32	1.510	0.583	2.856
11	0.087	0.000	0.000	33	1.729	0.625	3.481
12	0.100	0.000	0.000	34	1.981	0.658	4.139
13	0.115	0.000	0.000	35	2.269	0.696	4.835
14	0.131	0.000	0.000	36	2.599	0.740	5.575
15	0.150	0.000	0.000	37	2.976	0.788	6.363
16	0.172	0.000	0.000	38	3.409	0.843	7.206
17	0.197	0.000	0.000	39	3.905	0.931	8.137
18	0.226	0.000	0.000	40	4.472	1.047	9.183
19	0.259	0.000	0.000	41	5.122	1.210	10.393
20	0.296	0.000	0.000	42	5.867	1.431	11.824
21	0.339	0.000	0.000	43	6.720	1.739	13.563
22	0.389	0.000	0.000	44	7.697	2.158	15.721

No.	Diameter		Under %	No.	Diameter		Under %
45	8.816	2.667	18.388	67	174.616	0.103	100.000
46	10.097	3.207	21.595	68	200.000	0.000	100.000
47	11.565	3.705	25.299	69	229.075	0.000	100.000
48	13.246	4.071	29.370	70	262.376	0.000	100.000
49	15.172	4.272	33.642	71	300.518	0.000	100.000
50	17.377	4.356	37.998	72	344.206	0.000	100.000
51	19.904	4.409	42.406	73	394.244	0.000	100.000
52	22.797	4.510	46.916	74	451.556	0.000	100.000
53	26.111	4.694	51.610	75	517.200	0.000	100.000
54	29.907	4.949	56.559	76	592.387	0.000	100.000
55	34.255	5.233	61.792	77	678.504	0.000	100.000
56	39.234	5.484	67.276	78	777.141	0.000	100.000
57	44.938	5.643	72.919	79	890.116	0.000	100.000
58	51.471	5.644	78.563	80	1019.515	0.000	100.000
59	58.953	5.415	83.977	81	1167.725	0.000	100.000
60	67.523	4.889	88.867	82	1337.481	0.000	100.000
61	77.339	4.059	92.925	83	1531.914	0.000	100.000
62	88.583	3.023	95.948	84	1754.613	0.000	100.000
63	101.460	1.977	97.925	85	2000.000	0.000	100.000
64	116.210	1.124	99.049				
65	133.103	0.589	99.638				
66	152.453	0.258	99.897				

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HEADWATERS RESOURCES

Materials Testing & Research Facility
2650 Hwy 113 SW
Taylorsville, Ga. 30178
Phone 770-684-0102
www.headwaters.com

Filename :2750TS
Sample Name :"Control"
Material :Clay @ 800 NTU
Source :Samual Ginn C of E
Lot Number :2750
Test or Assay. Number :
Sample Preparation :

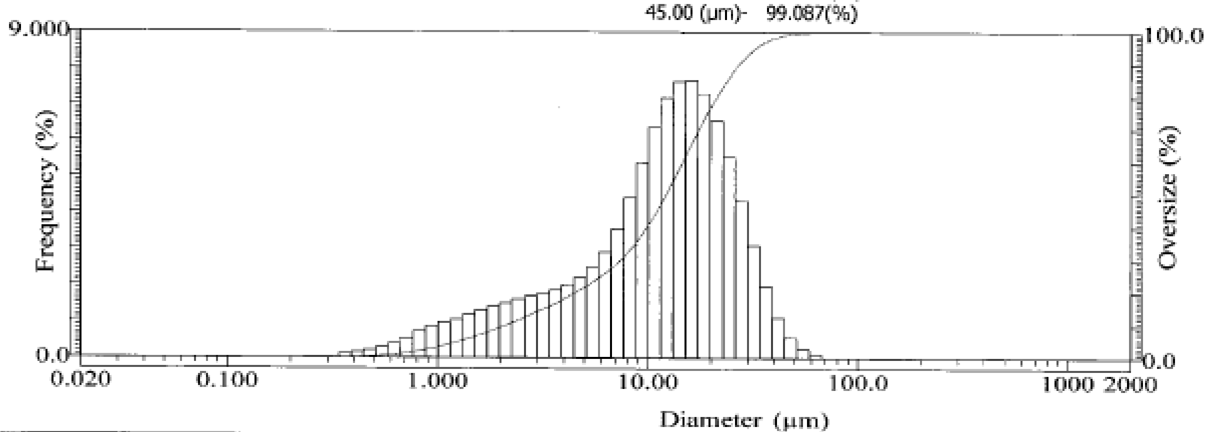
Circulation Speed :3
Ultra sonic :OFF
Laser T% : 95.5(%)
Lamp T% : 97.1(%)
Calc. Level :30
R.R.Index :150a040I
Variance : 99.744(μm²)
S.D. : 9.9872(μm)
CV : 72.2184
Geo. Mean : 9.7212(μm)
Chi-2 : 0.035431

Form of Distribution :Standard
Distribution Base :Volume

Sampling Times :10

S.P. Area : 11345(cm² /cm³)
Median : 12.2833(μm)
Mean : 13.8292(μm)
Mode : 16.1857(μm)
Span : 2.0481

:850.0 (μm)- 100.000(%)
300.0 (μm)- 100.000(%)
150.0 (μm)- 100.000(%)
75.00 (μm)- 100.000(%)
45.00 (μm)- 99.087(%)



No.	Diameter		Under %	No.	Diameter		Under %	No.	Diameter		Under %	No.	Diameter		Under %
1	0.022	0.000	0.000	23	0.445	0.154	0.263	45	8.816	4.406	35.107	67	174.616	0.000	100.000
2	0.026	0.000	0.000	24	0.510	0.212	0.475	46	10.097	5.364	40.471	68	200.000	0.000	100.000
3	0.029	0.000	0.000	25	0.584	0.286	0.761	47	11.565	6.349	46.819	69	229.075	0.000	100.000
4	0.034	0.000	0.000	26	0.669	0.389	1.150	48	13.246	7.163	53.983	70	262.376	0.000	100.000
5	0.039	0.000	0.000	27	0.766	0.532	1.682	49	15.172	7.627	61.610	71	300.518	0.000	100.000
6	0.044	0.000	0.000	28	0.877	0.719	2.401	50	17.377	7.655	69.266	72	344.206	0.000	100.000
7	0.051	0.000	0.000	29	1.005	0.875	3.276	51	19.904	7.269	76.535	73	394.244	0.000	100.000
8	0.058	0.000	0.000	30	1.151	0.966	4.242	52	22.797	6.536	83.070	74	451.556	0.000	100.000
9	0.067	0.000	0.000	31	1.318	1.052	5.293	53	26.111	5.526	88.597	75	517.200	0.000	100.000
10	0.076	0.000	0.000	32	1.510	1.179	6.472	54	29.907	4.328	92.924	76	592.387	0.000	100.000
11	0.087	0.000	0.000	33	1.729	1.312	7.784	55	34.255	3.081	96.005	77	678.504	0.000	100.000
12	0.100	0.000	0.000	34	1.981	1.416	9.200	56	39.234	1.964	97.969	78	777.141	0.000	100.000
13	0.115	0.000	0.000	35	2.269	1.506	10.706	57	44.938	1.112	99.081	79	890.116	0.000	100.000
14	0.131	0.000	0.000	36	2.599	1.606	12.312	58	51.471	0.560	99.641	80	1019.515	0.000	100.000
15	0.150	0.000	0.000	37	2.976	1.690	14.001	59	58.953	0.253	99.894	81	1167.725	0.000	100.000
16	0.172	0.000	0.000	38	3.409	1.756	15.757	60	67.523	0.106	100.000	82	1337.481	0.000	100.000
17	0.197	0.000	0.000	39	3.905	1.848	17.606	61	77.339	0.000	100.000	83	1531.914	0.000	100.000
18	0.226	0.000	0.000	40	4.472	1.986	19.591	62	88.583	0.000	100.000	84	1754.613	0.000	100.000
19	0.259	0.000	0.000	41	5.122	2.187	21.778	63	101.460	0.000	100.000	85	2000.000	0.000	100.000
20	0.296	0.000	0.000	42	5.867	2.476	24.254	64	116.210	0.000	100.000				
21	0.339	0.000	0.000	43	6.720	2.908	27.162	65	133.103	0.000	100.000				
22	0.389	0.109	0.109	44	7.697	3.538	30.700	66	152.453	0.000	100.000				

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Phone 770-684-0102
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Filename :2751TS
Sample Name :"Lamella"
Material :Clay @ 80-100 NTU
Source :Samual Ginn C of E
Lot Number :2751
Test or Assay. Number :
Sample Preparation :

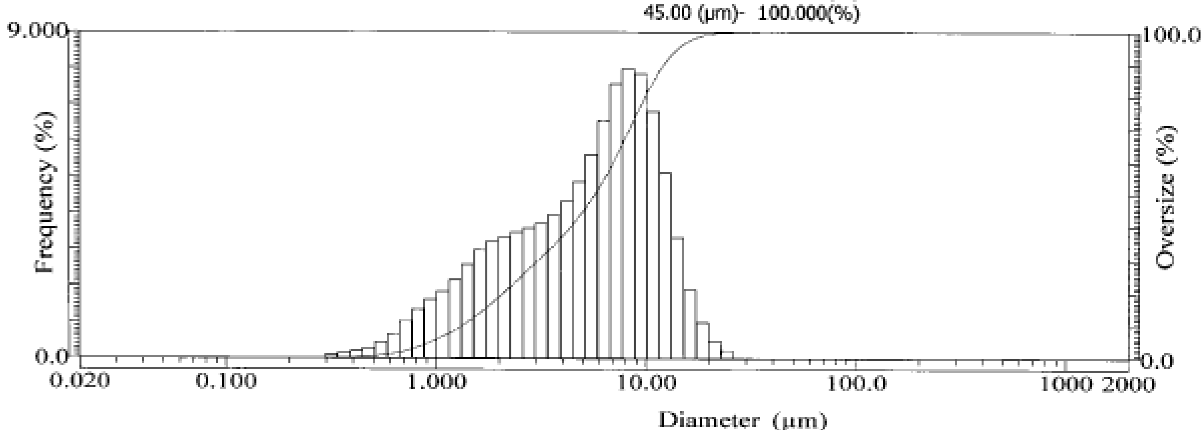
Form of Distribution :Standard
Distribution Base :Volume

Sampling Times :10

S.P. Area : 19358(cm^2 /cm^3)
Median : 5.6889(μm)
Mean : 6.3027(μm)
Mode : 8.2557(μm)
Span : 1.9108

Circulation Speed :3
Ultra sonic :OFF
Laser T% : 94.1(%)
Lamp T% : 98.1(%)
Calc. Level :30
R.R.Index :150a040I
Variance : 18.915(μm^2)
S.D. : 4.3492(μm)
CV : 69.0045
Geo. Mean : 4.6777(μm)
Chi-2 : 0.027754

:850.0 (μm)- 100.000(%)
300.0 (μm)- 100.000(%)
150.0 (μm)- 100.000(%)
75.00 (μm)- 100.000(%)
45.00 (μm)- 100.000(%)



No.	Diameter		Under %	No.	Diameter		Under %	No.	Diameter		Under %	No.	Diameter		Under %
1	0.022	0.000	0.000	23	0.445	0.200	0.442	45	8.816	7.980	73.363	67	174.616	0.000	100.000
2	0.026	0.000	0.000	24	0.510	0.294	0.736	46	10.097	7.835	81.197	68	200.000	0.000	100.000
3	0.029	0.000	0.000	25	0.584	0.444	1.180	47	11.565	6.793	87.990	69	229.075	0.000	100.000
4	0.034	0.000	0.000	26	0.669	0.667	1.847	48	13.246	5.098	93.089	70	262.376	0.000	100.000
5	0.039	0.000	0.000	27	0.766	1.013	2.860	49	15.172	3.313	96.402	71	300.518	0.000	100.000
6	0.044	0.000	0.000	28	0.877	1.353	4.213	50	17.377	1.901	98.303	72	344.206	0.000	100.000
7	0.051	0.000	0.000	29	1.005	1.621	5.834	51	19.904	0.991	99.294	73	394.244	0.000	100.000
8	0.058	0.000	0.000	30	1.151	1.846	7.681	52	22.797	0.483	99.777	74	451.556	0.000	100.000
9	0.067	0.000	0.000	31	1.318	2.147	9.828	53	26.111	0.223	100.000	75	517.200	0.000	100.000
10	0.076	0.000	0.000	32	1.510	2.569	12.397	54	29.907	0.000	100.000	76	592.387	0.000	100.000
11	0.087	0.000	0.000	33	1.729	2.963	15.361	55	34.255	0.000	100.000	77	678.504	0.000	100.000
12	0.100	0.000	0.000	34	1.981	3.203	18.564	56	39.234	0.000	100.000	78	777.141	0.000	100.000
13	0.115	0.000	0.000	35	2.269	3.321	21.885	57	44.938	0.000	100.000	79	890.116	0.000	100.000
14	0.131	0.000	0.000	36	2.599	3.444	25.329	58	51.471	0.000	100.000	80	1019.515	0.000	100.000
15	0.150	0.000	0.000	37	2.976	3.566	28.895	59	58.953	0.000	100.000	81	1167.725	0.000	100.000
16	0.172	0.000	0.000	38	3.409	3.699	32.593	60	67.523	0.000	100.000	82	1337.481	0.000	100.000
17	0.197	0.000	0.000	39	3.905	3.926	36.520	61	77.339	0.000	100.000	83	1531.914	0.000	100.000
18	0.226	0.000	0.000	40	4.472	4.302	40.822	62	88.583	0.000	100.000	84	1754.613	0.000	100.000
19	0.259	0.000	0.000	41	5.122	4.851	45.673	63	101.460	0.000	100.000	85	2000.000	0.000	100.000
20	0.296	0.000	0.000	42	5.867	5.597	51.270	64	116.210	0.000	100.000				
21	0.339	0.101	0.101	43	6.720	6.542	57.813	65	133.103	0.000	100.000				
22	0.389	0.140	0.242	44	7.697	7.570	65.383	66	152.453	0.000	100.000				

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