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Laboratory Evaluation of Methods to Separate Fine Grained Sediment from Stormwater

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July 1979

LABORATORY EVALUATION OF METHODS TO SEPARATE FINE GRAINED SEDIMENT FROM STORMWATER

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The deleterious effects of construction site stormwater runoff upon the nation's waterways have become of increasing concern in recent times. This report presents the results of a laboratory testing program of an inclined tube settler and Discostrainer for the removal of erosion sediment.

Francis T. Mayo
Director
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ABSTRACT

A literature survey had been conducted by the St. Anthony Falls Hydraulic Laboratory to assess various methods for separation of sediment from stormwater at construction sites. Two methods have shown some promise in this application, and a research program was initiated with the objective of evaluating the effectiveness of the methods in removing fine grained inorganic solids from water.

Experimental facilities were set up to test full-scale units of an inclined tube settler and a Discostrainer in an environment approximating that in the field. These units were tested for removal efficiencies of inorganic solids with sizes less than 100μ and influent concentrations of about 2000 mg/l. Measurements were made of the influent and effluent concentrations for various flow rates through the systems.

Results indicated that the installation of an inclined tube settler improved the efficiency of a sedimentation tank by about 20 percent at the highest overflow rate tested of about 200 lpm/m^2 ($5 gpm/ft^2$) for an average removal efficiency of about 60 percent. The inclined tube settler also reduced the sensivity of the overflow rate on the efficiency of sediment removal. Limited tests with alum added to the influent to increase flocculation indicated about a 6 percent improvement in removal efficiency.

The Discostrainer was found to be extremely sensitive to influent solids concentration. Thirty percent solids removal was the maximum attained for the tests conducted. Higher removal percentages may possibly be obtained by reducing the flow rate or influent concentration.

This report was submitted in fulfillment of Grant No. R803579 by the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from October 1, 1976 to July 1, 1978, and work was completed as of December 15, 1978.

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SECTION 1

INTRODUCTION

An increase in urban construction, such as shopping centers and large housing developments, has led to a stripping of vegatative cover and increased exposure of the underlying soil to erosion. Following a heavy or even moderate rainfall, the soil is eroded and the sediment laden runoff eventually finds its way to a natural stream or lake. This type of pollution is becoming of considerable concern, and efforts are being made to reduce its impact. Two alternatives appear to be possible; reduce the amount of erosion occuring by limited or localized stripping of the vegatative cover and providing protection for the exposed soil, or collect and subsequently process the runoff to substantially remove the sediment before discharge to the natural bodies of water. The St. Anthony Falls Hydraulic Laboratory has been engaged in a study to investigate various methods by which sediment can be removed from runoff.

The first part of the study consisted of a literature survey to determine the applicability of available solid separation devices or methods to this particular problem. The results have been previously reported (1). Of particular interest were devices or methods that were inexpensive, consumed little or no energy for operation, could be left unattended for long periods of time, required little maintenance, could be readily moved from one site to another, and had the capability of removing high percentages of inorganic particles in sizes of less than 100μ. On the basis of the above requirements, two devices were selected for further investigation. A commercially available unit was an inclined tube settler manufactured by Neptune Microfloc, Inc. which has been used in some sewage treatment plants for effluent clarification. Another commercially available device having success in a somewhat parallel application (combined sewer overflow and sanitary sewage treatment) was a disc strainer, and a small prototype unit was provided by the manufacturer, HYCOR Corporation, for evaluation.

The following report describes the results of the tests with the above mentioned units.

SECTION 2

CONCLUSIONS

Two commercially available solid separation devices have been tested in the laboratory to evaluate their capability of removing inorganic solids with sizes less than 100 μ from water. Results of these tests indicated that if an inclined tube settler were installed in a sedimentation basin, it would reduce the sensitivity of the efficiency of solid removal to overflow rate. The tube settler increased the performance of the basin by about 20 percent at the highest overflow rate tested for a total combined removal efficiency of 60 percent. Addition of alum to the influent increased the solids removal by about 6 percent, primarily due to the increase in flocculation.

Tests with a small Discostrainer equipped with screens of 45 μ openings indicated that the unit was extremely sensitive to the solids concentration of the influent. Thirty percent removal of solids was attained at influent concentrations of 1300 mg/1 and decreased to less than 10 percent at concentrations of 2100 mg/1. The limited tests have shown that the efficiency may possibly be improved by decreasing the flow rate through the unit or by decreasing the influent solids concentration.

It was found that the solid particles of interest were extremely difficult to separate from water utilizing physical unit processes. The results with the two devices tested were somewhat discouraging, and their use at a construction site to remove solid particles in the clay and colloidal size range which generally constitute substantial portions of the sediment fraction found in construction site runoff may not be economically justifiable.

A conceptual design was made of a debris basin fitted with inclined tube settlers for a small hypothetical construction site of about 10 hectares (25 acres). For a rainfall of about 1.3 cm/hr (0.5 in./hr), the estimated minimum cost to process the storm runoff from the site and remove up to 60 percent of the solids was about $5/lpm ($18/gpm) or $5000/hectare ($2000/acre).

SECTION 3

RECOMMENDATIONS

The inclined tube settler has shown some capability for removing fine, inorganic solids from water. As its use does reduce the size of the required sedimentation basin, the tube settler may be considered for application to construction sites where large basins are not feasible. The soil conditions of a particular construction site should be carefully examined, and if large percentages of clay and colloidal sized particles are not present, the units may have some benefits. The desired quality of the effluent must also be considered.

Although the performance of the Discostrainer was marginal in the limited tests conducted with a slurry of extremely fine, inorganic solids, further investigations should be carried out. The trend of the test data indicated that an improvement in solids removal efficiency may be possible at low inflow rates with high solids concentration, or high flow rates with low solids concentration. Additional tests should be initiated to verify this possibility. Also, it is suggested that tests be conducted in an attempt to optimize performance with organic or fibrous additives in the slurry, and to examine other screen configurations.

Section 4

THE TEST MATERIAL

SOIL SELECTION

The first objective of this study was to locate sediment material which could be used to evaluate sediment removal techniques. As erodible materials at a construction site may vary over a wide size range, it was decided to conduct the tests using extremely small particles which are known to be the most difficult to remove from water. The following criteria for the test material were established:

1. It should be typical of a wide range of possible applications and locations.

2. It should have a size distribution which covers the range of silt and clay sizes, ie, 1.0 to 100 μ.

3. It should be primarily inorganic.

4. It should be readily available in quantities large enough to test prototype scale devices.

5. The properties should be sufficiently well known so that the various removal techniques can be properly analyzed. The properties must be constant so test results are reproducible.

6. The material should be ready-to-use to avoid costly material preparation procedures.

After an extensive search and with the cooperation of soil authorities in the region, a local material was found which had most of the desirable characteristics. Consideration initially was given to using several standard materials having a wide range of physical and electrochemical properties, one of which would be typical of the sediment materials at any given construction site. However, the magnitude of effort required to establish and prepare these standard materials was considered far beyond the scope of this study. In addition, because of the wide variation in properties of different soil types and the strong influence of water quality on the characteristics of sediment suspensions, it was felt that no standard material used in a laboratory environment could simulate field conditions sufficiently well to reliably permit transferring the data to any specific construction site. The material chosen for this study was readily available locally, had the desirable particle size characteristics, and was usable without any special processing. A size distribution analysis of the selected material is shown in Figure 1.

SLURRY PREPARATION

In order to determine the effect of dilution water on the stability of the sediment suspensions, six hydrometer size-distribution analyses were carried out on the selected sediment material using untreated distilled water, city water, and river water. Upon comparison of the results of these experiments with the original size distribution, it was found that the fine sediment particles had a very definite tendency to flocculate and settle rapidly out of solution. Thus, the size distribution of the sediment in the settling tank could not be predicted. The distribution would depend on the amount of mixing, water temperature, dilution water quality, and other parameters, many of which could not be controlled. A series of experiments were carried out to determine whether a reasonably small dosage of some chemical could be added to the dilution water which would prevent this unpredictable flocculation from occurring in the settling tank. An attempt was made to stabilize the suspension by raising the pH by adding sodium hydroxide; there was a partial stabilization but the results were not satisfactory. It was known that sodium hexametaphosphate added to the suspension would keep the particles dispersed if added in sufficient quantities. A series of tests were run to find the minimum dosage of sodium hexametaphosphate which would be required to insure complete dispersion of the particles. The test results indicated that, in order to be confident that no flocculation was occurring, it would be necessary to add several hundred pounds for each run. This was not practical because of the cost and also such high concentrations of chemicals added to the water may alter the physical properties of the diluted water. In order to insure that the sediment initially was completely and uniformly dispersed, sodium hexametaphosphate buffered with sodium carbonate was used as a dispersing agent in the concentrated slurry tank. When the concentrated slurry was diluted to the test conditions with river water, the effect of the dispersing agent was eliminated and the material flocculated as before. Therefore, the size distribution in the settling tank was not predictable.

As a result of the above preliminary investigations, the following standard procedure was adopted for the preparation of the sediment slurry:

1. The soil was tested for moisture content and a quantity of soil required to achieve the desired sediment concentration was added to a slurry tank.

2. The dispersing agent, sodium hexametaphosphate buffered with sodium carbonate, was added and city water was introduced to provide the desired concentration of 100 g/1.

3. The slurry mixture was mixed briefly and allowed to stand approximately 12 hours.

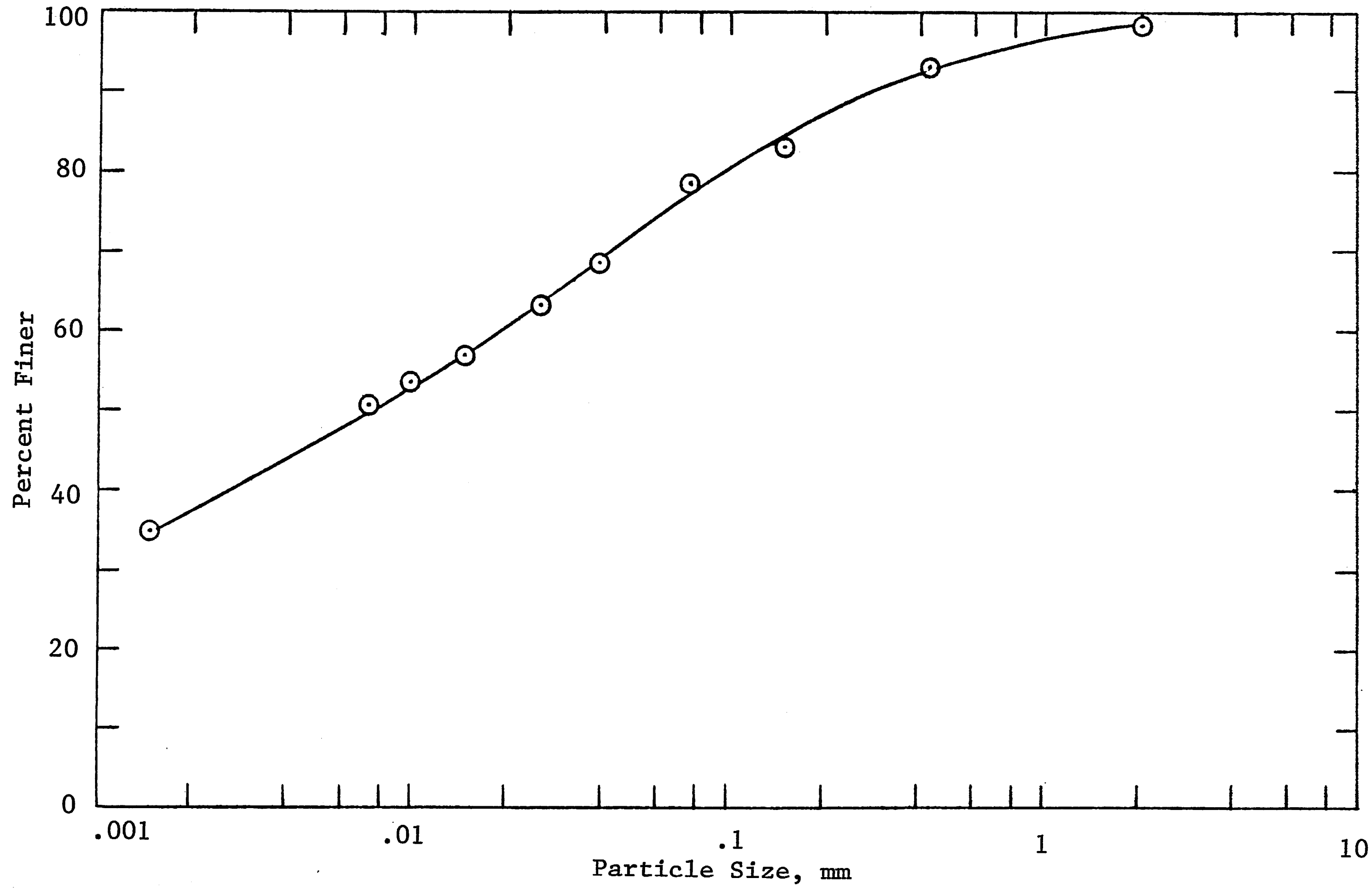


Figure 1. Size Distribution of Test Sediment.

4. The slurry was then mixed thoroughly for two hours before the test began.

5. The concentrated 100 g/l slurry was injected into the river water influent line to achieve the desired influent concentration by turbulent mixing. Contact time before entering the settling tank was less than 10 secs.

This procedure yielded a sediment suspension which began to flocculate slowly at an unknown rate as soon as the dilution began. Therefore, the settling properties of the particles in the influent were not known and the analysis of the test results were more difficult. However, it was found early in the test program that the moderate amount of flocculation that did occur did not seriously affect the test results because approximately 95 percent of the flocculated material still passed through the settling tank.

SECTION 5

THE INCLINED TUBE SETTLER

GENERAL CONSIDERATIONS

In a conventional settling basin, separation of solid particles from the water occurs naturally by gravity. The time required for such separation is dependent on the particle fall velocity and the distance that it must fall to reach the bottom. For very small particles with very low fall velocities, the settling time is extremely long. As an example, it requires about 230 days for clay particles of 0.1 μ diameter to settle 0.3m (1 ft) in water of 10°C (50°F). Several schemes have been employed to reduce the detention time, and generally involve a reduction in fall distance. Typical of these schemes involves the passage of flow through stacked plates. A more practical scheme has been to pass the flow through inclined tubes; the slope of the tube contributes to self cleaning of the settled material on the bottom of the tube. The inclined tube concept has been utilized in clarification of effluent from waste treatment plants with some success (2). It has been found that the tube settlers also permit a higher flow rate through the basin while maintaining good efficiency of particle removal.

Several commercial units of inclined tube settler are available. A typical module, as manufactured by Neptune Microfloc, Inc., is shown in Figure 2. This module is constructed of a lightweight plastic and consists of passageways 5 x 5 cm (2 x 2 in.) in cross section with a length of 61 cm (24 in.) inclined at an angle of 60° to the horizontal. In use, the module is submerged to a shallow depth below the water surface. The particle laden water enters the module from the bottom, passes upward through the tubes, and exits at the top. Average flow velocity through the tubes is very low, less than 3 mm/sec. (0.01 fps), and the larger particles settle to the tube invert, where they eventually drop out of the tube to the bottom of the settling tank. The deposited material may be periodically collected and removed.

For application to removing sediment from runoff of construction sites, it was envisioned that a number of tube modules would be installed at the downstream end of a settling basin. The larger solid particles would be settled in the basin itself, and a large percentage of the finer particles would be removed by the inclined tube modules. It should be noted that the tubes would still require a settling basin, although the surface area of the basin may be reduced to about 1/3 the area required without the tubes.

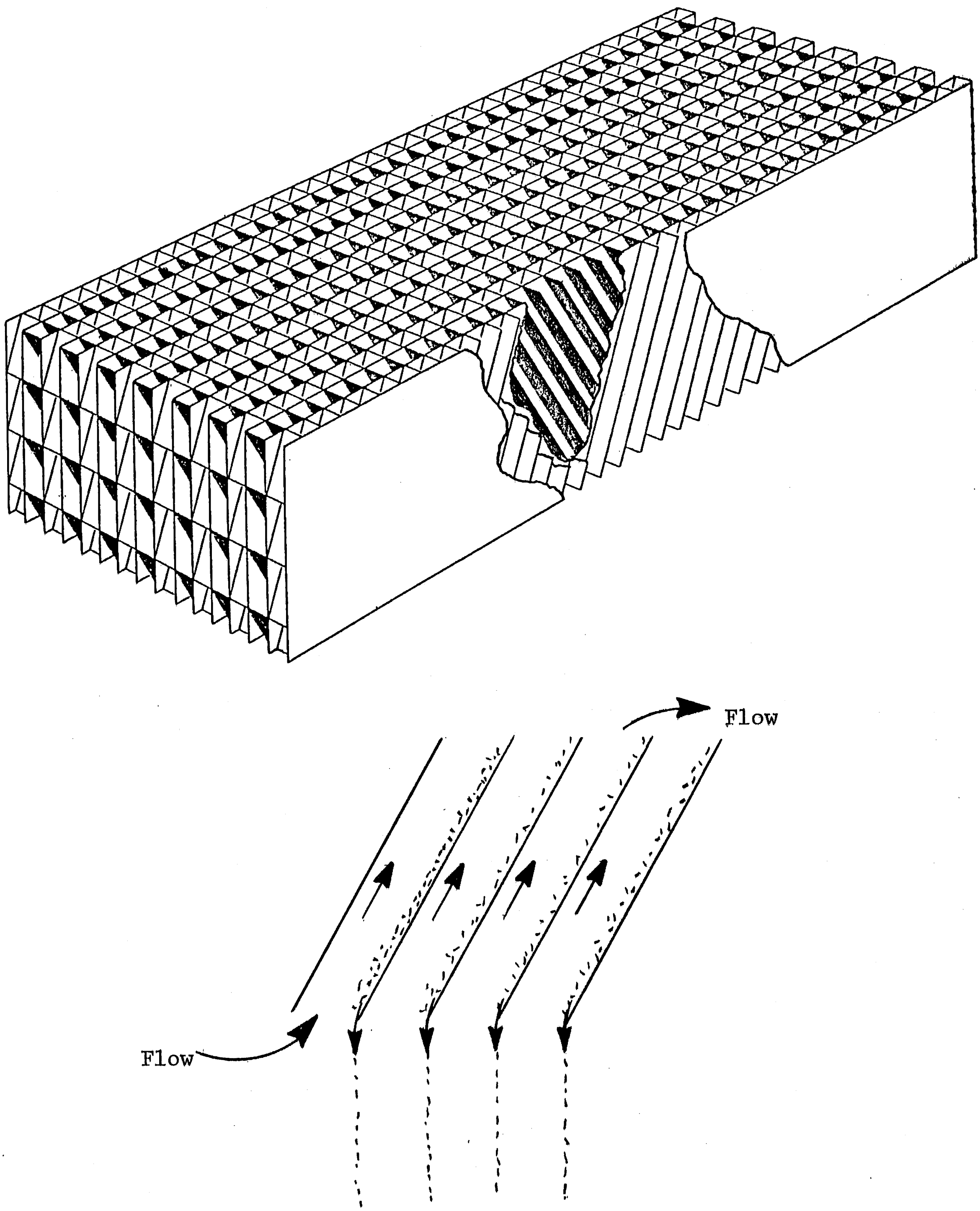


Figure 2. Typical Module for an Inclined-Tube High Rate Settler from (2).

The success of such a scheme is dependent on the capability of the tube settler in removing fine, inorganic solids. As previously noted, good performance has been observed in removing particles which may have been largely organic. Some carefully controlled laboratory tests have been made to evaluate the variables which influence the performance of a single inclined tube in removing turbidity in water (3). Attractive percentages of turbidity removal were reported. The problem addressed in the current study was the evaluation of a full-scale inclined tube settler module exposed to essentially inorganic solids of less than 100 μ in size in an environment similar to that expected in the field.

FACILITY AND PROCEDURES

The tube settler evaluation test facility is shown schematically in Figure 3. The sediment material was first measured and mixed in the slurry tank by the procedure outlined in Section 4 above. The slurry was mixed with a propeller mixer powered by a variable speed drive. The mixing speed was set at the maximum of about 60 rpm, which could be tolerated without spilling the slurry mixture in order to minimize the sorting of particle sizes in the tank. The concentrated slurry was pumped from the tank with a 100gpm centrifugal pump and discharged into the clear water line leading to the settling tank. The clear or dilution water was taken from a supply line fed by gravity from the Mississippi River. Both the water supply line and the slurry feed line had orifice meters and control valves installed to regulate the discharge and sediment concentration entering the sedimentation tank.

The settling tank was designed to be a simplified version of what might be used in the field. Construction details of the experimental set-up are shown in Figure 4. It was basically a rectangular tank 1.83 m (6 ft) deep, 0.76 m (2.5 ft) wide, and 6.1 (20 ft) long. One side of the tank consisted of a transparent glass wall to allow for visual observation of particulate settling characteristics. The mixed slurry and river dilution water influent entered an inlet chamber at one end of the tank. A slotted wall separated the inlet chamber from the rest of the tank to distribute and unify the flow. The tube settler selected for the study was manufactured by Neptune Microfloc, Inc. and was supported at the downstream end of the tank near the water surface. A divider wall was installed in the top half of the tank at the upstream end of the tube settler to prevent short-circuiting of the flow in the tank. The water level in the tank was controlled by an adjustable weir located at the downstream end.

The test system was set up and the flow calibrations were carried out. A set of operating curves were computed relating the slurry concentration, slurry flow rate, and clear water flow rate to the total influent flow rate and sediment concentration. The particle size and sediment concentration distribution in the slurry tank were checked to verify that there was no stratification.

The following standard test procedure was followed:

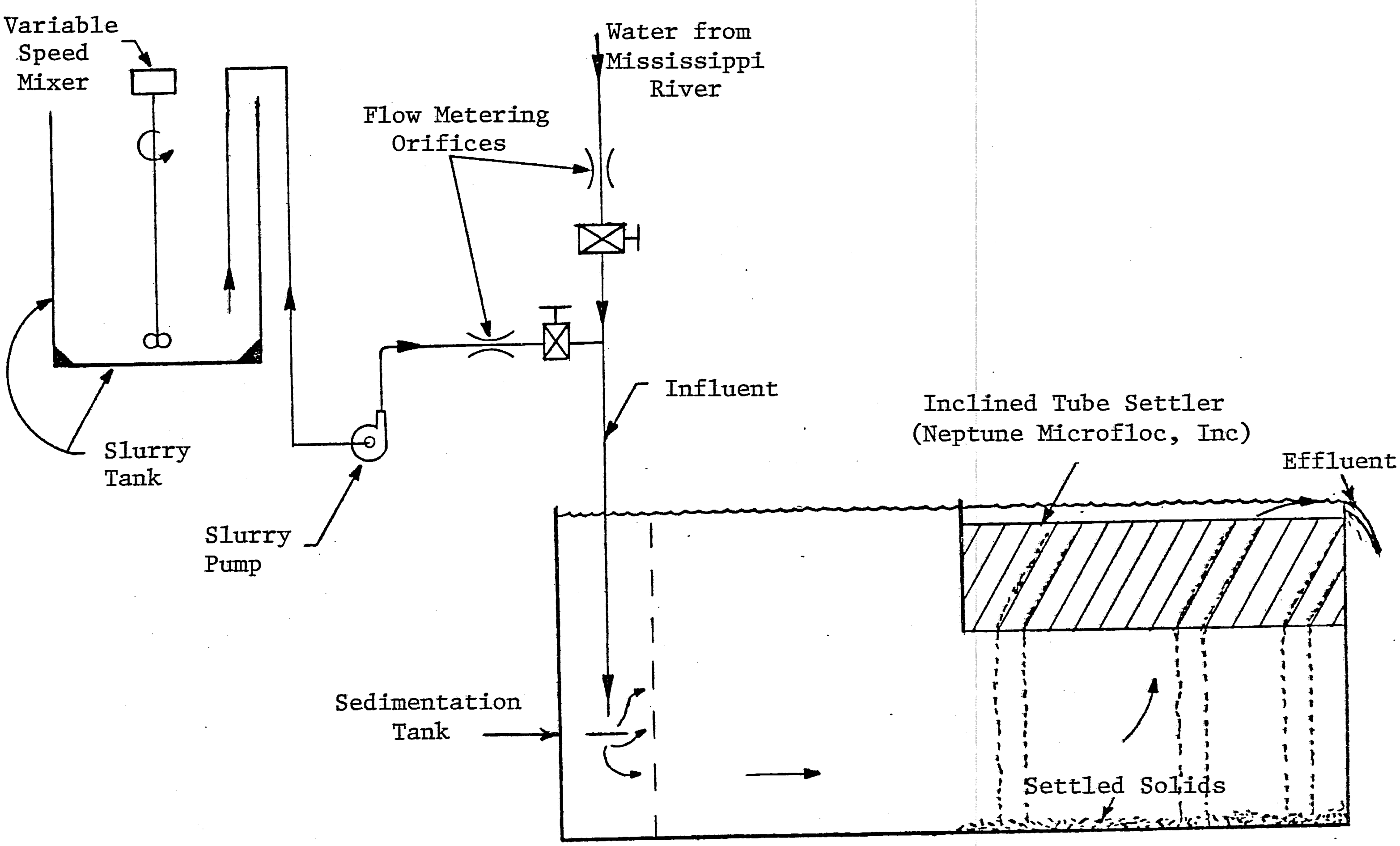


Figure 3. Facility Schematic for Inclined-Tube Settler Evaluation.

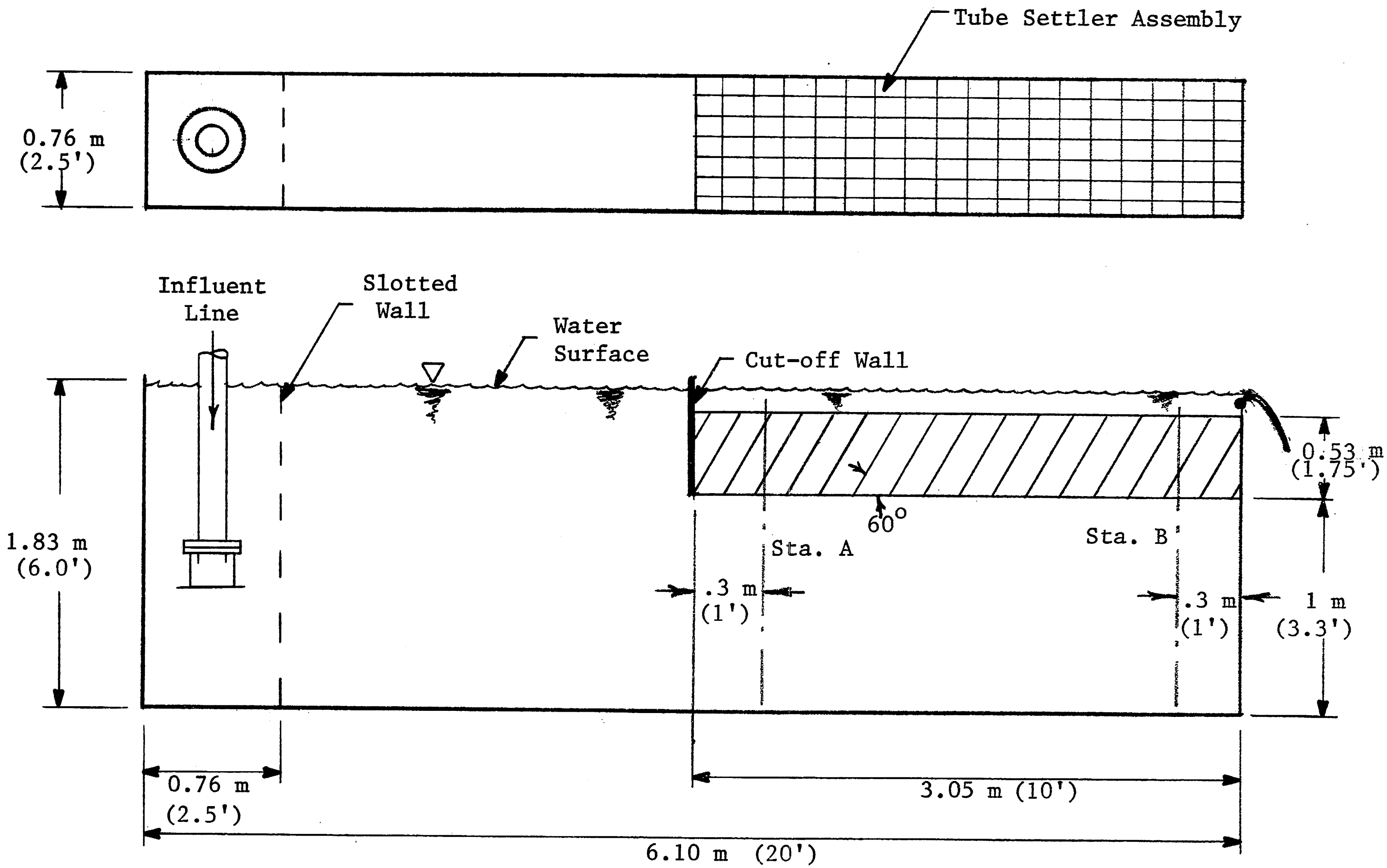


Figure 4. Sedimentation Tank Details.

1. Soil, water, and dispersing agent were added to the slurry tank, mixed briefly and allowed to stand overnight. The slurry tank was then mixed thoroughly for several hours before beginning the test.

2. The river water supply channel was flushed for a period of time to obtain uniform influent water temperatures.

3. Water and slurry flow rates were set at predetermined values using the operating curves to establish the desired influent concentration and overflow rate.

4. The settling tank was filled and allowed to stabilize at the set operating conditions for the particular test run to be accomplished.

5. Samples were taken of the slurry and effluent at 10 minute intervals during the run. The temperature in the settling tank was monitored continuously during each run.

In addition to the inflow and outflow data, the temperature and sediment concentration distributions in the settling tank were measured during two runs.

The samples taken during the tests were evaluated using the following procedure:

1. Slurry samples

   a. Determine total volume of the sample.

   b. Pour sample through a #325 sieve (44 μ openings) and measure the quantity retained on the sieve.

   c. Determine the concentration of material passing the #325 sieve by evaporating 20 ml of the sample and weighing the residue. (Corrections were made for the dissolved solids present in the water.)

   d. Determine suspended solids concentration from steps a through c.

2. Effluent and settling tank samples

   The same procedure was used except that there was no need for passing the sample through the #325 sieve.

Initially the turbidity of the effluent and settling tank samples was measured. However, the low removal effectiveness on suspended matter had little effect on the turbidity and the turbidity measurements were abandoned. The efficiency of removal was calculated as follows:

$$\% \text{ Removal} = 100 \left(\frac{C_{in} - C_{eff}}{C_{in}} \right)$$

where C_{in} and C_{eff} are the concentration by weight of the influent and effluent, respectively. The effluent concentration used was an average of all effluent concentration measurements made.

For each test the design concentration of the influent was 2000 mg/l. The actual concentration was determined by three alternate methods:

1. Samples were taken of the slurry at the beginning and end of the test to determine an average slurry concentration. The concentration was calculated based on this average slurry concentration and the known flow rates of slurry dilution water.

2. An average concentration of material passing the #325 sieve in the slurry was determined from the two slurry samples. Calculations of influent concentration were than based on this concentration.

3. All the material added to the slurry tank was assumed to be in suspension thus producing a slurry of known concentration. The influent concentration was then calculated based on this concentration.

Of the three methods above, the first was found to give the most consistent results. All of the subsequent analysis and discussion will refer to removal efficiencies determined using the slurry concentration as determined in alternate one.

The first tests were conducted without the tube settler in place to determine the performance of the settling tank. The tube settler bundle was installed and the tests were repeated to check the effect of the tube settler. The last two runs were made with and without the tube settler in place and with the addition of alum to the slurry tank to evaluate the effect of coagulants on the removal efficiency. No dispersing agents were added to the slurry tank during the test with the coagulant. Comparisons were also made of the distribution of sediment concentration in the settling tank with and without the coagulant added.

EXPERIMENTAL RESULTS

The results of the tests with the inclined tube settler are summarized in Table 1. The overflow rate has been calculated based on the total discharge through the system divided by the top surface area of the settler tubes. As previously noted, the target influent concentration was 2000 mg/l for all tests, and the values listed in the Table were the actual measured values. Examination of the removal efficiencies attained indicates considerable

TABLE 1. SUMMARY OF TEST RESULTS INCLINED TUBE SETTLER

Run No.	Overflow Rate lpm/m^2	(gpm/ft^2)	Water Temp. ^oC	(^oF)	Influent Conc., mg/l	Effluent Conc., mg/l	Percent Removal
2	81.4	(2)	4	(39)	2040	603	70.4
3	81.4	(2)	3	(38)	1944	830	57.3
4	81.4	(2)	3	(38)	2068	655	68.3
5	81.4	(2)	-	-	1862	723	61.2
6	122.1	(3)	2	(35)	1728	581	66.4
7	122.1	(3)	4	(40)	1891	803	57.5
8	122.1	(3)	8	(47)	1791	932	48.0
9	162.8	(4)	5	(41)	1880	947	49.6
10	162.8	(4)	3	(38)	1685	798	52.6
11	203.5	(5)	3	(38)	1754	1031	41.2
12	40.7	(1)	4	(40)	1566	946	39.6
13	40.7	(1)	4	(40)	2549	1141	55.2
14	81.4	(2)	7	(45)	1982	924	53.4
15(T)	81.4	(2)	6	(43)	1808	825	54.4
16(T)	81.4	(2)	6	(43)	1580	734	53.5
17(T)	122.1	(3)	8	(47)	2002	827	58.7
18(T)	122.1	(3)	15	(59)	2214	746	66.3
19(T)	40.7	(1)	16	(61)	2230	811	63.6
20(T)	40.7	(1)	16	(61)	2722	822	69.8
21(T)	162.8	(4)	18	(64)	2068	965	53.3
22(T)	162.8	(4)	17	(63)	1921	835	56.5
23(T)	203.5	(5)	16	(61)	-	792	-
24(T)	203.5	(5)	17	(63)	1930	786	59.3
26(T) Alum*	81.4	(2)	18	(65)	1892	557	70.6
27 Alum*	81.4	(2)	18	(65)	2017	731	63.8

Note: (T) indicates inclined tube settler installed
* Concentration 500 mg/l

scatter in the data, which may be expected in tests of an installation of this type. To show trends more clearly, the data have been plotted in Figure 5 using an average value of the removal efficiency for a given overflow rate. The extreme ranges of data have also been shown for each point.

Several trends are to be noted. Without the tubes installed, approximately 50 percent of the solids have been settled in the tank. The decrease in removal efficiency at the lowest overflow rate was probably caused by "short circuiting" within the settling tank; this phenomenon was reduced considerably by the addition of the settler. The efficiency also drops off with increasing overflow rate. After the tubes were installed, the removal efficiency was slightly higher in general, and efficiency was less dependent on the overflow rate. At the highest overflow rate, the removal was increased by nearly 20 percent by the presence of the inclined tubes. The addition of 500 mg/l of alum to the influent with a 15 minute detention time increased the efficiency of removal by about 6 percent, both with and without the tube settler.

By referring to the sediment size distribution in Figure 1 (p. 6) it can be seen that the removal efficiencies of 60 to 70 percent achieved with the tube settler imply that fines with sizes into the clay range were removed both with and without the addition of coagulants. This indicates that a considerable amount of natural flocculation was occurring in the influent as discussed in Section 4.

The effect of the tube settler on the vertical distribution of sediment concentration at the longitudinal centerline of the settling tank is shown graphically in Figure 6. Locations of the two measurement stations are shown in Figure 4. The sediment concentration is plotted versus distance from the water surface for runs made with alum added to the slurry tank and with and without the tube settler in place. It can be seen that the use of the tube settler increases the sediment concentration in the settling tank while decreasing the concentration in the influent. The effect of the higher removal rate within the tube settler can be clearly seen.

The temperature in the settling tank was carefully surveyed with a thermistor temperature probe to determine whether there was any thermal stratification in the settling tank which could significantly influence particulate settling characteristics. However, the temperature was constant throughout the tank and no stratification was observed.

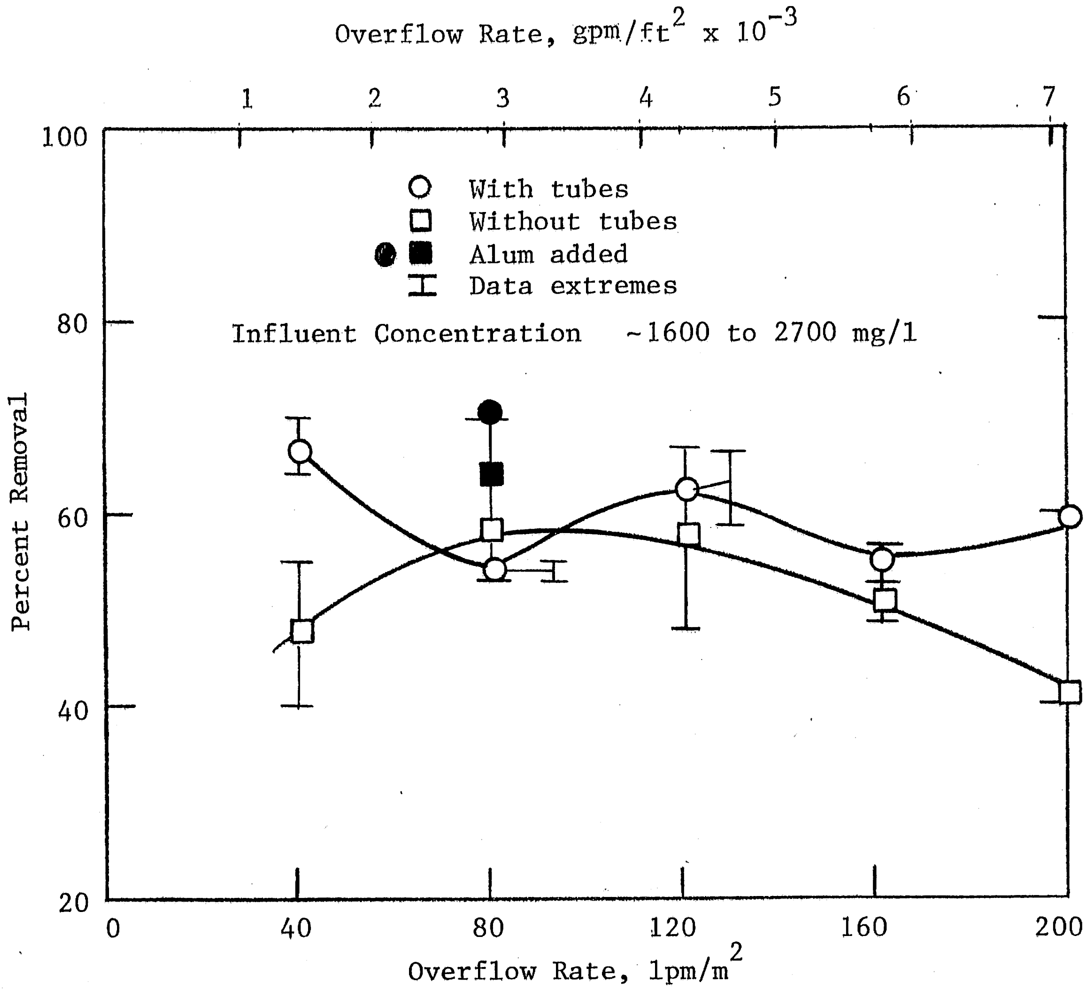


Figure 5. Solids Removal as a Function of Overflow Rate, Inclined-Tube Settler.

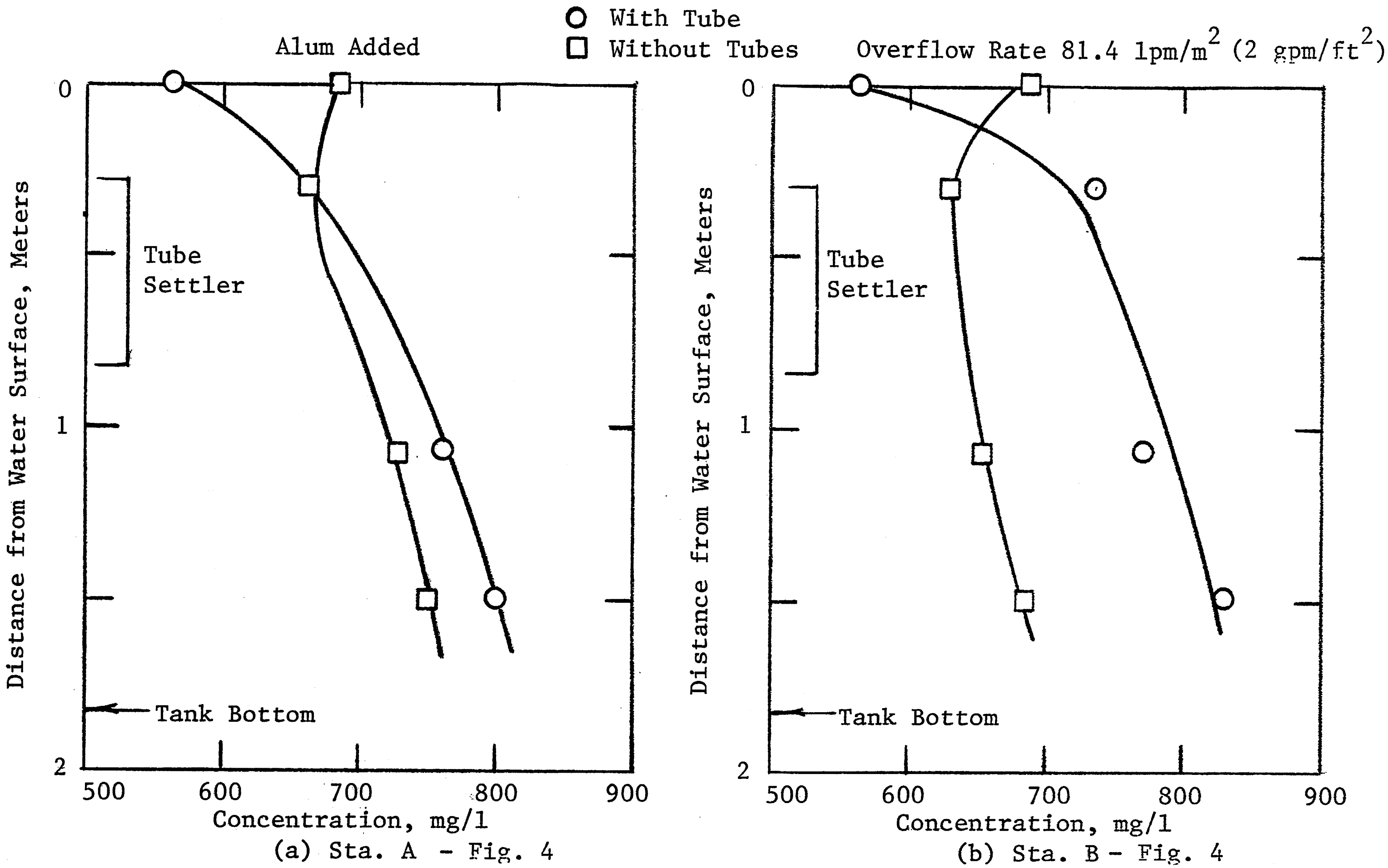


Figure 6. Variation of Concentration with Depth in Sedimentation Tank, Influent Concentration 1900 mg/l.

SECTION 6

THE DISCOSTRAINER

GENERAL CONSIDERATIONS

The Discostrainer had been observed to perform very well in the treatment of combined sewer overflow and sanitary flows, especially where there was a high percentage of fibrous material present in the waste stream. Based on these observations it was felt that the Discostrainer might have potential for the treatment of construction site runoff. A test unit was obtained from the manufacturer (HYCOR Corporation) and a series of tests were run using the same material as discussed in Section 4.

The Discostrainer is a disc straining device which, because of its design, is able to separate solids by a combination of straining, sedimentation, and filtration. The general construction and operating details of the Discostrainer (4) are shown in Figure 7. The device consists of a series of stainless steel mesh-covered discs in a specially designed chamber. Each pair of discs forms a separation unit. The influent is routed into the cavity between pairs of discs and flows outward through the wire mesh leaving the captured solids behind. These trapped solids form a precoat material which may aid the filtration effect. A spray system is used to flush the trapped solids from the mesh back into the cavity between the discs. The spray system can utilize the filtered water with a built-in recirculating pump or an external water supply may be used. As the solids concentration between the discs increases, the slurry in the downstream end of the cavity becomes sufficiently thick so that the solids can be swept up by the rotating discs and out through the solids discharge opening, or adjustable weir window.

The Discostrainer is a compact and uncomplicated device which is capable of handling a fairly wide range of discharges and influent solids concentrations. It does not require a full-time operator and the power and head requirements are quite low. It was felt that if the performance with inorganic solids could be shown to be satisfactory, then it would be well suited for use at construction sites.

The Discostrainer Model DS-110, evaluated in these tests, was a small prototype unit with one pair of discs. It was equipped with a recirculating spray system and stainless steel wire mesh with 45 μ openings. The rated capacity of the test unit was 568 lpm (150 gpm) and flux of 379 lpm/m^2

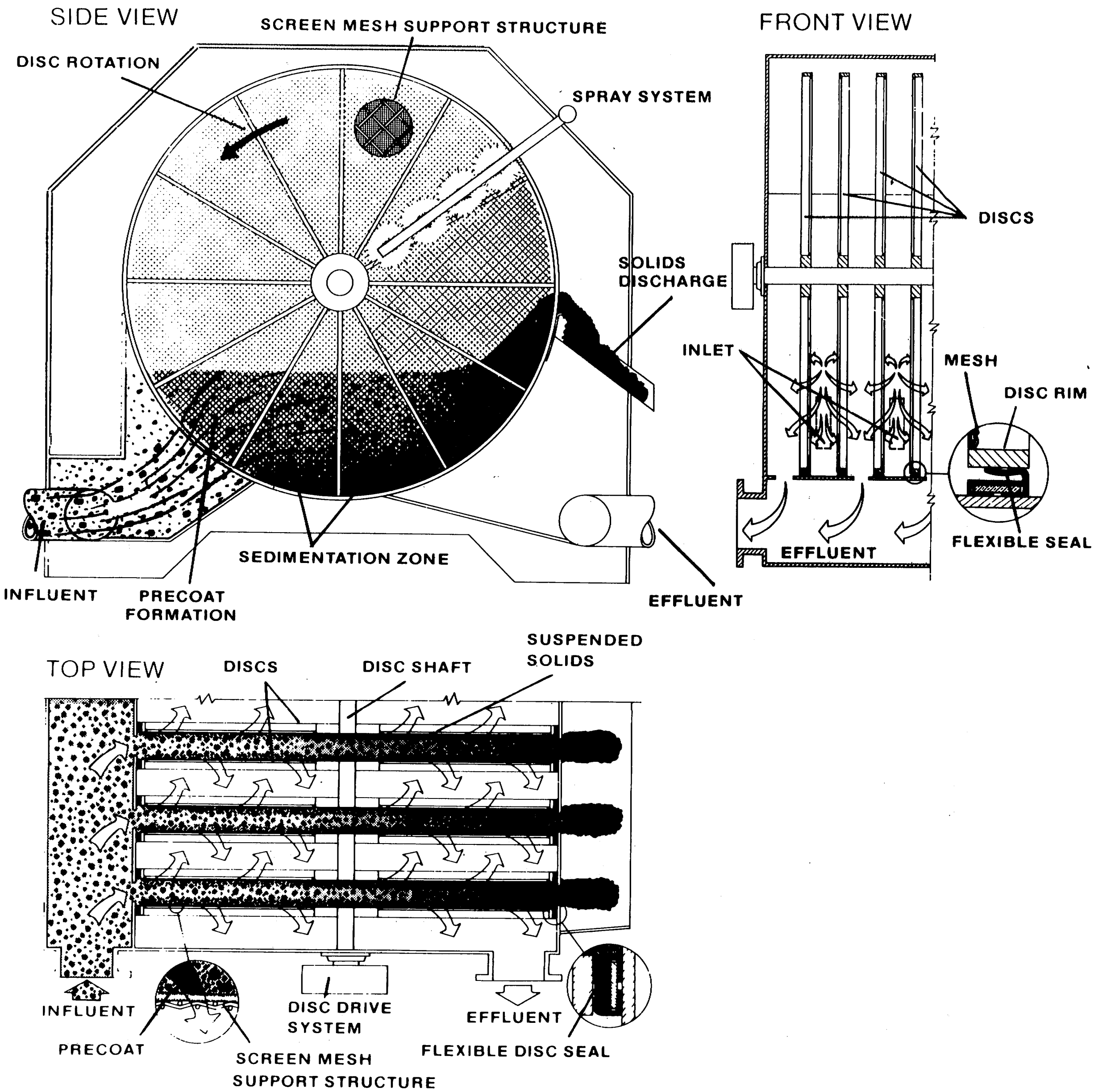


Figure 7. Construction and Operating Features of Discostrainer from (4).

($9.3\ gpm/ft^2$) in raw sanitary sewage with suspended solids of 300 mg/l or less when equipped with a wire mesh with 200 μ openings. The total open area of both the mesh used for these tests and the rated mesh was approximately 30 percent, so any variation in rated discharge should be primarily due to the differences in the concentration and physical properties of the suspended solids.

FACILITY AND PROCEDURES

The Discostrainer was evaluated in the test facility shown in Figures 8 and 9. The test facility was similar to the one used previously for the tube settler except for modifications in the slurry mixing and feed system. As can be seen in the schematic drawing (Figure 8), a high speed recirculating jet was used to mix the concentrated slurry rather than the propeller used in the previous tests. A variable-speed peristaltic pump was used to meter the concentrated slurry into the mixing tube of the influent line.

The Discostrainer was operated with inflow rates of 189, 379, 473, and 568 lpm (50, 100, 125, 150 gpm), fluxes of 126, 253, 315, 379 lpm/m^2 (3.1, 6.2, 7.8, 9.3 gpm/ft^2), and inflow solids concentrations of 850 to 2270 mg/l. The headloss through the screens was determined by measuring the difference in elevation of the water level in the inlet chamber and the bottom edge of the discs. The influent and effluent samples were taken at the inlet chamber and effluent pipe, respectively. The samples were analyzed for solids concentration using the same procedure as for the tube settler. Flow was established in the Discostrainer by first setting the primary flow of clear water, then starting the disc drive and sprayer pump. The slurry feed system was then turned on to inject the concentrated sediment slurry into the influent line.

EXPERIMENTAL RESULTS

Representatives of the local distributer of the unit, Northwestern Power Equipment Company, were notified and observed the initial tests. The initial runs with the Discostrainer were entirely unsuccessful. Immediately after the slurry flow was started the mesh plugged or blinded, and the water level in the inlet chamber increased until the water discharged through the overflow outlet. The blinding continued as long as the flow was maintained, even after the slurry feed line was turned off. The sprayer system cleared the mesh as the discs rotated past them but the mesh blinded again as soon as it re-entered the flow. There was sufficient material trapped between the discs to cause the mesh to blind even when no additional slurry was added. This rapid blinding was partially caused by a deficiency in the slurry feed system which caused a surge of high sediment concentration to enter the Discostrainer when the slurry flow was first turned on. The slurry feed system was subsequently modified so the initial solids concentration could be controlled and so long as the inflow concentration was carefully monitored, the screens could be prevented from blinding. However, the persistence of this problem illustrates the sensitivity of the square-mesh screen to plugging by granular particles.

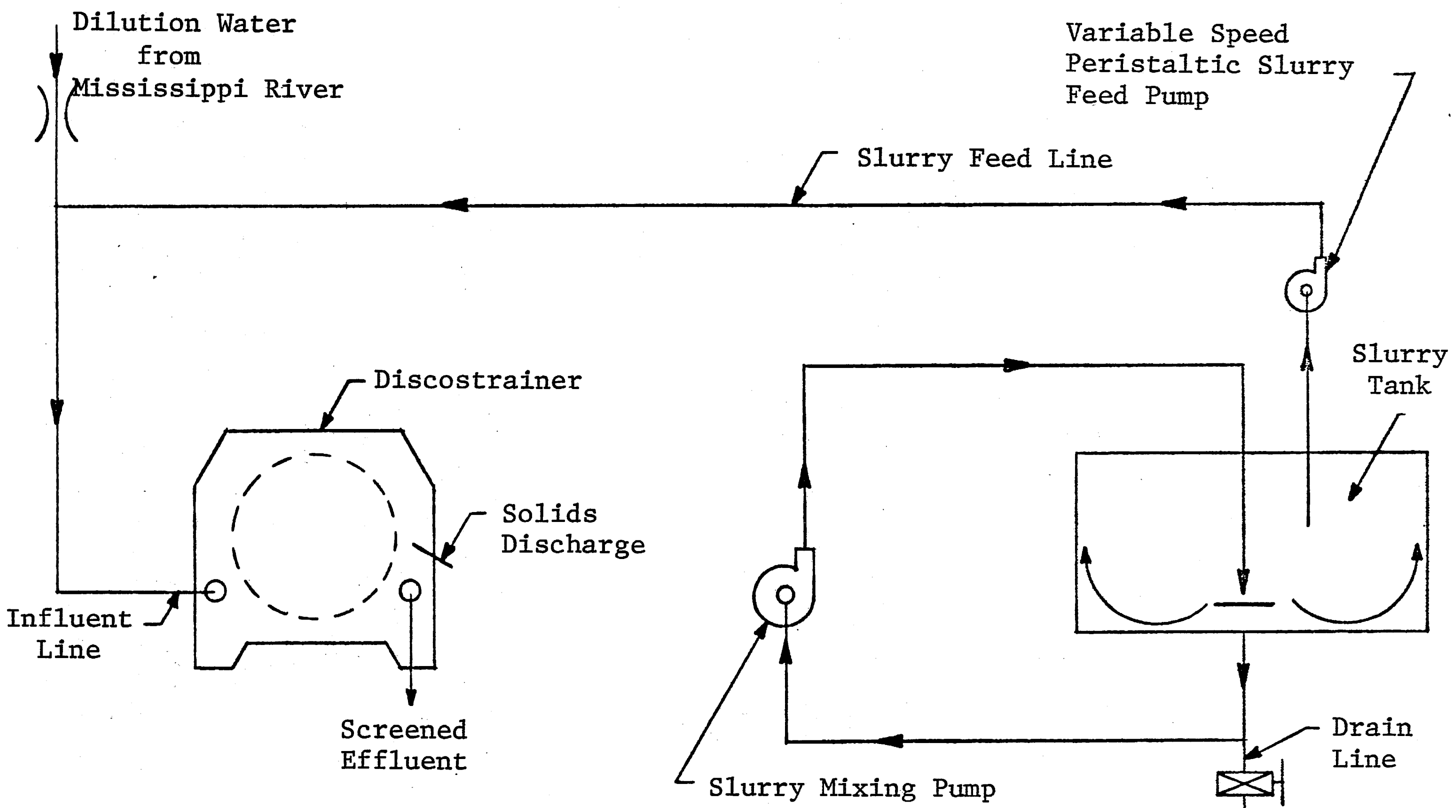
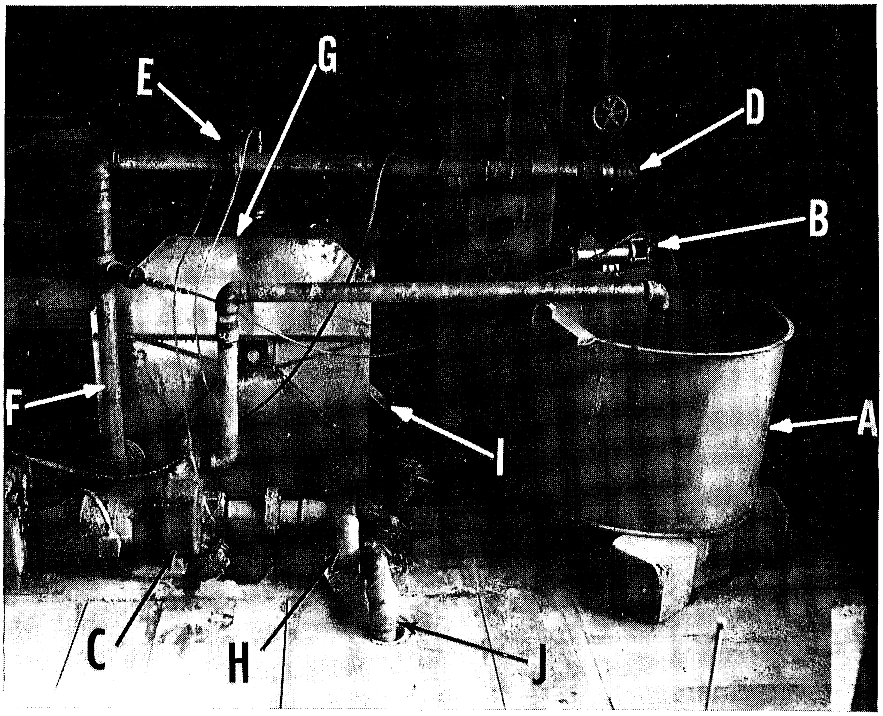


Figure 8. Facility Schematic for Discostrainer Evaluation.



A.	Slurry Tank	F.	Influent Line
B.	Slurry Feed Pump	G.	Discostrainer
C.	Slurry Mixing Pump	H.	Effluent Line
D.	Dilution Water from River	I.	Solids Discharge
E.	Inflow Metering Orifice	J.	Drain

Figure 9. Photo of Discostrainer Set-up.

A tabulation of the essential test data shown in Table 2 gives the average values of several measurements taken during each test after the slurry feed system was modified. The run time for each test was typically about 45 to 60 minutes during which time 6 to 8 samples of the inflow and outflow were taken. The length of the runs was limited by the capacity of the slurry tank.

TABLE 2. SUMMARY OF RESULTS FOR DISCOSTRAINER

Run	Flow Rate		Flux		$\bar{C}_{in}$	Removal Rate	Head Loss		Spray Source
	lpm	(gpm)	lpm/m^2	(gpm/ft^2)	mg/l	%	cm	(in.)	
1	189	(50)	126	(3.1)	1350	8.9	15.5	(6.1)	Recirc.
	379	(100)	253	(6.2)	1570	22.2	26.2	(10.3)	Recirc.
	473	(125)	315	(7.8)	1345	3.7	30.7	(12.1)	Recirc.
2	379	(100)	253	(6.2)	2100	5.7	23.6	(9.3)	Recirc.
3	379	(100)	253	(6.2)	1620	6.1	20.3	(8.0)	Recirc.
4	379	(100)	253	(6.2)	1630	10.6	26.2	(10.3)	City water
5	189	(50)	126	(3.1)	1690	33.1	16.5	(6.5)	City water
	379	(100)	253	(6.2)	1300	27.5	27.2	(10.7)	City water

The removal rate was determined from the difference in suspended solids concentration between the inlet chamber and the effluent pipe. By referring to the sediment size distribution shown in Figure 1 (p. 6) and assuming that the particles suspended in the inlet box are primarily less than 100 μ, the 45 μ mesh openings could be expected to remove about 12 percent of the material. The minimum removal rate actually varied from about 6-10 percent. This discrepancy may be due to the existence of a greater amount of settling in the inlet chamber than assumed above. It is also possible that some of the coarser sediment was forced through the mesh by the high pressure backflush spray. Visual observations indicated that the spray penetrated the mesh and blasted across the cavity and impinged on the opposite side disc with considerable force. There were not enough data available to determine the exact cause of the discrepancy. The seals between the discs and the housing were tight and it is very doubtful that they leaked significantly. To remove the influence of the solids in the recirculated water spray on the results, some brief tests were made using a city water spray source. Run numbers 4 and 5, made with a low pressure clear water backflush using city water, showed some tendency toward higher removal rates, probably because the lower intensity spray jets did not force the sediment material through the opposite side mesh.

A plot of percent removal as a function of inflow solids concentration for a given inflow rate is shown in Figure 10a. As the concentration of the inflow increases, the percent removal decreases. In Figure 10b, data have been plotted to show the influence of the rate of solids loading on the screens, which is represented by the product of the inflow rate and concentration. With the exception of one point, a general trend is established showing that the removal efficiency decreases with an increase of solid loading. Thus, the possibility is suggested that the higher efficiency may be experienced with very low inflow rates of high solids concentration, or higher flow rates with very low solids concentration. Project budgeting did not permit an experimental verification of these conditions.

The rated discharge for this mesh and sediment material is considerably lower than the published value of 568 lpm (150 gpm) with 70 mesh 200 μ screen. The maximum removal rates achieved were about 30 percent. This in itself is not very impressive, however, the 30 percent removal rate implies that the Discostrainer was removing material which was considerably smaller (approximately 50 percent) than the openings in the mesh. This indicates that some of the trapped solids were forming a pre-coat on the mesh. The higher removal rates did not occur consistently or predictably and the results could not be repeated very well from one run to the next.

The relationship between headloss and flow rate is shown in Figure 11. The headloss is the difference in elevation between the inlet chamber water surface and the bottom edge of the discs and is a measure of the blockage in the screens. The Discostrainer was operated with plain river water with a very small percentage of suspended solids (mostly in the form of organic matter and algae) at flow rates of up to about 946 lpm (250 gpm) and flux 631 lpm/m^2 (15.5 gpm/ft^2) with not more than a few centimeters of headloss. This was true even after long runs when the sludge was beginning to noticeably thicken in the cavity between the discs. However, when the test sediment was added to the river water, the headloss was very strongly dependent on discharge and the Discostrainer could not be operated successfully at flow rates greater than 473 lpm (125 gpm) and flux 315 lpm/m^2 (7.8 gpm/ft^2) without causing blinding. There was no apparent relationship between the headloss and removal efficiency.

Several attempts were made to optimize the flow rate and the disc rotational speed. The performance was too inconsistent to give any definite results.

The solids discharge action was never observed due to the relatively short run times and the low removal rates. However, before using this system for the removal of purely inorganic waste, this feature would have to be checked very carefully. If the trapped solids were primarily non-cohesive, the thickened sludge would not be discharged as well as the organic and cohesive material for which this unit was designed.

The Discostrainer is not very well suited for the removal of inorganic fine grained sediments such as may normally be found in construction site

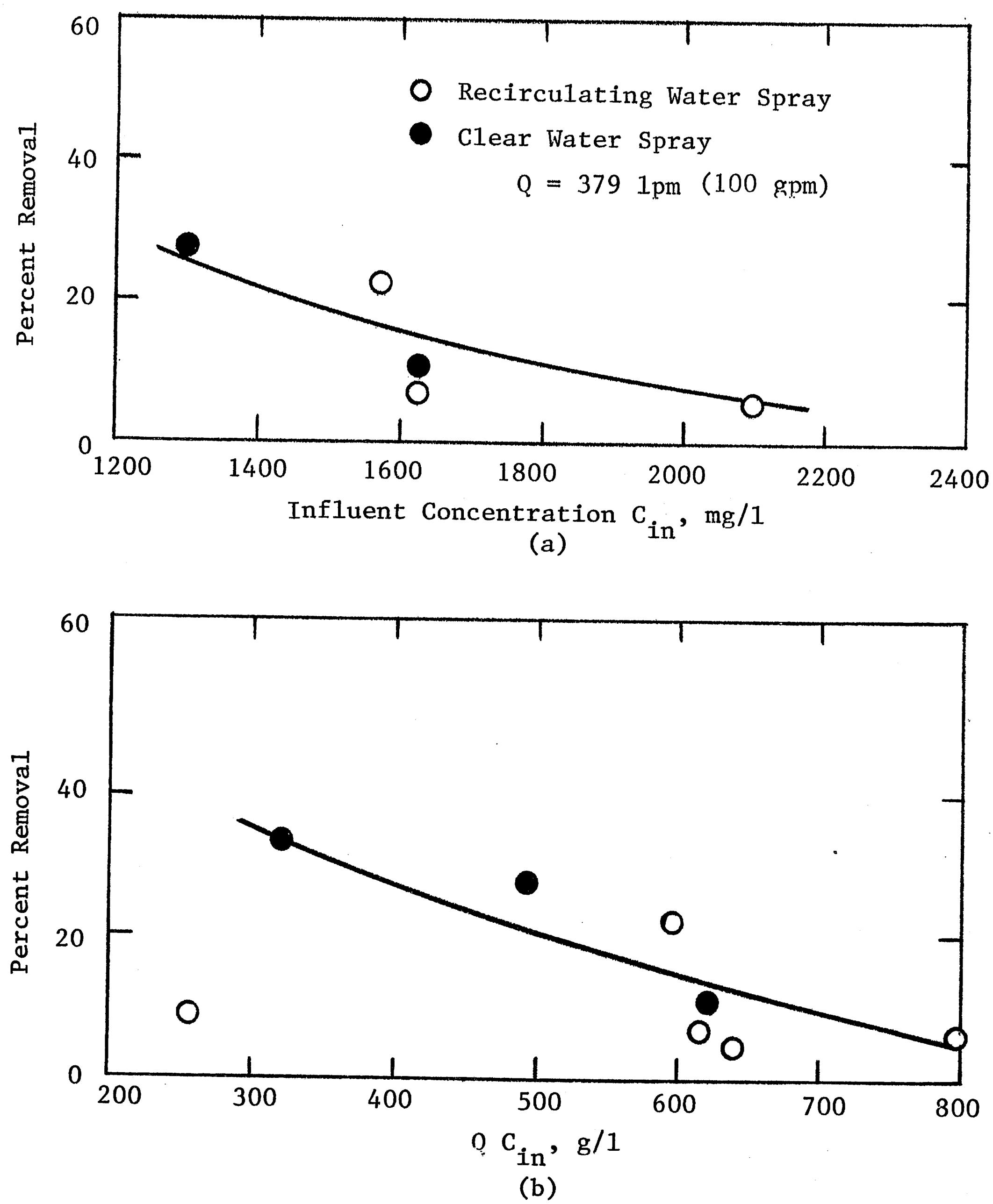


Figure 10. Solids Removal for Discostrainer.

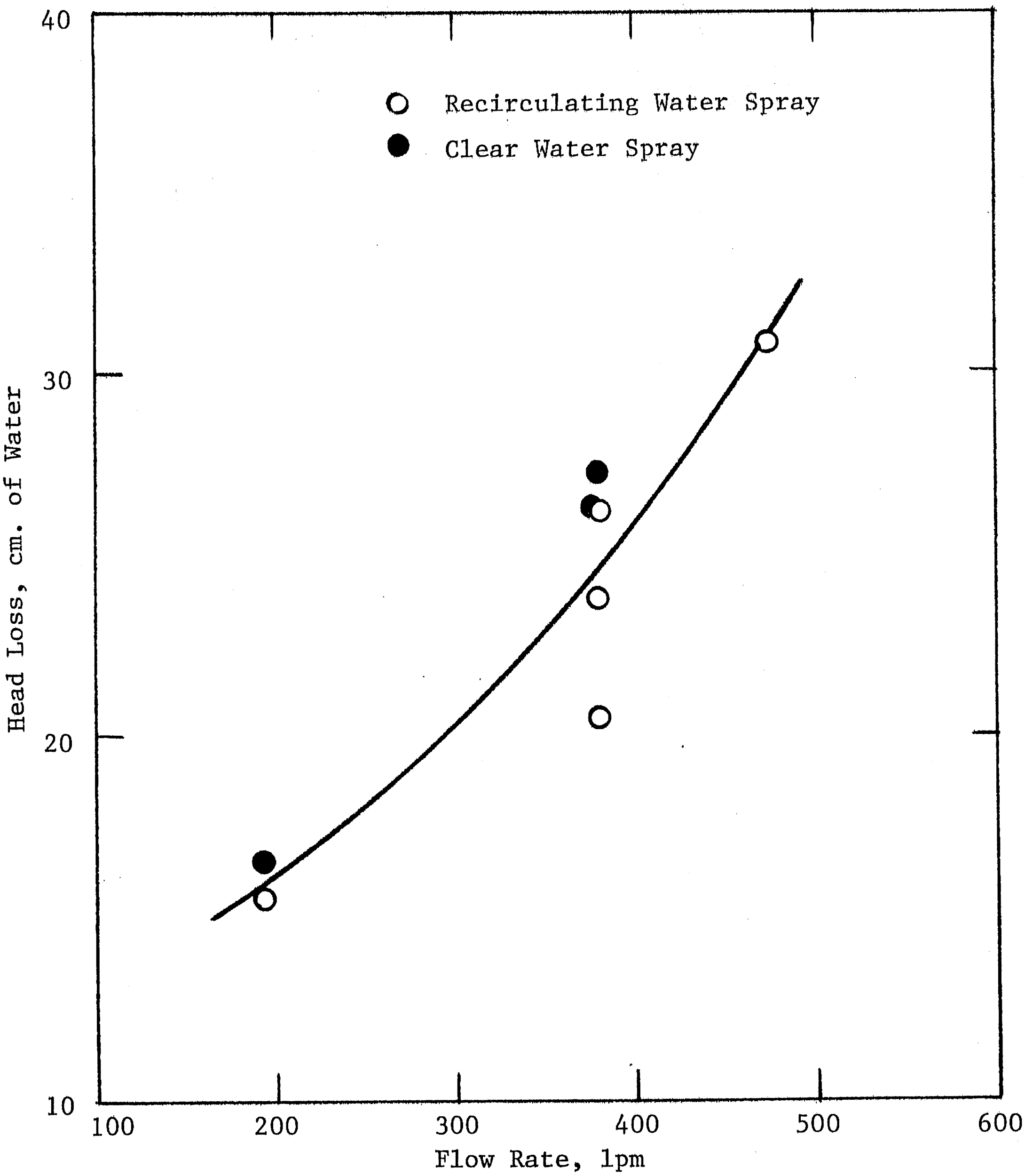


Figure 11. Head Loss Across Discostrainer Screens.

runoff. The unit could probably be made to work fairly well over a very narrow range of inflow conditions, however, the tendency to "blind" when overloaded slightly by either high concentrations or high flow rates limits its applicability for this purpose. The indications are that the performance with organic or fibrous material is very good and where a high percentage of fibrous material would be expected, the unit works well. The organic material would form a pre-coat on the mesh and prevent blinding. No tests were run in this program to try to optimize performance with organic or fibrous additives to the slurry. A possible improvement might be to equip the discs with mesh that has some other shape of opening, either slotted holes or a non-woven fiber fabric. Such tests were not within the scope of this investigation.

SECTION 7

REQUIREMENTS FOR A HYPOTHETICAL CONSTRUCTION SITE

Each particular construction site has its own unique characteristics, such as topography, underlying soil conditions, hydrologic exposure, etc. Many of these items have been discussed in (1). It is therefore difficult to arrive at a typical design for a solids removal scheme which can be applied to a wide variety of situations. However, in the following a hypothetical case has been assumed to illustrate some of the features of an inclined tube settler used in conjunction with a debris basin. The case to be considered is a small construction site with an area of 25 acres, which may be typical for an industrial or commercial development area. The site will be exposed to a rainstorm with an intensity of 0.5 in/hr.

Some general features of a possible runoff collection and treatment scheme are shown in Figure 12. The basin would be located at the downstream end of the construction site, and the excavation required is dependent on the local topography. The minimum depth recommended for the basin is 8 ft when tube settlers are used, and as discussed in (1), the basin should have a length to width ratio of about 4. Baffles should be placed in the vicinity of the inlet to the basin to reduce turbulence of the incoming stream. These baffles may consist perhaps of material such as snow fencing. To further reduce the effect of turbulence of the flow on the performance of the tube settlers, the tube settlers are placed near the downstream end of the basin. Following the general guidelines of the manufacturer, it is recommended that 1/4 to 1/3 of the basin area not be covered with the tube settlers. The tube modules are supported on a light framework, and the top of the modules are submerged 2 ft below the water surface. A solid barrier is shown at the upstream end of the modules which insures that all of the flow enters the tubes from the bottom of the module. After the flow passes through the tube modules, it is collected by a series of perforated pipes or passes over a weir and discharged. If chemicals are to be added to increase flocculation, they would be introduced upstream of the baffles. The scheme shown in Figure 12 will be designed to continually process the runoff from the storm. Following the storm event, flow through the tube modules will cease, and the runoff will be retained in the basin and particles allowed to settle by gravity. The cleared water then can be gradually released through a small pipe drain, and during dry periods the settled solids can be removed for proper disposal. The material may require further dewatering after removal from the basin.

The runoff from the site may be approximated from the rational formula (1)

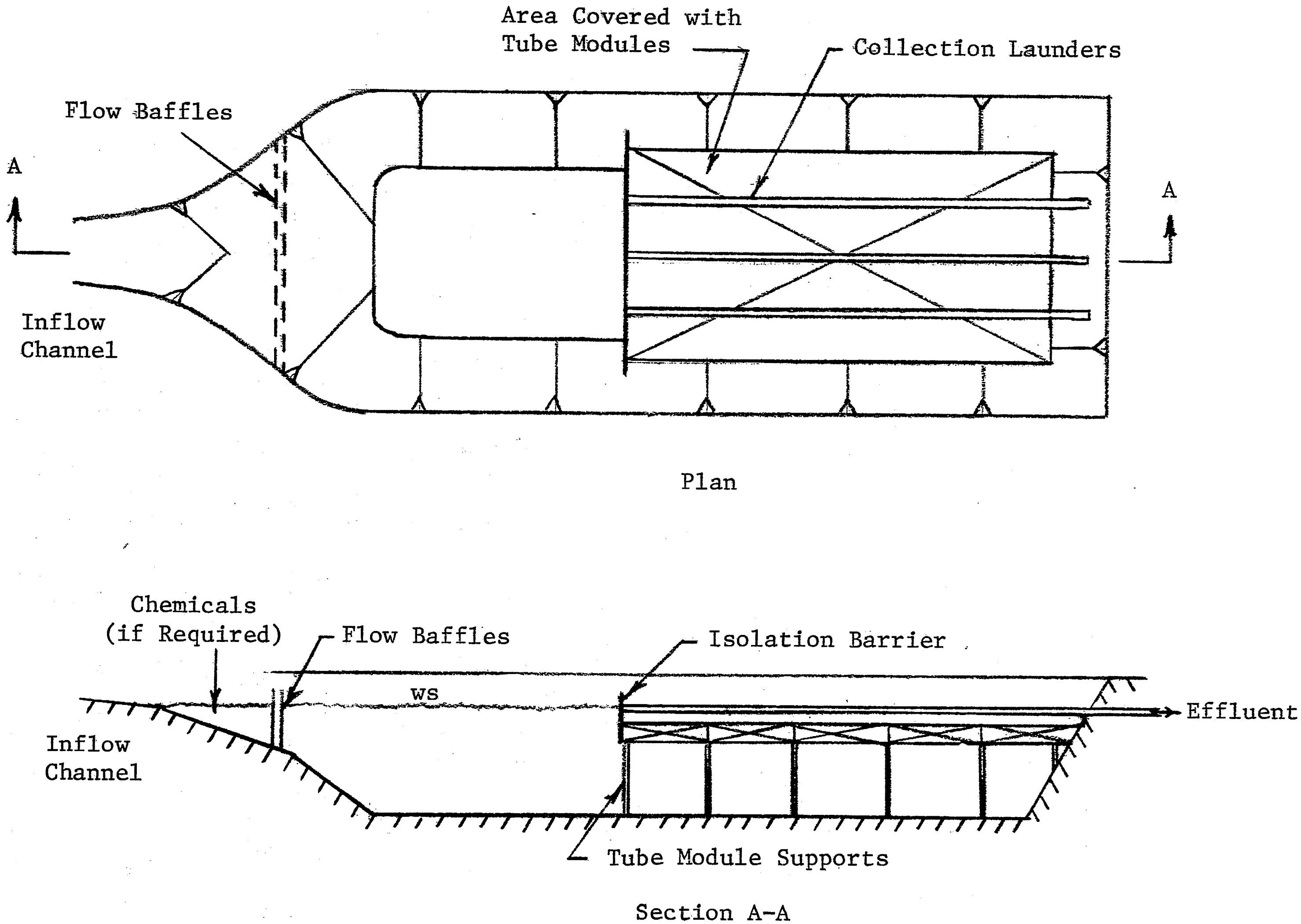


Figure 12. Conceptual Design of a Debris Basin Fitted with Inclined Tube Settlers.

$$R = KP$$

where R = runoff in time span in inches/acre

K = runoff coefficient

P = average precipitation in inches over time span

The runoff coefficient, K, is dependent on the exposed material and varies over a wide range. Runoff over a deep gravel bed may be essentially zero, whereas impervious soils such as clay may yield nearly complete runoff. For the present purpose, K will be assumed to be 0.5. Thus, for the given storm, the amount of runoff is 43560 x 0.5 x 0.5/12 = 908 ft^3/hr/acre of watershed, which reduces to 0.25 cfs/acre or 113 gpm/acre. It is readily apparent that the drainage and collection layout be such that handling of water not associated with the site be minimized. In this example, only the runoff from the 25 acre site will be considered.

The experimental data obtained in the Laboratory study indicated that the percentage removal of fine particles did not change significantly with overflow rate up to the maximum plan area tested of 5 gpm/ft^2. A slightly more conservative value of 3 gpm/ft^2 will be used as the design overflow rate. The required plan area of the tube modules is therefore 113 x 25/3 = 942 sq. ft. As the standard tube modules are 10 ft long and 2.5 ft wide, an arrangement of 8 units wide and 5 units long provides an area coverage of 1000 sq. ft. The total surface area of the basin with a length to width ratio of 4 is 1600 sq. ft so that about 0.6 of the surface area is covered with tubes.

The tube module support system should be designed for a surface loading of 7.5 psf, with support members at each end of the module. As the installation is considered necessary only during the period of the project, the support system could be fabricated using simple timber construction techniques.

Some rough cost figures have been assembled for construction of the solids removal system. These costs are based on the assumption that about 750 cu. yds of excavation are required for the basin and heavy equipment is available at the site, a four man crew can construct the module support framing in one week, install the modules in two days, and complete the peripheral items such as baffles, drain lines, and overflow system, in about five days. The costs are summarized below:

Excavation	$ 2,500
Tube Modules	32,000
Support Framing	5,000
Module Installation	1,500
Baffles, drains, outlet	4,000
Contingencies	5,000
	$50,000

The total estimated minimum cost reduces to about \$2000/acre of construction site. The addition of chemicals to the influent would increase the cost by about \$3000 for equipment. The quantity of chemical to be added is dependent on the characteristics of the suspended solids and the water itself. With the concentration of 500 mg/1 of alum used in the Laboratory tests, the cost of alum at \$.10 per pound would be about \$72 per hour of treatmment. If the basin site is to be returned to its initial condition at the end of the construction program, additional costs would be incurred.

It should be emphasized that the above costs are only approximate, and may vary quite widely, dependent on local conditions. With this system, the Laboratory results indicate that about 60 percent of the influent solids with concentrations of about 2000 mg/1 can possibly be removed down into the clay size range.

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16. ABSTRACT

A literature survey had been conducted by the St. Anthony Falls Hydraulic Laboratory to assess various methods for separation of sediment from storm water at construction sites. Two methods have shown some promise in this application, and a research program was initiated with the objective of evaluating the effectiveness of the methods in removing fine grained inorganic solids from water.

Experimental facilities were set up to test full-scale units of an inclined tube settler and a Discostrainer in an environment approximating that in the field. These units were tested for removal efficiencies of inorganic solids with sizes less than 100 μ and influent concentrations of about 2000 mg/l. Measurements were made of the influent and effluent concentrations for various flow rates through the systems.

Results indicated that the installation of an inclined tube settler improved the efficiency of a sedimentation tank by about 20 percent at the highest overflow rate tested of about 200 lpm/m^2 (7000 gpd/ft^2). The inclined tube settler also reduced the sensitivity of the overflow rate on the efficiency of sediment removal. Limited tests with alum added to the influent to increase flocculation indicated about 6 percent improvement in removal efficiency.

The Discostrainer was found to be extremely sensitive to influent solids concentration. Thirty percent solids removal was the maximum attained for the tests conducted. Higher removal percentages may possibly be obtained by reducing the flow rate or influent concentration.

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