EPA 440/9-76-026

Methods To Control Fine-Grained Sediments Resulting From Construction Activity

December 1976

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Water Planning and Standards
Washington, D.C. 20460

This report is issued under Section 304(e)(2)(C) of Public Law 92-500. This Section provides:

> "The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall issue to appropriate Federal agencies, the States, water pollution control agencies, and agencies designated under Section 208 of this Act, within one year after the effective date of this subsection (and from time to time thereafter) information including...(2) processes, procedures, and methods to control pollution resulting from -
>
> (C) all construction activity, including runoff from the facilities resulting from such construction;..."

This publication is the third in a series issued under Section 304(e)(2)(C) of Public Law 92-500 concerning the control of water pollution from construction activity. The first report, "Processes, Procedures and Methods to Control Pollution From All Construction Activity", was issued in October 1973 (Publication No. EPA-430/9-73-007). The second was entitled "Methods of Quickly Vegetating Soils of Low Productivity, Construction Activities (Publication No. EPA-440/9-75-006). It was published in July, 1975.

This document was prepared for use by planners, engineers. resource managers, and others who may become involved in programs to effectively provide for sediment control. Standard erosion and sediment control measures are usually effective for preventing the runoff of the <u>total</u> sediment load. The effectiveness of these standard techniques; however, has been found to be relatively poor with regard to preventing the runoff of the fine-grained fractions, such as the silts and clays.

The objective of this study was to research practical, cost-effective methods which would help to reduce specifically the fine-grained sediment pollution derived from construction activities. The prime consideration during this study was the use or adaptation of existing technology, as described in the current literature or data, to the fine-grained sediment pollution problem.

EPA-440/9-7

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METHODS TO CONTROL FINE-GRAINED SEDIMENTS RESULTING FROM CONSTRUCTION ACTIVITY

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY

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November 1976

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ACKNOWLEDGEMENTS

This document was prepared for the Environmental Protection Agency by Hittman Associates, Inc. of Columbia, Maryland. Principal authors were Mr. Michael A. Nawrocki, Program Manager, and Mr. James M. Pietrzak, Associate Engineer. Project Officer for the Environmental Protection Agency was Mr. Robert Thronson, Hydrologist with the Non-point Source Branch.

SECTION I

SUMMARY

The following course of action is offered for increasing the amount of fine-grained sediment which is retained on a construction site. The discussion summarizes the most promising control alternatives. Utilization of a specific technique, or combination of techniques, depends upon the degree of fine-grained sediment control required and the characteristics of the soils present at the site.

For pre-sediment pond control of fine-grained sediment, or when the installation of a sediment pond is not feasible because of site constraints, plastic filter cloth fences appear to be very effective for controlling fine-grained sediment. Where sediment detention ponds are to be provided and no plastic filter cloth fence is used, two ponds in series should be installed since efficiency measurements on these systems indicate that they are more efficient than a single pond of the same overall surface area. In designing the pond(s) the following should be considered:

1. The performance of a preconstruction site survey and analysis which includes the type and grain size distribution of the soils. This will provide for the accurate sizing of the pond system according to anticipated flow rates and the characteristics of the soils in the site area.

2. Provision of baffles or compartments within the sediment pond(s).

3. Ensure that the length-to-width ratio of the pond be kept on the order of 5 to 1.

4. The use, where feasible, of very wide inflow and outflow structures.

5. Provision, where wide inflows are not possible to obtain, of energy dissipators to decrease the flow velocity.

6. The use, where space is available only for a standard riser pipe, of risers which have improved fine-grained sediment retention capability. These include siphon-drawdown or plastic filter cloth wrapped units.

Additional fine-grained sediment control can be achieved through the addition of chemical flocculants. For this, a two pond system is recommended, with the chemical being added into the outflow from the first pond.

There is also some available water treatment equipment which can be used at the outlet structure of a sediment pond to achieve fine-grained sediment removal.

SECTION II

INTRODUCTION

Background

The implementation of an effective erosion and sediment control plan based on current standards can prevent much of the potential sediment pollution generated on a construction site. Standard erosion and sediment control measures are usually effective in preventing runoff of the total sediment load. However, the effectiveness of these standard techniques has been found to be relatively poor as far as the prevention of the runoff of the fine-grained fraction of the sediment, i.e., silt and clay is concerned.

The objective of this study, therefore, was to research practical, cost-effective methods which would help to reduce specifically the fine-grained sediment pollution derived from construction activities. The prime consideration during this study was the use or adaptation of existing technology, as described in the current literature or data, to the fine-grained sediment pollution problem.

For the purpose of this study, fine-grained sediment, or silt and clay, is defined according to the Unified Soil Classification System. This classification includes as silt and clay any particles 74 microns or less in diameter, i.e., those passing through a No. 200 U.S. Standard Sieve. Therefore, the methods investigated during the course of this study focused primarily on controlling particles in this size range.

The term soils, when used in this report, includes those natural aggregates of mineral grains, or other materials, that can be separated by such gentle mechanical means as agitation in water. Sediment refers to the individual particles of material which have been eroded from their original locations, transported, and deposited by runoff waters. In-place soil materials may consist of a great range of individual particles varying from fine clays to boulders. Others may be fairly uniform such as sands, gravels, or clays. In most construction site areas, the sediment most subject to erosion and causing pollution problems consists of from clay to coarse sand-sized materials. Silts and clays are considered to be the fine-grained portions discussed in this report.

Study Methodology

Methods for the control of fine-grained sediment can be grouped into four general categories. These categories closely follow the lines along which a standard erosion and sediment control plan is implemented, since it was found that the control of fine-grained sediment can best be achieved by modification and expansion of a standard erosion and sediment control plan designed in accordance with good current practice. Thus, the methods investigated during this study were grouped so as to show how utilization of these techniques can complement and improve the fine-grained sediment removal ability of a standard erosion and sediment control plan.

The first category consists of standard erosion control techniques which are used on construction sites and which may tend to reduce the production of fine-grained sediment on the site. Proper planning of construction activities as well as various runoff control and surface soil stabilization techniques which are used in an effort to keep the soil in place on a construction site are included in this category.

The second category or line of defense involves the use of adequate sediment control measures. They include sediment traps, sediment filters and buffers, and detention basins or sediment ponds to retain the fine-grained sediment on site. Modification of and addition to original sediment and erosion control plan designs is, in most cases, necessary to specifically improve the retention of fine-grained sediments.

Use of post-depositional (post-sediment pond) devices and techniques comprises the third fine-grained sediment control line of defense. It involves the installation of mechanical separation devices, which are capable of removing fine-grained particles from water, at the overflow structure of the sediment retention basins.

The final aspect of the control technology is the removal and disposal of the fine-grained sediment from detention ponds and post-depositional devices. It includes the reemoval, dewatering, drying, and, possibly, the utilization of the sedimentary materials.

This study, therefore, concentrated on identifying and assessing the applicability, practicality, effectiveness, and economics of techniques in the four above categories which could be used to control fine-grained sediments resulting from construction activities.

SECTION III

CONCLUSIONS

1. The overall control of fine-grained sediments can best be achieved through the modification and expansion of a standard erosion and sediment control plan.

2. Standard erosion control measures such as mulches, chemical binders, etc., which are designed to keep the sediment in place, are most effective on coarse-grained particles. Some fine-grained sediment control is also achieved, however, through use of these methods.

3. Fences constructed of plastic filter cloth appear to be one of the most effective fine-grained sediment control devices. These fences can be used around the periphery of a construction site to contain most of the fine-grained sediment before it enters a sediment pond, or when the installation of a sediment pond is not feasible.

4. Conventionally-designed sediment detention ponds need to be modified to achieve removal of more of the fine-grained sediments. Pond characteristics which can be modified to achieve more effective fine-grained sediment control include the installation of baffles or compartments within the pond, provision of a more effective pond length-to-width ratio, use of very wide inflow and outflow wiers, redesign of outfalls, and the installation of energy dissipators in the pond intake area.

5. Multiple sediment detention ponds in series appear to have a greater settling efficiency than a single large pond of equivalent surface area.

6. Chemical coagulants and flocculants used in conjunction with a multiple pond system can achieve good control of fine-grained sediments.

7. There is some available equipment which can be used at the outlet structure of a sediment pond to achieve further fine-grained sediment removal. Of this equipment, hydrocyclones appear to be the most cost-effective for the widest variety of situations.

8. The most feasible equipment for removing sediment from sediment ponds include standard draglines, crane-operated scrapers, conventional front-end loaders, and, for larger ponds, hydraulic dredges.

9. Scarification or reworking of sediment, either after it has been removed from a pond or after the pond has been drained, is an effective method of dewatering the sediment. Placement of sediment removed from ponds on drying beds which consist of underdrains with layers of sand and/or gravel on top has also been shown to be effective in dewatering in some cases.

10. Ultimate disposal or reuse of fine-grained sediments removed from sediment ponds depends upon the local economics of transporting the sediment to the place where it will be used. Agricultural and some landfill uses appear to offer the best alternatives for reuse.

SECTION IV

RECOMMENDATIONS

For Fine-Grained Sediment Control

1. Continue to use standard erosion control techniques on construction sites. They effect some fine-grained sediment control but, more importantly, they keep the coarser-grained particles in place, thus making it possible to design downstream sediment control devices to specifically and more efficiently remove the fine-grained sediments from the water.

2. Utilize plastic filter cloth fences for sediment control wherever possible.

3. Include the following factors in the design and construction of sediment ponds to achieve more efficient detention of fine-grained particles:

    a. Adequate pond surface area based on settling theory and the individual site characteristics.

    b. Baffles or compartments within the pond.

    c. A pond length-to-width ratio of approximately 5 to 1.

    d. Very wide inflow and outflow wiers where feasible.

    e. Energy dissipators to slow the flow prior to entering the pond.

f. Riser pipes redesigned to achieve more fine-grained sediment removal. Examples of such redesigns include the siphon drawdown type or the riser wrapped in plastic filter cloth.

4. Use chemical flocculants in conjunction with a two-pond system, with the flocculant being added after runoff flows through the first pond.

For Research Needs

1. Determine the exact effect of recommended sediment pond modifications on efficiencies. In-field evaluations of each of the above recommended modifications need to be performed. The modifications should be evaluated both singly and in combination with other modifications.

2. Encourage the conduct of field trials of the various pieces of post-depositional equipment which have been identified as being most feasible. Practical trials are needed to determine their range of applicability and costs in comparison to other fine-grained sediment control measures.

3. Perform additional economic and technical field evaluations using multiple sediment ponds in conjunction with flocculant additions.

4. Conduct studies to determine if flocculants used in standard water treatment practices are toxic under any anticipated conditions.

SECTION V

EROSION CONTROL MEASURES

Basic Concepts

The first consideration in the control of sediment on a construction site is to keep as much of the soil in place as possible. This is accomplished through the use of good on-site erosion control techniques. Within the past few years, many advancements have been made in the field of erosion control on construction sites. They include application of techniques which can be grouped into three general areas of control:

- Good construction planning to include staging of construction whenever possible in order to minimize the area of land disturbed at any given time

- Runoff control through planned stormwater drainage and management

- Utilization of a combination of vegetative, mulching, and other stabilization measures to shield and stabilize the surface soils.

These control techniques were developed to retain most of the overall soil materials on the site, not specifically for fine-grained sediment control.

In order to determine the effect that standard erosion control techniques have on the production of fine-grained sediment, a literature review was performed. In addition, representatives of agencies actually responsible for implementing erosion and sediment control programs were contacted for their opinions on this matter. The prevailing opinion among these agencies was that although little definitive data is available concerning the effectiveness of these presently existing methods specifically for fine-grained sediment control, use of these standard practices will still effect some reduction in the amount of fine-grained sediment leaving a construction site.

There are some available data, however, which cover various aspects of the effectiveness of the standard erosion control techniques in preventing fine-grained sediment runoff. Therefore, this section will present brief descriptions of the commonly-used erosion control techniques and provide guidelines for their applicability and probable cost effectiveness in controlling fine-grained sediment.

Erosion Control Techniques

Construction Planning

Land development plans which take into consideration the climate, topography, soils, existing vegetative cover, and natural drainage systems of both the proposed construction site and its neighboring areas will provide an insight into fine-grained sediment control. Since the amount of this material generated on a site depends primarily upon the composition of the soils present at the site and the site runoff factors, information on these parameters is invaluable during the initial site planning phase. Climatological data is readily available for most proposed construction sites from the National Weather Service. Information on soils at the site is similarly available from many Federal and State Departments of Agriculture, Geology, and Mining; universities; and others. Topography and natural drainage system surveys, performed utilizing both maps and actual field inspection, will help to identify problem areas. Field surveys of the existing vegetation are needed to identify critical areas or places where natural buffer strips can be left for erosion control. These natural buffer strips can decrease the velocity of runoff and trap sediment, thus retaining it on site.

Reduction in both the area of disturbed land and the amount of time it is left bare also will help to reduce the amount of fine-grained sediment in runoff leaving the site. Basically, this technique requires that the amount of bare soil exposed to erosive processes at any one time be minimized by proper staging or phasing of the construction. For example, a large development might be able to be constructed in phases whereby a number of small areas are constructed and stabilized in sequence rather than exposing the entire area to construction activity at the same time. This might require more comprehensive planning and scheduling of the various construction phases if the overall project schedule is to be maintained.

Plans for the retardation of runoff waters during construction must also be implemented effectively if control of silt and clay is to be achieved. These plans should provide for effective control of increased runoff caused by changes in soil horizons and surface conditions both during and after development.

<u>Runoff Control</u>

The control of runoff is perhaps the most important means of reducing or preventing soil erosion. Along with the impact of falling raindrops, runoff is a major cause of soil erosion. The rate of runoff, that is both the quantity and velocity of the surface flow, is directly related to the rate of erosion. Physical factors having the greatest effect on both the amount and velocity of runoff are: soil infiltration rate, surface roughness, slope steepness, and slope length. These factors can be controlled to a certain degree, thus reducing overall soil loss and, in turn, possibly reducing the amount of fine-grained sediment which must be controlled while being transported by runoff water. This requires that slopes and drainage systems be properly designed and that both temporary and permanent runoff control practices be employed during and after completion of construction. Runoff control involves three major considerations:

- Decreasing the amount of total runoff
- Limiting the land surface area over which the runoff flows
- Proper handling and disposal of concentrated flows.

When the amount of runoff generated on a site is reduced, the potential for erosion is correspondingly reduced. Surface roughening and loosening are two means of doing this. Scarification and "tracking" (i.e., movement of a cleated dozer up and down a slope) often are used as means of protecting the slope and increasing infiltration. Care must be taken to insure that an equipment operator understands that the surface materials must be roughened in a manner that impedes flow rather than channelizing it and causing it to concentrate.

Contour benching and furrowing are two methods of runoff control which have been utilized to a great extent in agricultural practice to reduce soil erosion. They can also be effectively applied on many construction sites.

The interception of runoff before it reaches highly-erodible, exposed surface areas, or before it accumulates to a critical concentration, and diverting it to a stabilized disposal area is another means of reducing soil erosion. This is accomplished with the use of diversion structures such as ditches, dikes, and terraces. The principal goal of interception and diversion is to control the velocity of the runoff and protect critical areas of the construction site.

Once the runoff becomes concentrated, grade control structures may be required to prevent gully erosion or stream channel degradation. These structures prevent excessive erosion by reducing velocities in watercourses or by providing lined channel sections or structures that can withstand high flow velocities. They include downdrains used to channel concentrated runoff down erodible slopes, check dams or weirs which reduce the flow gradient and physically impede channel degradation, channel linings which shield the channel from erosion, energy dissipators to slow and impede the runoff, and level spreaders which spread the flow.

Table 1 presents the most commonly used runoff control methods and their functions as related to erosion prevention.

Surface Soil Protection

Another general type of erosion control procedure used during construction consists of minimizing the period of time that a graded area is exposed by promptly providing surface protection upon completion of the grading activity. This requires the use of short term forms of protection while the long term forms of stabilization are becoming established.

Table 1. RUNOFF CONTROL METHODS

Control Method	Functions
Selective Grading and Shaping	Reduces critical slope lengths and gradients, thus slowing runoff.
Vegetative Buffer Strips	Slows runoff velocity, thus filtering sediment from runoff. Reduces volume of runoff by increasing surface ponding.
Roughened Surface	Reduces velocity while increasing infiltration rates. Collects sediment and holds water.
Benches	Reduces runoff velocites by decreasing effective slope lengths. Retains some sediment. Provides access to slopes for revegetation.
Diversion Structures	Collects and directs water from vulnerable areas to prepared drainageways and so reduces erosion potential.
Grade Control Structures	Slows velocity of flow, reducing erosive capacity. Usually permanent.
Grassed Waterways	Grass tends to filter sediment and slow runoff and so stabilizes drainageways.
Level Spreader	Collects channel or pipe flow and converts it to sheet flow. Increases deposition.

Short term forms of surface protection include the use of chemical emulsions to bind the soil particles into a more erosion resistant mass; the use of various matting materials such as jute, wood excelsior, paper, etc.; and the utilization of straw, hay, woodchips and other relatively low-cost mulch materials to shield the soil surface from the action of raindrop splash and runoff. Fast-growing annual and perennial plant materials which both shield and bind the soil can also be used in conjunction with the mulch while the hearty, perennial plant materials such as grasses, forbs, and shrubs which will be used for permanent stabilization and landscaping become firmly established.

Effectiveness

Relative Effectiveness of Techniques

Some important comparisons have been made between the use of different types of mulches, varying mulch application rates, and other erosion control techniques. Although these comparisons were not specifically related to fine-grained sediment control, they are important in that control of overall soil erosion is expected to result in the control of some of the fine-grained sediment. In addition, good on-site erosion control, even if effective primarily for the control of the coarse-grained soil particles, can increase the effectiveness of downstream sediment control devices which are designed primarily for fine-grained sediment control by reducing their need for maintenance due to the accumulation of coarse-grained sediment.

Table 2 presents comparisons of the relative effectiveness, on a fairly fine-grained soil, of various erosion control measures normally used on construction sites. The comparisons in Table 2 were made based on data from experimental test plots on gently sloping land. As can be seen from Table 2, the amount of erosion generated on a site varies widely when different standard erosion control techniques are applied. In general, though, it can be seen that as the application rate of a given mulch or soil binding technique increases, the amount of erosion generated decreases. There is a point, however, where the economics of the overall sediment and erosion control plan come into play. At this point, it is less expensive to provide downstream sediment control, instead of increasing the application rate in order to hold more soil in place. Thus, mulch or chemical treatment rates should be developed on the basis of the cost-effectiveness of the overall erosion and sediment control plan.

Table 2. RELATIVE EFFECTIVENESS OF EROSION CONTROL TREATMENTS (USING CHECK PLOT AS 100) (REF. 1, 2, 3)

Treatment	Application Rate per hectare	Application Rate per acre	Relative Erosion[a]
Fiberglass and asphalt emulsion	1,123 kg & 1,406 l	1,000 lb & 150 gal	1.4
Asphalt emulsion	11,234 l	1,200 gal	1.9
Prairie hay and asphalt emulsion	1,123 kg & 11,234 l	1,000 lb & 1,200 gal	3.0
Prairie hay and asphalt emulsion	1,123 kg & 1,406 l	1,000 lb & 150 gal	5.3
Fiberglass	1,123 kg	1,000 lb	5.3
Woodchips	13,473 kg	12,000 lb	6.2
Woodchips	20,209 kg	18,000 lb	6.4
Wood cellulose fiber (as a slurry)	3,930 kg	3,500 lb	10.0
Asphalt emulsion	5,617 l	600 gal	14.0
Wheat straw (disk-packed, cross-slope)	2,245 kg	2,000 lb	14.6
Prairie hay (disk-packed, cross-slope)	2,245 kg	2,000 lb	17.4
Prairie hay	1,123 kg	1,000 lb	20.4
Prairie hay and asphalt emulsion	561 kg & 1406 l	500 lb & 150 gal	21.0
Asphalt emulsion	2,808 l	300 gal	27.5
Resinous soil binder	11,234 l	1,200 gal	28.4
Prairie hay (disk-packed, cross-slope)	1,123 kg	1,000 lb	29.7
Wheat straw (disk-packed, cross-slope)	1,123 kg	1,000 lb	47.0
Sawdust (disked in with tandem disk)	5.08-cm depth	2-in.depth	60.6
Asphalt emulsion	1,406 l	150 gal	64.6
Prairie hay (disk-packed, cross-slope)	561 kg	500 lb	65.5
Elastomeric emulsion	341 l	90 gal	68.9
Woodchips	2,727 kg	6000 lb	69.8
Resinous soil binder	5,617 l	600 gal	86.5
Emulsifiable latex	303 l	80 gal	94.6
Sawdust (disked in with tandem disk)	2.54-cm depth	1-in.depth	94.8
Check (Untreated)	0	0	100.0
Wheat straw (disk-packed, cross-slope)	561 kg	500 lb	124.3
Check (disk-packed, cross-slope)	0	0	124.8
Woodchips	2,245 kg	2,000 lb	194.5
Prairie hay (disk-packed, downslope)	1,123 kg	1,000 lb	195.7
Check (disk-packed, downslope)	0	0	545.0

[a] *Average of three storms replicated twice for each treatment. All treatments compared to an untreated check plot, Sharpsburg silty clay, 6% slope, Lincoln, Nebraska (rated at 100.). All plots were similarly prepared by plowing and smoothing.*

Table 2 only presents data on the relative effectiveness of erosion control treatments on gently sloping land. It is virtually impossible, however, that all construction activities would occur on flat or gently sloping land. Tables 3 and 4, therefore, present the relative effectiveness of some erosion control techniques which would normally be used on more steeply sloping land. Table 3 presents the results of experiments on a cut slope at a 3:1 slope in a relatively fine-grained soil, and Table 4 presents the results of experiments on a 2:1 fill slope in a similar soil. These two tables show that the relative effectiveness of a given erosion control method depends on a number of factors, including the surface characteristics (i.e., cut or fill, etc.), the steepness of slope upon which it is applied, and other factors. This emphasizes the importance of adequate site investigations and preconstruction planning before an overall erosion and sediment control plan is adopted.

Although most erosion control techniques will provide substantial protection to a bare soil, there are data which indicate that some control techniques may not be as effective as previously thought. Meyer, Wischmeier, and Daniel (Ref. 4) performed an experiment in which six different erosion control treatments were imposed on an area denuded by a bucket loader and a bulldozer. The treatments were: scalped only (no further treatment), scarified to a depth of 5.08 to 10.16 cm (2 to 4 in.), mulched with 2.24 metric tons per hectare (1 ton/acre), covered with 10.16 cm (4 in.) of topsoil, covered with 0.61 m (2 ft) of loose subsoil fill, and covered with 0.61 m (2 ft) of compacted subsoil fill. They found no significant difference at the 95 percent confidence level between the scalped only, scarified, and compact fill treatments for all tests. This included tests on dry to very wet soil, all of which showed that scarification did not significantly reduce erosion on the test plots. This conclusion is also supported by the data presented in Table 2. Plots that were disk-packed, cross-slope (similar to cross-slope scarification) showed greater erosion than the untreated check plot.

Light applications of straw, hay, and woodchip mulches (i.e., applications less than normally recommended) were also found to be relatively ineffective in preventing erosion according to the data presented in Table 2.

Table 3. RELATIVE EFFECTIVENESS OF MULCH TREATMENTS ON AN EARTH CUT WITH A 3:1 SLOPE (REF. 1)

Mulch Treatment	Application Rate per hectare	Application Rate per acre	Relative Erosion[a]
Jute netting			100
Wood excelsior mat			110
Fiberglass & asphalt emulsion	1,123 kg & 1,406 l	1,000 lb & 150 gal	140
Woodchips & asphalt emulsion	13,473 kg & 1,406 l	12,000 lb & 150 gal	230
Prairie hay & asphalt emulsion	2,245 kg & 1,406 l	2,000 lb & 150 gal	250
Asphalt emulsion	11,234 l	1,200 gal	250
Coarse ground corncobs & asphalt emulsion	11,227 kg & 1,406 l	10,000 lb & 150 gal	450
Prairie hay anchored with paper net	2,245 kg	2,000 lb	790
Fiberglass	1,123 kg	1,000 lb	790
Wood cellulose (as a slurry) & asphalt emulsion	1,123 kg & 1,406 l	1,000 lb & 150 gal	850
Wood cellulose (as a slurry)	1,123 kg	1,000 lb	1,290
Kraft paper netting			2,070
Emulsifiable latex	1,406 l	150 gal	2,540

[a] *Total erosion from three simulated rainstorms replicated twice for each treatment. All treatments compared to jute netting (rated at 100) and are in silty clay, Firth, Nebraska.*

Table 4. RELATIVE EFFECTIVENESS OF MULCH TREATMENTS ON AN EARTH FILL WITH A 2:1 SLOPE (REF. 1)

Mulch Treatment	Application Rate per hectare	Application Rate per acre	Relative Erosion[a]
Asphalt emulsion	11,234 l	1,200 gal	16
Woodchips & asphalt emulsion	13,473 kg & 1,406 l	12,000 lb & 150 gal	28
Jute netting			100
Prairie hay & asphalt emulsion	2,245 kg & 1,406 l	2,000 lb & 150 gal	104
Wood excelsior mat			159
Coarse ground corncobs & asphalt emulsion	11,227 kg & 1,406 l	10,000 lb & 150 gal	234
Wood cellulose (Brand A) (as a slurry)	1,572 kg	1,400 lb	310
Fiberglass & asphalt emulsion	1,123 kg & 1,406 l	1,000 lb & 150 gal	345
Wood excelsior	4,491 kg	4,000 lb	391
Wood cellulose (Brand B)	1,572 kg	1,400 lb	811
Wood excelsior & wood cellulose	393 kg & 1,179 kg	350 lb & 1,050 lb	1,500

[a] *Total erosion for three simulated rainstorms replicated twice for each treatment. All treatments compared to jute netting (rated at 100) and are in silty clay, Wahoo, Nebraska.*

Fine-Grained Sediment Control

In the investigation of the effectiveness of erosion control techniques, a number of research studies have found that the percentage of fine-grained material in the runoff from a site is greater than the percentage of fine-grained material in the original in-place soil (Ref. 1, 7, 8). This was true even with the application of standard erosion control techniques. Tables 5 and 6 illustrate this point. Thus, standard erosion control practices are not only more effective on coarse-grained sediment, but they also reduce the total amount of sediment generated.

Analysis of these two tables shows a definite shift toward more fine-grained sediment in runoff following land disturbance. As more of the coarse-grained fraction is retained on site by control measures, the percentage of fine-grained sediment in runoff increases. The data indicates that standard erosion control techniques tested are more efficient in retaining coarse-grained particles on site than they are in retaining the fine-grained ones. The main function of these standard erosion control techniques, then, is to effect some retention of fine-grained particles but mainly to retain the coarse-grained soil particles on the site so that the downstream sediment control devices can more efficiently control the fine-grained particles.

Utilization Recommendations

When applied as recommended, the standard erosion control techniques show an ability to hold some of the fine-grained soil particles in place. However, they have a much greater efficiency in controlling coarse-grained particles.

More effective fine-grained sediment control can be achieved at a fairly high cost either by utilizing some of the more effective erosion control techniques shown in Tables 2, 3, and 4 or by increasing the application quantities of the various mulches. In an overall erosion and sediment control program, however, the most cost-effective means of controlling the fine-grained portion of the sediment would be to first use good, sound erosion control techniques to keep the majority of the coarse-grained soil particles and some of the fine-grained ones in place, and then utilize sediment ponds, other downstream sediment control measures, and post-depositional devices to prevent the fine-grained materials from leaving the construction site. When the coarse-grained soil particles are kept in place, downstream sediment

Table 5. SOIL PARTICLE SIZE IN RUNOFF FROM TEST PLOTS MULCHED WITH WHEAT RESIDUE ON A 2.3% SLOPE (REF. 1)

Average Erosion		Runoff	Percent Soil Particle Diameter				
(kg/ha)	(tons/acre)	(cm)	$>50\mu$ coarse silt	$50\text{-}20\mu$ medium silt	$20\text{-}5\mu$ fine silt	$5\text{-}2\mu$ coarse clay	<2 microns fine clay
4339	1.94	4.06	31.5	23.5	19.7	9.3	16.0
2074	1.04	5.08	33.4	17.7	19.5	8.1	21.3
830	0.42	2.90	25.9	9.1	25.3	8.1	31.6
285	0.14	2.77	47.4	8.6	15.9	5.1	23.0
Soil in place			68.5	18.5	6.8	1.2	5.0

Table 6. AVERAGE SOIL PARTICLE SIZE DISTRIBUTION IN RUNOFF FROM A HIGHWAY CONSTRUCTION SITE (REF. 7, 8)

Condition	Percent Soil Particle Diameter		
	$2000-62\mu$ (medium sand-silt)	$62-4\mu$ silt to clay	$<4\mu$ clay
Average suspended solids in 4 streams before construction	7	53	40
Average suspended solids in 4 streams during construction	1	30	69
Average suspended solids in runoff leaving the construction area	3	27	70
Topsoil at site	42	42	16
Exposed subsoil at site	40	35	25

control measures will function more efficiently and retain more of the fine-grained particles. Also, they will require less maintenance in the form of periodic clean out.

SECTION VI

SEDIMENT CONTROL TECHNIQUES

Types of Control

Even with the best on-site erosion control plan, some sediment can be expected to be generated due to the nature of the construction activities being conducted. Soils are constantly being disturbed and their characteristics changed. These activities constantly produce loose, bare soils so that it is almost impossible to prevent sediment movement from the site without adequate sediment control measures.

To control the sediment resulting from erosion, various standard practices are used to contain or trap the sediment and thus prevent it from leaving the construction site. These practices can be divided into three general types: pre-sediment pond techniques such as small check dams to contain a portion of the sediment near its point of origin, filter barriers which remove the suspended sediment before it enters a drainageway, and buffer strips which detain sediment being transported by sheet flow; sediment ponds, which are impoundment structures constructed to detain runoff long enough to remove additional sediment from the runoff by the action of gravitational settling; and post-sediment pond devices which remove additional fine-grained sediments from the water leaving the sediment pond.

Pre-Sediment Pond Techniques

Sediment traps or filters are small, often temporary structures used at various points within the construction area to detain runoff for very short periods of time and trap heavier sediment particles. Examples of such structures include pits dug along ditches and other areas where runoff is concentrated, low gravel dikes placed across graded roadways or in drainage ditches, and straw bale barriers placed at the base of slopes and in drainage ditches.

The effectiveness of sediment traps consisting of gravel dikes and straw bales depends upon the relationship between the size distribution of the sediment and the void spaces in the devices which detain sediment but pass the water. Reed (Ref. 8) measured the effectiveness of check dams (traps) used on a highway construction site. He found that the rock dams and straw bales had trapped the sand, some silt, but little clay. His measurements, given previously in Table 6, showed that three percent of the sediment in the runoff was greater than 62μ (medium sand-silt) in diameter, 27 percent was between 62 and 4μ (silt to clay), and the remainder, 70 percent, was less than 4μ microns in diameter (clay). Due to the size distribution of the particles in the runoff from his measured construction site, he found that the check dams were less than ten percent effective, that is, a minimum of 90 percent of the material reaching these check dams passed through them. Therefore, the main use of check dams appears to be to trap coarse-grained sediment.

Other filtering techniques include preservation of natural vegetative buffers or the installation of new vegetative buffers downslope of an exposed area. The installation or preservation of relatively flat vegetated buffer areas at the base of steep slopes is an effective means of detaining sediment being transported in sheet flow.

One recent innovation which appears to be a very effective fine-grained sediment control technique is the use of fences built of plastic filter fabric. These barriers have been successfully used on construction sites in both North Carolina and Virginia. On a highway construction site in Virginia, the filter barrier removed 99.6 percent of the total sediment in the runoff (Ref. 9).

Plastic filter fabric fences usually consist of wooden posts spaced approximately 3.0 m (10 ft) apart with large-hole wire (hog wire) fencing fastened to the posts. The filter fabric, approximately 0.91 m (3 ft) high is then fastened to the wire fence. On the upstream side of the fence, the fabric is anchored into a ditch which is then backfilled in order to keep the runoff from flowing under the fence. Plastic filter fabric will last from 9 to 18 months in such usage. Burlap could also be used, but it deteriorates more rapidly.

Most filter material will transmit water at a rate of about 10^{-2} cm/sec, which would be equivalent to the settling rate of an approximately 8-micron diameter particle (Ref. 10, 11). Thus, these fabrics would be very good for retaining fine-grained sediment since particles larger than this size can be expected to settle out of suspension behind the fabric filter fence.

Material costs for plastic filter fences range from $1.08 to $11.50 per square meter ($0.10-$1.10/sq ft), installed. About 55 percent of the total installed cost is labor, 15 percent is the filter fabric, and 30 percent of the cost is due to other materials required to make the fence (Ref. 9).

Sediment Ponds

Conventional Design

One of the conventional methods of controlling the sediment in the runoff from a construction site is through the construction of a sediment retention basin at a point which intercepts the surface runoff. These sediment basins are not designed to achieve any set effluent water quality criterion or to remove any given percentage of the sediment in the inflow. Rather, the size of the basin is usually determined by utilizing a rule-of-thumb on the volume of the basin required based on the area of land disturbed. For example, the State of Maryland, following criteria developed by the U.S. Soil Conservation Service, requires that the sediment basin site should be designed to provide adequate sediment storage for not less than 127 cubic meters per hectare (0.5 acre-inch per acre) of disturbed land (Ref. 12).

Sediment basins designed by these rules-of-thumb are generally very effective in trapping the coarse-grained fraction of the sediment in the runoff. In order to retain the fine-grained sediment, however, conventionally-designed sediment basins must be redesigned to improve their effectiveness.

Theoretical Design Requirements

Ideal Settling of Particles

Within a detention pond, the removal of sediment from run-off water is accomplished through settling of the particles to the bottom of the pond. For the settling of discrete particles in a suspension of low solids concentration, termed free or ideal settling, three flow regimes have been identified according to classical settling theory. The governing equation for the settling velocity within each flow regime is (Ref. 13):

Stokes' Law:

$$V_s = \frac{g}{18\nu}(S_s - 1)D^2 \qquad Re<1 \qquad (1)$$

Transitional Region:

$$V_s \left[= 2.32(S_s - 1)D^{1.6}\nu^{-0.6}\right]^{0.714} \qquad 1<Re\leq 1000 \qquad (2)$$

Newton's Law:

$$V_s = 1.82\left[g(S_s - 1)D\right]^{0.5} \qquad 1000<Re<25000 \qquad (3)$$

where:
- V_s = critical settling velocity, cm/sec
- g = acceleration due to gravity = 981 cm/sec^2
- D = diameter of a spherical particle, cm
- S_s = specific gravity of the particle
- ν = kinematic viscosity of water, cm^2/sec
- Re = Reynolds number = $V_s D/\nu$

Figure 1 illustrates the extent of these flow regimes.

As can be seen by the above equations, designing a pond which will provide for maximum settlement of fine-grained particles can be more difficult, because many of the variables which need to be quantified for input to the design are not normally measured during the course of the preliminary design or site investigations. The factors which must be known or assumed before an analysis can be made are:

- Design outflow rate (design storm flow)
- Expected suspended solids concentration in the inflow

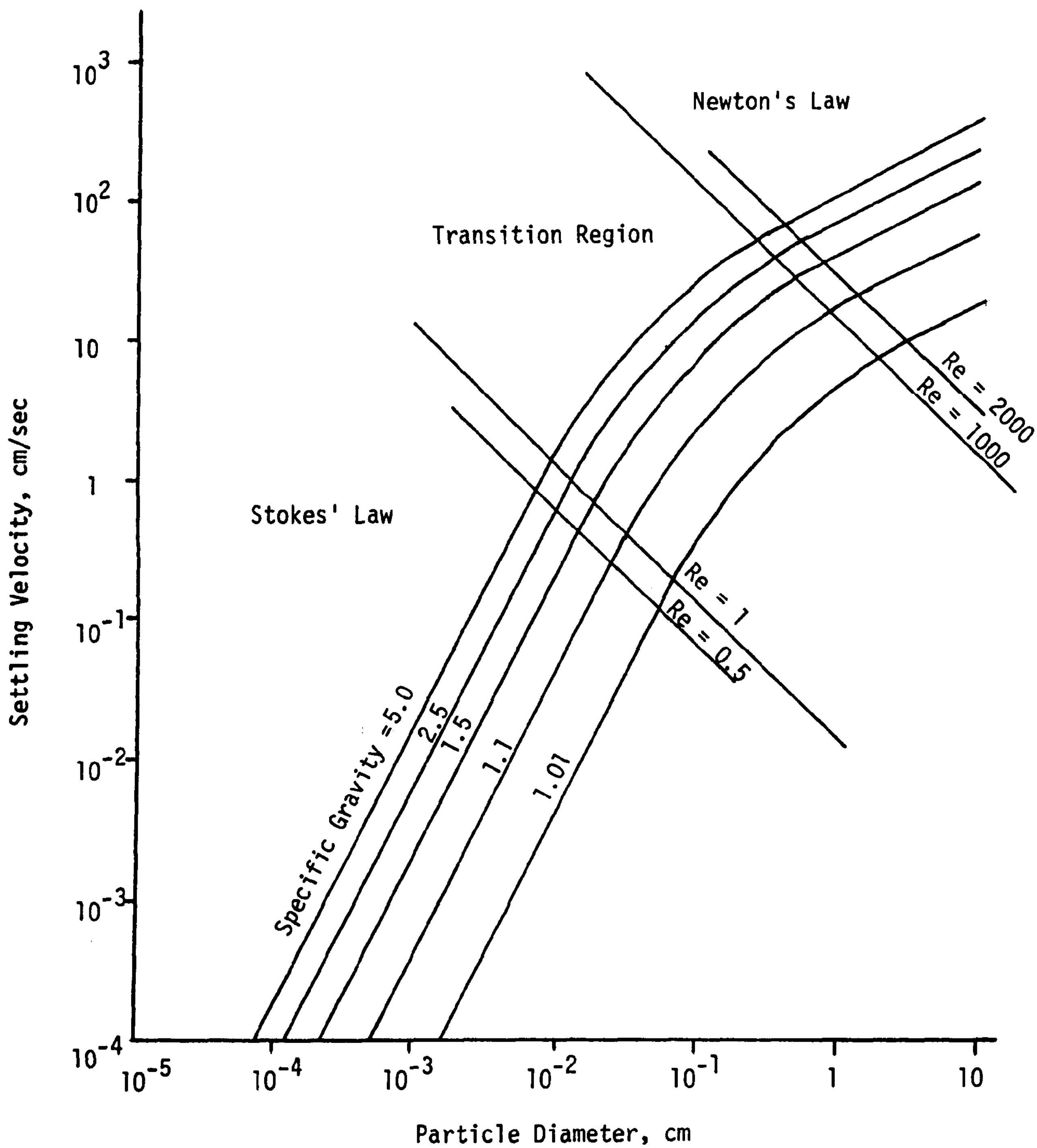


FIGURE 1. Ideal Settling Velocity for a Sphere (10°C Water)

- Specific gravity and anticipated grain size of the incoming solids

- Anticipated pond water temperature.

In the design of sediment ponds to provide for the deposition of sediments, the ratio of the pond outflow to the surface area of the pond, Qo/A, is termed the overflow velocity, Vo. therefore:

$$Vo = Qo/A \tag{4}$$

Based on the above relationship, it can be shown that if the critical settling velocity of any size sediment particle is greater than the overflow velocity, that particle and all larger than it will settle out. Increasing the area of the pond, therefore, would decrease the overflow velocity. This means that the critical settling velocity for the largest size particle to be settled would also decrease. Thus, at a given overflow velocity, increasing the pond surface area would effect the settling of smaller particles within the pond.

There is a limit of practicality, however, on how large a pond surface area can be provided in order to induce the settlement of fine-grained particles. As can be seen from Table 7, the pond area required to settle fine-grained particles increases rapidly as the particle size to be settled decreases.

Table 7. MINIMUM SEDIMENT POND AREA REQUIREMENTS FOR SELECTED PARTICLES FOR A .0283 m^3/sec. (1 cfs) OUTFLOW (Ref. 14)

Particle Diameter (microns)	Minimum Area Required m^2	ft^2
60 (fine sand)	7.43	80
40 (fine sand)	13.5	145
10 (silt)	189	2030 (0.046 acres)
1 (coarse clay)	18,900	203,000 (4.6 acres)
0.1 (fine clay)	1,890,000	20,300,000 (466 acres)

Factors Affecting Ideal Settling

In any sediment pond, it is unlikely that purely ideal settling conditions will be met. Factors which disturb these conditions and thus alter the pond area required (as calculated using ideal settling theory) include:

- Shape of the suspended particles
- Water turbulence
- Bottom scouring of deposited sediment
- Short circuiting, i.e., when the runoff water travels through the pond in less time than the calculated detention period
- Nonuniform deposition of materials
- Entrance and exit effects
- Specific gravity and velocity of the inflow.

In most cases, the effects of the above factors would be to increase the required pond surface area over that calculated by ideal settling theory. Therefore, these significant factors affecting particle settling should be considered in the design of the sediment pond.

Particle Shape

The ideal settling equations (Equations 1, 2, and 3) were derived assuming a spherical particle and, for each of the three flow regions, the drag coefficient for a sphere becomes an approximate unique function of the Reynolds number. However, suspended sediment particles in water are hardly ever spherical. Drag coefficients for spheres, cylinders, and disks differ significantly at high Reynolds numbers (>1000). At low Reynolds numbers (≤ 10), the settling velocities of rod-like and disk-like particles are, respectively, 78 percent and 73 percent of the velocity of an equal-volume spherical particle (Ref. 15).

Turbulence

The horizontal velocity through a sediment pond also affects the particles which have settling velocities roughly equivalent to the overflow velocity. This is called the turbulence effect, even though it occurs with flows at low Reynolds numbers in the laminar flow range.

The net result of turbulence is to prohibit the settling of certain particle sizes, which are carried out with the overflow instead of settling. An expression which can be used to compute the removal ratio of any size particle with turbulence present has been developed (Ref. 16). This removal ratio is defined as the fraction of particles of a given size that would be settled in a detention pond with turbulence present. Thus, a removal ratio of 1.0 would mean that all particles larger than or equal to the given size would be settled even with turbulence present. This removal ratio is a function of the flow velocity per unit of surface area in the settling zone.

Scouring

Scour velocity is defined as the horizontal channel velocity required to start in motion particles of size D, and is given by the equation (Ref. 16):

$$v_c = \sqrt{\frac{8B}{F} g \; (S_s - 1) D} \tag{5}$$

where:

v_c = scour velocity, cm/sec

B = "stickiness" factor, 0.04 for unigranular sand and 0.06 for cohesive, interlocking material (Ref. 17)

F = Darcy-Weisbach friction factor, usually 0.02 to 0.03, depending on the surface over which flow is taking place (Ref. 17)

and the other parameters are as previously defined in Equations 1 through 3. In sediment detention ponds, the horizontal velocity through the pond should be kept less than the scour velocity so that settled small particles are not scoured from the bottom of the pond. The theoretical scour velocity is seen to be independent of the dimensions of the pond.

Short Circuiting

The effects of short circuiting are emphasized by mixing of the materials within the pond, high inlet velocities, and density currents. Experiments have been performed on settling tanks of various shapes to determine the influence which the tank shape has on the settling of particles. Table 8 presents the results of these experiments (Ref. 16). A higher short circuiting factor in Table 8 indicates that short circuiting is more of a problem.

Table 8. SHORT CIRCUITING FOR SETTLING TANKS

Type of Tank	Short-Circuiting Factor (F_{sc})
Ideal dispersion tank	-
Radial-flow circular	1.2
Wide rectangular (length=2.4xwidth)	1.08
Narrow rectangular (length=17xwidth)	1.11
Baffled mixing chamber (length=528xwidth)	1.01
Ideal basin	1.0

The surface area (A, in m^2) of a pond can be increased to approximately account for short circuiting as follows:

$$A = \left(F_{sc} \frac{Q}{V_s} \right) \qquad (6)$$

where:

Q = flow, m^3/sec
V_s = critical settling velocity, m/sec

Methods for Improving Pond Efficiency

It has been shown that the pond surface area required to remove fine-grained sediments often will become prohibitively large at the flow rates anticipated on many construction sites. Therefore, it is necessary to use techniques which increase sediment pond efficiency, that is, provide for the settling of fine-grained materials with less pond surface area than that specified by theoretical analysis.

Use of Internal Baffles and Design of Pond Configuration

Recently, research on sediment ponds in conjunction with lignite mines in Poland has yielded insights into improvement in efficiency. The use of baffles within ponds has shown promise. Baffles increase the distance which the water must travel and also, if properly placed, provide for utilization of the full area of the pond. Thus, the settling of particles within the pond is enhanced. Partitioning of the pond into a number of chambers and then introducing overflow water from particular chambers along the entire width of the sediment pond also has improved performance (Ref. 18).

Dye tests on experimental sediment ponds in Poland have also shown that maximum efficiency can be expected when the length-to-width ratio is maintained at about 5 to 1 (Ref. 19).

Modification of Standard Inflow and Outflow Structures

Standard sedimentation ponds usually have a perforated riser type outflow, while inflow is usually through nothing more than the natural channel. Increased retention of fine-grained sediment in basins can be accomplished through utilization of improved inflow and outflow devices or techniques.

Construction of some type of energy dissipator(s) at the pond entrance will, by producing a reduction in the inflow velocity, cause deposition of sediment before it reaches the pond. Simple barriers of logs or woody debris from clearing operations have worked well for this purpose on numerous construction sites. Modifying the inflow to the sediment basin so that the flow enters along as much of the entire width of the basin as possible is another inflow modification technique which has proved effective (Ref. 18, 19).

Since perforations in an outflow riser pipe which is usually used in sediment ponds allow fine-grained sediment to escape, alternate techniques for draining the pond but still retaining fine-grained sediment are needed. One such technique involves the use of plastic filter cloth wrapped around a standard perforated riser. This technique has been utilized previously in sediment ponds for small dredging operations and proven effective. One problem with this technique is that, after a time, the filter cloth tends to plug with the fine-grained sediment. The outflow riser then acts as a simple nonperforated riser and the sediment pond retains water to the riser top. Although this is effective in terms of fine-grained sediment control, it might be unacceptable from a safety standpoint.

Another device for improving sediment pond efficiency through improved outflow design involves a siphon arrangement in a nonperforated riser pipe. This is illustrated in Figure 2. As shown, the intake for the siphon pipe, located at the approximate elevation of the desired cleanout level of the pond, would help in implementing cleanout procedures when the required sediment storage capacity has been reached by providing a readily visible reference point. If the pond is not cleaned when the sediment reaches the bottom of the siphon pipe, the pond will not drain between storm events.

Use of a very wide overflow wier instead of a standard riser pipe has also been shown to be effective in increasing pond efficiency (Ref. 18, 19). Using this device, outflow velocities in the wier intake area are decreased, thus ensuring that fine-grained particles are not carried out with the overflow.

The use of sand wiers or filter dams at sediment basin outflows may be useful for filtering-out fine sediment. They are currently being investigated by the U.S. Army Engineer Waterways Experiment Station in connection with dredged material containment areas.

Use of Multiple Sediment Ponds

In a number of cases, two or more sediment ponds in series have been used to increase the detention of fine-grained materials, instead of one larger basin covering the same area. Applications of the value of this technique have been studied for both the surface coal mining and dredging industries. Data has shown that multiple sediment ponds in series are more efficient, i.e., they remove finer particles than a single, larger pond of the same total surface area is predicted to (Ref. 20, 21). The multiple basin concept is similar to that of a compartmentalized, larger sediment basin. Thus, higher removal efficiencies can be expected from both multiple sediment basins and a compartmentalized, larger basin.

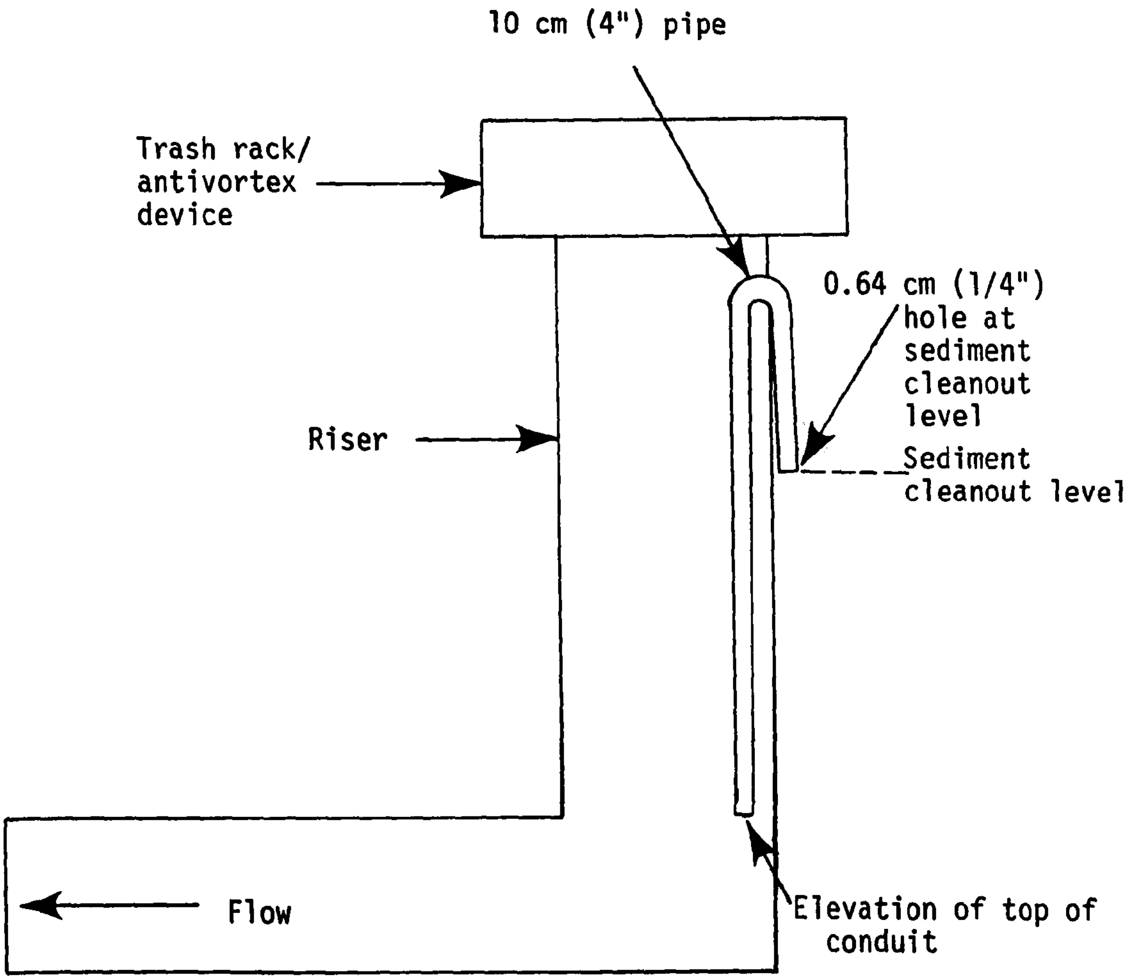


FIGURE 2. Siphon Arrangement in Riser Pipe (Ref. 20).

Use of Flocculants

Basic Concept

Flocculants are chemicals or other materials used to induce fine-grained sediments to flocculate or aggregate into small clumps. This increases their rate of settling. Figure 3 illustrates the use of two sediment ponds when chemical addition is used to enhance the settling of fine-grained sediment. The first pond is designed to settle coarse-grained sediment. Flocculants are added to the outflow from the first pond. In this way, the chemicals would be used for the finer-grained materials in the most effective and economical manner. The required flocculant dosage increases with increasing concentrations of sediment to be flocculated. Thus, by settling the coarse-grained particles prior to the addition of a flocculant, a more cost-effective dosage can be determined.

Types of Flocculants

Commonly used flocculants include (Ref. 22):

- Metal Salts

  Aluminum sulfate
  Ferrous sulfate
  Ferric chloride

- Metal Hydroxides

  Aluminum hydroxides
  Calcium hydroxide

- Synthetic Polymers or Polyelectrolytes

  Anionic
  Cationic
  Nonionic

Selection of Flocculant and Dosage

The selection of the proper flocculant and the proper dosage required are important parameters in the process of flocculation. These selections depend upon the characteristics of the solution and the specific material to be flocculated. There is no accurate theoretical method or rule-of-thumb for selection of a flocculant and its dosage. However, a

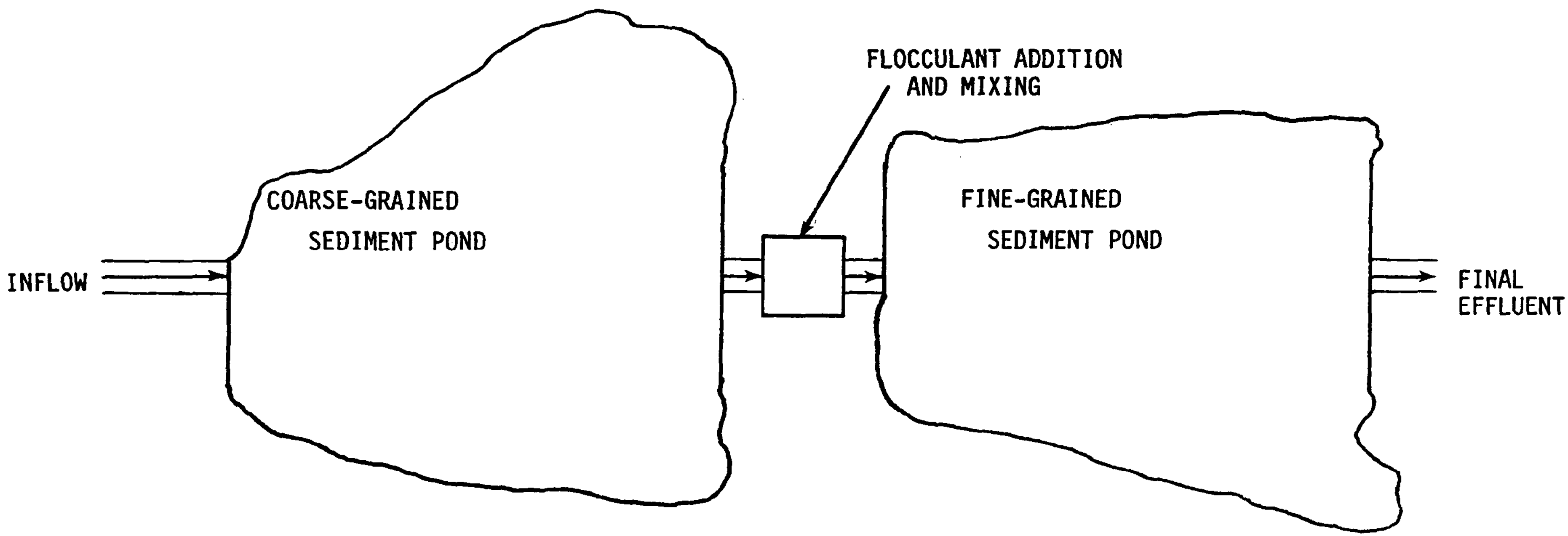


FIGURE 3. Flocculant Addition in Two-Pond System.

rough estimate of the amount of flocculant required can be determined through use of a standard laboratory jar test or by measurement of the zeta-potential or electric charge of the suspended sediment with a meter. The optimum dosage for best results will, of course, have to be adjusted to suit the existing field conditions. Polymer flocculants are usually used in small doses, on the order of a few mg/l.

Possible Environmental Impacts of the Use of Polymers

Research has been performed to identify some of the possible hazards of the use of polymers of various chemical compositions. Acrylamide and acrylonitrile polymers are among those approved for use as flocculant aids in treatment for potable water. However, these may become hazardous to animals and man if contaminated with their own chemical monomers (Ref. 23). While this is considered to be an unlikely occurrence in standard water treatment practice, there is reason for the exercise of caution where these polymers are to be used as sediment coagulants in sediment ponds located on construction sites. For example, approximately 1.9×10^6 liters (500,000 gal) per day of sediment-laden runoff waters may have to be treated from time-to-time with about 9 kg (20 lb) of these polymers. From time-to-time the mixture of sediment and polymer must be removed from sediment basins and disposed of in designated landfills, by mixing with surface soils, or some other technique. Under these conditions, the opportunity is great for interaction to occur between the polymer and various microorganisms, not only in the sediment pond, but also when the sediment-polymer mixture is disposed of. No definitive information is known relative to the rate of biodegradation of the acrylamide and acrylonitride polymers by soil microorganisms. Nor is there any known information with respect to the phytotoxicity or toxicology of such potential degradation products. But, the need for caution in the use of these polymers is underlined not only by the fact that their monomers are neurotoxic, but also because of limited knowledge concerning the biodegradation products and their potential effects on plants, animals, and man.

Carboxymethylcellulose (CMC) and polymers of ethylene oxide are also used as flocculants in water treatment practices. Carboxymethylcellulose is reported to be physiologically inert on oral ingestion by animals and man (Ref. 24). However, under the conditions of use in construction site sediment ponds, there is need for the exercise of caution with respect to overall environmental concerns, because some of the chemical and enzymatic reactions involving CMC produce compounds which are soluble in water. These compounds can subsequently cause water quality degradation.

Both the low and high molecular weight polymers of ethylene oxide possess a very low order of toxicity to animals and man. However, they are subject to oxidation by direct combination with oxygen (as in air) at ordinary temperatures, and because of this, various antioxidants such as phenolic materials, sulfur, and phenothiazine, at concentrations of 0.01 to 0.1 percent, are used with ethylene oxide to alleviate this tendency (Ref. 25). The exact pollution potential of these antioxidants under construction site conditions is not known, although all of the above antioxidants have some toxic effects (Ref. 26).

Practical Experience

Systems which feed chemical flocculants to enhance the settling characteristics of suspended sediments in water have been installed at a number of sediment pond sites. For the most part, these systems have proven effective. Following are brief discussions of some of the better known examples of this type of treatment alternative. These examples point out some of the major considerations which must be taken into account during the use of this control technique.

Lake Needwood, Maryland

A chemical flocculation system is currently being used to treat sediment-laden water above Lake Needwood, a multiple use lake in Montgomery County, Maryland. The system was installed along the stream channel upstream of a 1.2-hectare (3-acre) forebay to the lake. The forebay, which was constructed for detention of the flocculated suspended solids, is periodically dredged to remove the settled solids. In this way, the large majority of the suspended solids are removed before they reach the lake proper, further downstream.

The drainage area to the lake is 31.3 km^2 (12.1 mi^2) and the design inflow ranges from a baseflow of about 0.11 m^3/sec (4 cfs) to 7.1 m^3/sec (250 cfs), a storm which occurs on the average of once every five years (Ref. 27, 28). Flocculant addition, which is added to the inflow in proportion to the flow, begins when the flow reaches 0.57 m^3/sec (20 cfs).

Enough flocculant is added for the stream to contain about 5 ppm. Inflow water quality to date has ranged from 15 to over 20,000 ppm of suspended solids (Ref. 27, 29).

Since the system was installed in 1967, the forebay-chemical flocculant system has removed from 90 to 95 percent of the suspended solids (Ref. 27, 28). It was found that approximately 240 meters (800 ft) of flow along the stream channel was needed to thoroughly mix the chemical. Removal of accumulated sediment from the forebay by dredging is done approximately once every two years. No adverse ecological consequences have been observed as a result of the operation. Annual chemical costs have been $3600 per year, which equates to about $1.14 per hectare of drainage area ($0.46 per acre) (Ref. 30).

Centralia, Washington

Another application of chemical flocculants to help remove suspended solids, in this instance in a two-pond system, is being used for sediment control from a surface mining site near Centralia, Washington. The first pond is used to settle out the coarse-grained sediment. A coagulant is added to the overflow from the first pond. Fins and angle-iron obstructions on the first pond outflow cause turbulence, which promotes rapid mixing of the chemical. The flocculant is metered into the stream according to the flow rate in order to consistently maintain a 5 ppm concentration in the stream. Flow rates averaged in the 0.38 to 0.63 m^3/sec (13 to 22 cfs) range. Table 9 summarizes the effectiveness of this system of flocculation.

Table 9. EFFECTIVENESS OF TWO-POND AND CHEMICAL ADDITION SYSTEM, CENTRALIA MINE (Ref. 31)

Location	Volume Percent Solids	Turbidity (JTU)	Suspended Solids mg/l
Inflow to first pond	1.5-2.0	1000+	10,000-15,000
First pond overflow (at chemical addition station)	0.4-0.7	85-120	120-130
Second pond overflow	*	4-15	*

*Data not available

Poland

Good suspended solids removal efficiencies, using chemical flocculants in sediment ponds, have also been achieved at coal strip mining sites in Poland. Effluents of 20 mg/l have been obtained with the use of chemical flocculants in conjunction with sediment ponds designed according to previously discussed criteria. Thorough mixing of the chemical with the inflow waters was essential. It was provided by a long, open channel between the chemical addition station and the sediment pond, where turbulent mixing took place (Ref. 18, 19).

Economics

Prices for liquid polyelectrolytes range between approximately $0.20 and $0.25 per kg ($0.45-$0.55 per lb) depending upon the manufacturer and the quantity purchased. Liquid polyelectrolytes are ready to be added directly into the flow and need not be mixed beforehand. Dry polymer, which can be mixed with water at the construction site before addition to the stream, costs in the range of $0.70 to $0.90 per kg ($1.50 to $2.00 per lb) in concentrated form. Since it must be diluted for use, however, it results in a lower unit cost than the liquid polyelectrolytes.

Experimental Techniques

Laboratory experiments have shown that the use of gamma radiation considerably accelerates the settling of solids out of a suspension. The exact mechanism which causes this accelerated settling was not reported. However, under laboratory conditions, radiation doses in the range of 500-1000 k Rad caused a two to three times increase in the settling rate, and a significant decrease in oxygen consumption, color, and turbidity of the water. The effects of the radiation treatment appeared to be greater in suspensions of greater electrokinetic potential and which had a high percentage of fine-grained material.

Despite positive results achieved under laboratory conditions, this method is not expected to be used on a practical level. This is due to the high cost of the technique and the uncertainties of the duration of the radiation effects on the water (Ref. 18).

Post-Sediment Pond Techniques

Description

In many cases, outflow from a sediment pond may still contain too much sediment even though the pond design was modified specifically to increase removal of fine-grained sediment. In other cases, the economics may not justify the use of chemical additives or revised sediment basins in order to achieve even greater removal of fine-grained sediment. Therefore, this section presents alternative or additional ways to remove fine-grained sediment from the water. Basically, they involve the use of standard suspended solids removal or separation equipment at the outflow of sediment ponds. Figure 4 presents the basic concept of this system.

Suspended solids removal equipment which is used in wastewater treatment, sand and gravel processing, and by various manufacturing industries was studied for applicability to this problem. Basic parameters which were assumed for equipment sizing and performance purposes are on Figure 4. They include an inflow of about 0.063 m^3/sec (1000 gpm) with a suspended solids content of 500-1000 mg/l, consisting mainly of fine-grained sediment. The equipment also has to have the ability to remove particles less than 74 microns in diameter (silts and clays), have relatively low maintenance requirements, and require a minimum of auxiliary equipment such as pumps, motors, etc. Another basic consideration was the portability of the equipment. Emphasis was placed on portability so that the equipment could be used again by a contractor on other construction sites.

Feasible Equipment Types

After an intensive literature review and interviews with equipment manufacturers' representatives, the following types of equipment were selected as being feasible for removing silt and clay in a post-sediment pond role on construction sites:

- Vacuum filters
- Upflow filters
- Tubular pressure filters or strainers
- Microscreens
- Hydrocyclones
- Separator screens

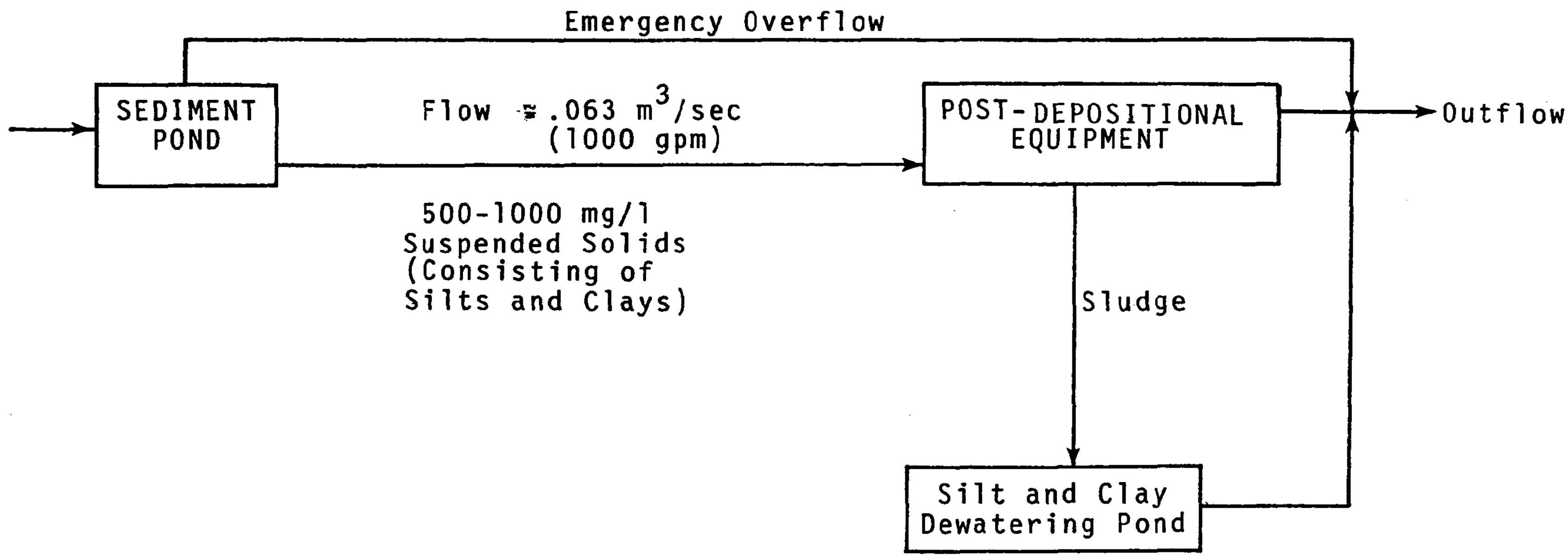


FIGURE 4. Basic Concept of Use of Post-Sediment Pond Equipment.

- Gravity settlers (inclined tube settlers)
- Centrifugal concentrators
- Two-stage separators

Vacuum Filters

The vacuum filter is similar to the more widely known pressure filter. The principal difference is that with a vacuum filter, filtration is performed in an open tank where the elements can be easily inspected. The pump of a vacuum filter is located on the discharge side, thus it is used to pump water away from the filter after it is filtered. The elements of a vacuum filter can be either of the cylindrical or the vertical leaf type.

A vertical leaf type vacuum filter is shown in Figure 5. Suspended material is caught and retained on the filter element. In the cylindrical or rotary type vacuum filter, a drum which is covered with the filter media revolves in a tank filled with the slurry to be filtered.

The filter elements of either type of equipment can be coated with a substance such as diatomaceous earth or other precoat material so that particles much finer than the openings in the filter element can be retained. Vacuum filters operate at low differential pressures, on the order of 0.42 to 0.70 kg/cm^2 (6-10 psi). When a precoat substance is utilized on a vacuum filter, particles down to about one micron in diameter can be removed and very clean effluents result. Influent slurries, however, usually must be limited to less than a one percent solids concentration. The vacuum filter can be cleaned by either hosing, internal sluicing, or air bump backwashing.

Upflow Filters

The upflow filter incorporates four sediment removal techniques, resulting in an overall effective method of water clarification. Basically, it involves the filtration of water in an upward direction through progressively finer filter media. This traps solids throughout the entire filter column. Gravity also plays a role in the upflow filter since the larger solids tend to settle out of the liquid being filtered as it works its way up through the media. Prevention of the movement of the filter materials is accomplished by the use of restrictive screens and grids. Polyelectrolytes can be added to the sediment-laden influent for further solids removal by the filter.

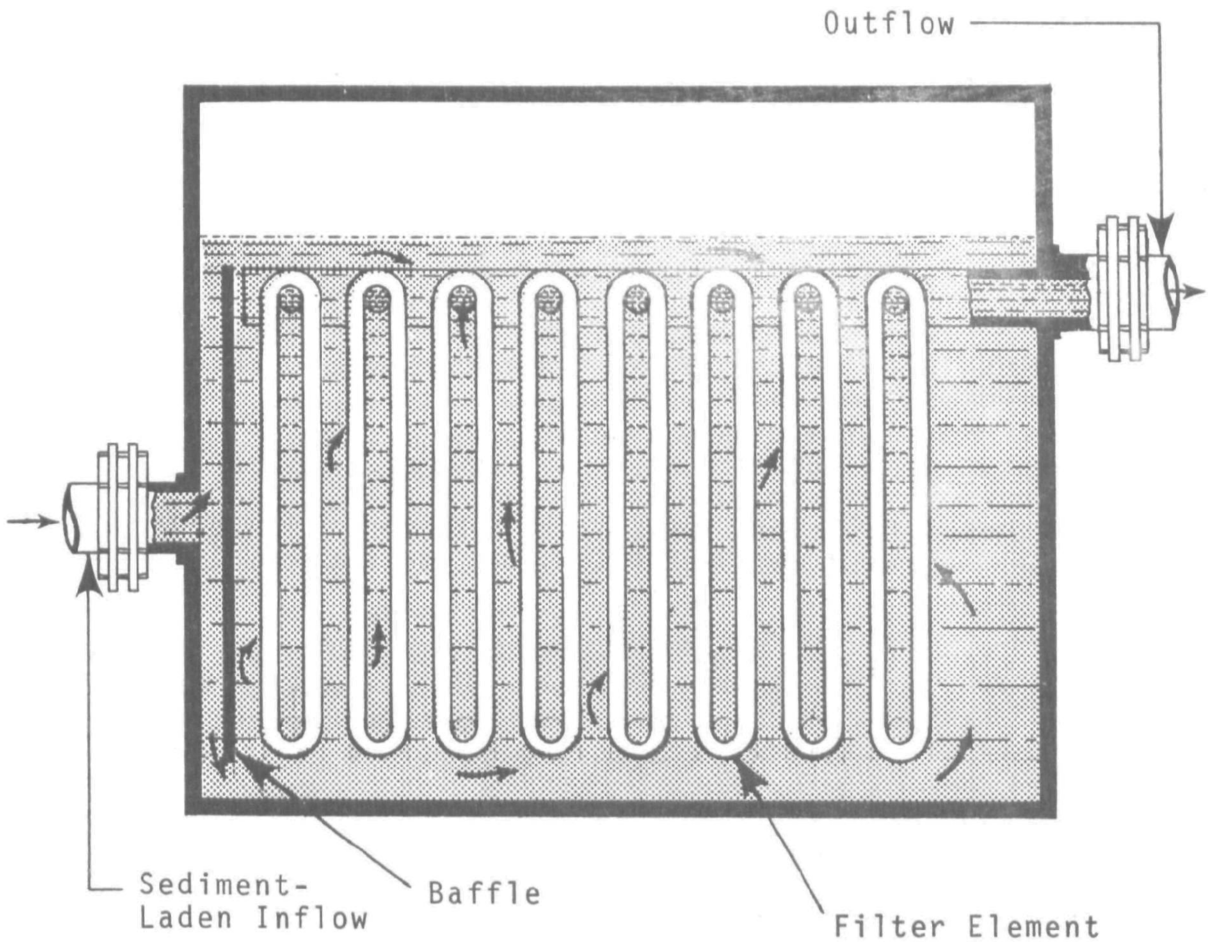


FIGURE 5. Cross Section of Typical Vertical Leaf Vacuum Filter.

Tubular Pressure Filters or Strainers

This unit consists of a vertical pressure vessel containing tubular filter elements. As shown in Figure 6, sediment-laden water, under pressure, enters the filter element chamber where the filter tubes or cartridges are housed. It is forced through the walls of the filter cartridges, with the clarified water flowing into the hollow cores of the cartridges and then being removed from the filter. Periodically, the particles are washed from the walls of the cartridges and discharged from the filter through a bottom drain. This cleansing action, termed backwashing, is accomplished by reversing the pressure in the filter and applying it from inside the cartridges toward the outside, thus knocking the particles off. The filters can also be equipped with disposable cartridges, which are replaced instead of backwashed when they become clogged.

Common materials which filter cartridges or tubes are constructed of include cemented sand grains, stainless steel screening, cellulose, and glass. The size of sediment particles to be removed by a filter depends upon the size of the void spaces in the material used in the cartridges. Sizes of particles removed range from a few hundred microns (sand) for some tubes made of stainless steel screening, to less than one micron (clays) for some special application cartridges. Filtering capacities per unit area of filter material decrease as the size of sediment particles removed decreases.

Filter elements can usually be precoated with a filter aid to remove a higher percentage of the sediments. When a filter aid is used, retention of particles down to a few tenths of a micron in diameter is possible.

These types of filters can be set up to be operated in the manual, remote manual, or fully automatic mode.

Microscreens

A microscreen consists of a rotating drum with a fine screen around its periphery. Feed water enters the interior of the drum through the open end and passes radially through the screen with deposition of solids on the inner surface of the screen. At the top of the drum, pressure jets of effluent water are directed onto the screen to remove the deposited solids. A portion of the backwash water penetrates the screen and dislodges solids which are captured in a waste hopper and removed through the hollow axle of the unit.

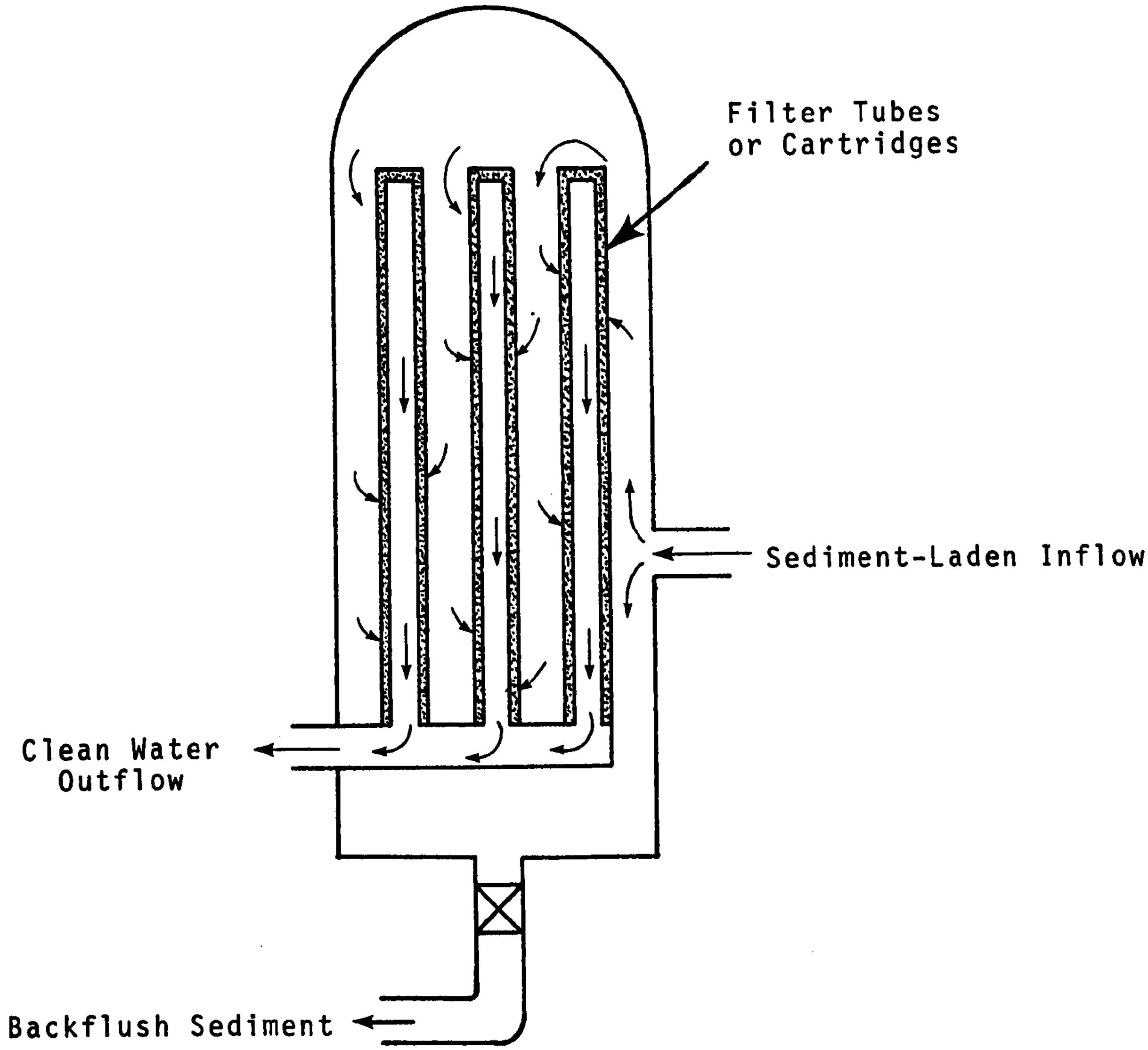


FIGURE 6. Simplified Operation of a Typical Pressure Filter or Strainer.

Hydrocyclones

A hydrocyclone uses centrifugal force to cause incoming fluid and sediment particles to accelerate rapidly and uniformly in an open conical section. Maximum centrifugal force is reached at a bottom orifice where rejected material is discharged. Clarified effluent is discharged from the top of the cone. Figure 7 shows the basic operation of a hydrocyclone cone.

Hydrocyclones are simple, efficient, and low cost devices for removal of sediment solids from sediment-laden water. There are no moving parts, and the removal of particles as fine as five to ten microns in diameter (silts and clays) can be accomplished. Incoming waters containing up to 16 percent solids can be treated.

Hydrocyclone cones come in a variety of sizes and a number of them can be grouped together in banks to obtain virtually any desired flow rate. The most common sizes which would be applicable to construction sites have top diameters which range from 5 to 30.5 cm (2 to 12 in.) in diameter. Generally, the smaller the cone size, the finer the particle size that can be removed at a given differential pressure (the difference between incoming and outgoing pressures), albeit at a smaller flow rate. Normally, hydrocyclones operate at pressure differentials between 0.7 and 4.2 kg/cm^2 (10-60 psi).

Separator Screens

This category of suspended solids removal equipment comprises a wide variety of vibrating screens. The screens normally consist of rectangular or circular structures supporting wire mesh screens. Water is introduced directly onto the screen surface. Solids are detained on the surface while the screened water exits downward through the screen. Trapped solids are vibrated to the outer periphery of the screen element for disposal.

Screens are available to remove a wide range of particle sizes. Particle sizes removed by these screens ranges from a few hundred microns in diameter (sand) to somewhat less than 50 microns. Sediment removal rate decreases, of course, with decreasing size of particle removed.

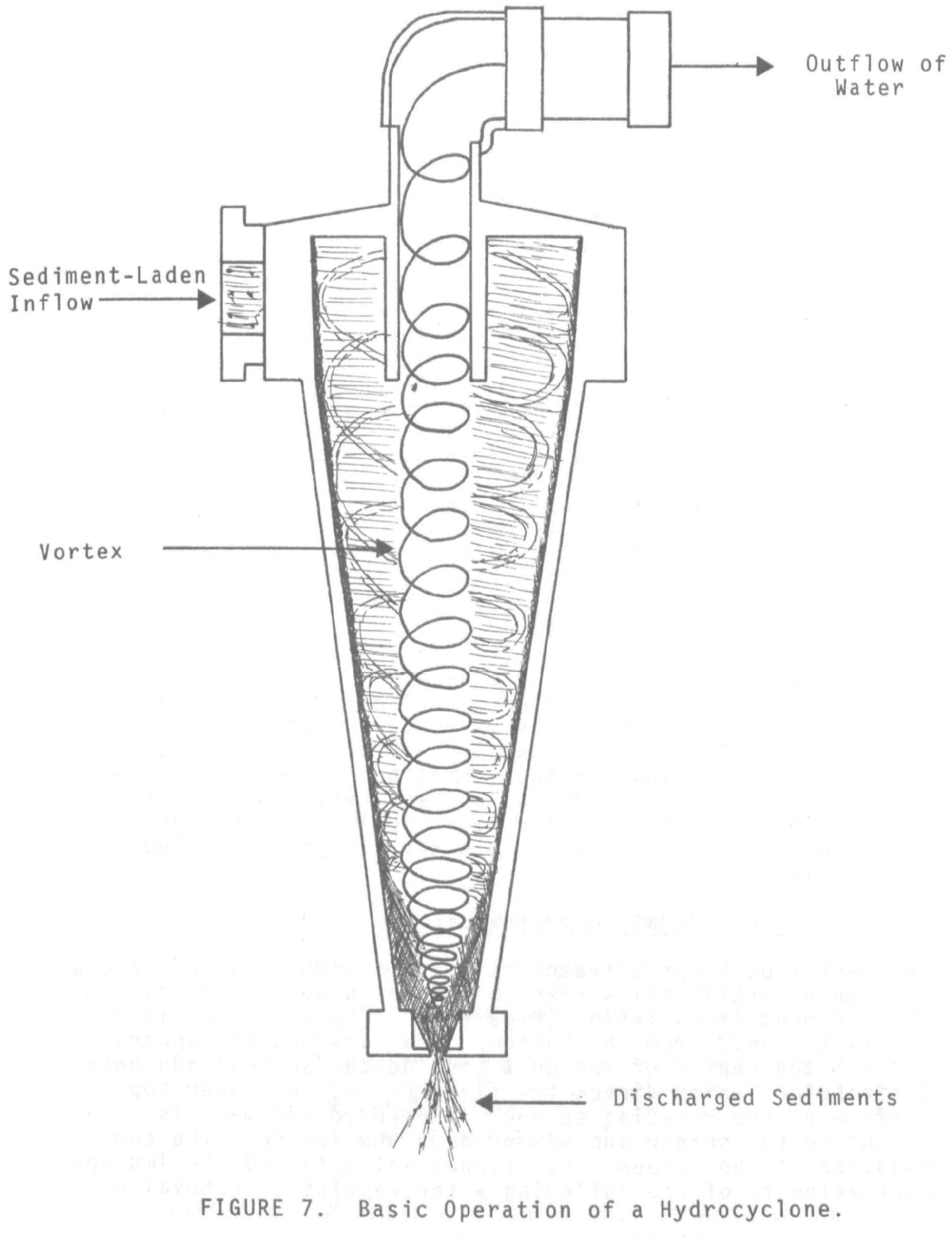


FIGURE 7. Basic Operation of a Hydrocyclone.

Gravity or Inclined Tube Settlers

The principle of operation of the inclined tube settler is illustrated in Figure 8. Water entering from the bottom of the tube and flowing up the tube at velocity v_f contains particles having a settling velocity, V_s. The resultant velocity vector, v_r, tends to move the particles toward the tube wall where they become entrapped in a layer of particles previously settled. The steep inclination of the tubes causes the sludge to counterflow along the side of the tubes after it accumulates. It then falls into a sediment storage sump below the tube assembly. The inclined tube settler configuration also requires influent and effluent chambers to distribute the flow to the tubes and to collect it after clarification.

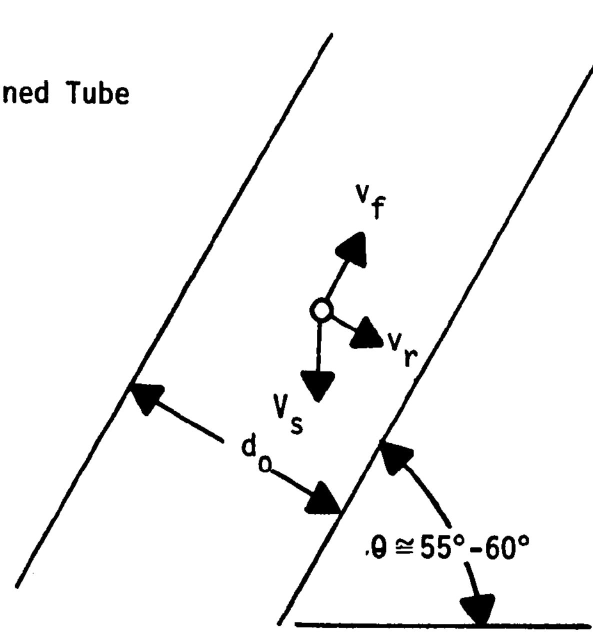
Inclined tube settlers are manufactured with tubes having various geometrically-shaped cross sections. Systems employing flocculation with inclined tube settlers are capable of removing particles less than 10 microns in diameter (fine sand). They are usually used to clarity influent waters which have under 1000 mg/l of suspended solids. Typical flow rates through inclined tube settlers are on the order of 8.5 to 14.2 liters/min/m^2 (3 to 5 gpm/ft^2). The number of tubes may be increased to provide treatment for virtually any flow rate desired.

There is limited operating data available on gravity settlers which is applicable to construction site installations, however, most installations have produced satisfactory performance. Problems with buildup of slime growth, which may constrict shallow passages, have been reported, consequently, periodic cleaning may be required. In view of this factor, an allowance for accessibility to the settling units should be incorporated into the design of inclined tube facilities.

Centrifugal Concentrators

The centrifugal concentrator utilizes a high flow rate and a fine-mesh centrifugal screen to remove suspended solids from the sediment-laden inflow (Figure 9). The incoming fluid enters the unit from the bottom. The flow travels upward through the center of the unit (inside the screen) and onto distributors which direct the flow against the inner top surface of the rotating screen. Suspended sediment is caught in the screen and washed down the inside. The combination of the screen's rotational velocity and the impingement velocity of the inflowing water results in removal of

Single Inclined Tube



$$(v_f) \text{ maximum} = \frac{V_s \bullet L \cos\theta}{d_o} \qquad \text{(Simple Theory)}$$

where:

- v_f = flow velocity through the tube
- v_r = resultant velocity vector
- V_s = settling velocity of a particle
- L = length of the tube
- θ = inclination angle
- d_o = diameter of the tube

FIGURE 8. Principle of Operation of an Inclined Tube Settler (Ref. 22).

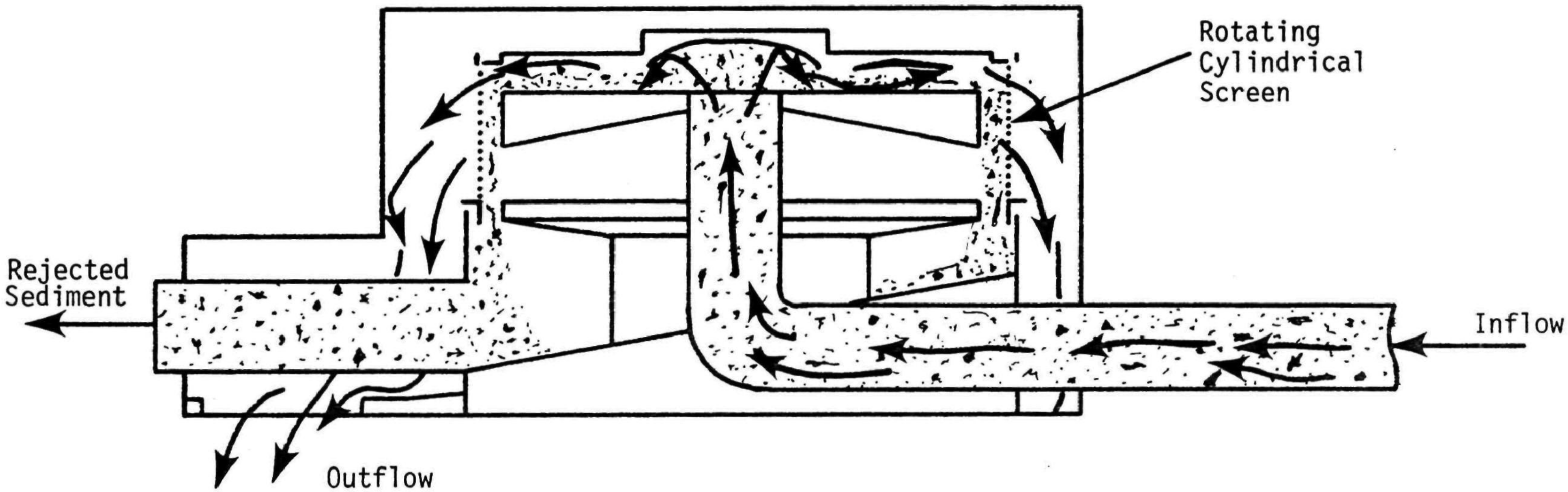


FIGURE 9. Cross Section of Centrifugal Concentrator.

particles smaller than the screen mesh openings. These centrifugal units can remove particles down to around 40 or 50 microns in diameter (silts).

Two-Stage Separators

This equipment is similar to conventional hydrocyclones. However, instead of the standard cone shape, the walls of the separator are cylindrical. Therefore, flow velocities decrease as solids are spun through orifices in the center rather than increase as in standard hydrocyclones.

The flow enters the separator at a high velocity. Solid matter is spun through tangential openings in the inner shell and settles to the bottom of the separator where it is discharged. After the sediment has been removed, the water exits at the top of the separator. Removals of up to 98 percent of all solids greater than 44 microns (silt) have been reported for this piece of equipment.

Cost-Effectiveness

Table 10 presents a summary of the capital costs and relative effectiveness of the various pieces of post-sediment pond equipment identified above. Included are capital cost per unit of flow, anticipated smallest diameter particle removed, design flow rates of the equipment, and the ancillary equipment, supplies, power, and facility requirements.

The table provides a compilation of the data received from a number of manufacturers of the equipment. Hence, the unit capital costs show quite a variance for some of the pieces of equipment. The smallest particle size removed also varies somewhat, depending upon the manufacturer. The actual cost to a contractor will vary depending upon the exact specifications of the equipment. For example, whether or not such things as automatic solids unloading, automatic backflushing, totally automatic operation, and the required feed pump are specified will have a bearing on the total investment which must be made. Table 10 is provided as a general guide to the relative costs and sediment particle sizes removed by the various pieces of equipment. Specific site characteristics and the amount of fine-grained sediment either removed by sediment ponds or retained on site by other techniques will determine whether or not the use of post-sedimentation equipment is necessary and, if it is necessary, what type of equipment would be the most effective for a specific construction site. The particle size of

Table 10. POST-SEDIMENT POND EQUIPMENT COSTS AND REMOVAL EFFICIENCIES

Equipment Type	Unit Capital Cost (1975), $/liter/min ($/gpm)	Approximate Smallest Particle Removed (microns)	Design Flow, liters/min (gpm)	Remarks
Vacuum Filter Vertical Leaf, Diatomaceous Earth Filter Coat	71 (270)	1 (fine clay)	1100 (300)	Requires centrifugal pump and electricity. The system is self-contained and skid-mounted. Clean water for initial filling and washdown must be available. A simple equipment shelter is required.
Rotary Drum with Precoat	528 (2000)	1 (fine clay)	160 (40)	Requires two pumps and electricity. Precoat material not included in price. Uses about 1450 kg (3200 lb) of precoat each 24 hr of operation.
Upflow Filters	21-25 (80-95)	2-10 (clay-silt)	3780 (1000)	Feed pump required. Can be skid-mounted. Polyelectrolyte costs not included.
Tubular Pressure Filters or Strainers	5-13 (20-50)	30 (silt)	3780 (1000)	Pump required. Incoming solids limited to about 1000 mg/l. Includes automatic backflush.
Microscreens	17-23 (63-88)	20-40 (silt)	2650-3290 (700-870)	Requires electric power supply, leveled pad, wash water supply and pumps. Cost includes pump and controls.
Hydrocyclones	1-3 (4-10)	10-20 (silt)	3780-4160 (1000-1100)	Includes all valves, gauges, supports, headers, and piping. Requires feed pump. Skid-mounted.
Separator Screens	3-17 (10-63)	45-50 (silt)	190-1900 (50-500)	Electrical power required. Cost includes screen motor. Site requirements include a level base, and a possible support frame for the feed unit.
Gravity or Inclined Tube Settlers	31-48 (127-182)	1-10 (clay-silt)	470-2400 (120-920)	Requires influent pump. Particle size removed assumes flocculant addition. Unit is fully assembled and ready to install.
Centrifugal Concentrator	16 (60)	44 (silt)	1890 (500)	Cost includes feed pumps and electrical controls. No special foundation or enclosure required. Influent range = 2000-3000 mg/l suspended solids. Requires electrical power.
Two-Stage Separator	3-9 (10-35)	44 (silt)	1510-4540 (400-1600)	Feed pump required. Rated to remove 98% of particles of specified size.

the fine-grained sediment which must be removed to meet a specific effluent water quality is, of course, one of the basic considerations.

The applicable post-sediment pond equipment identified in Table 10 were further analyzed to determine which pieces of equipment have the highest applicability to construction site conditions. The equipment parameters which were most important in this analysis included the ability to process at least 3780 liters/min (1000 gpm) with suspended solids contents of not less than about 1000 mg/l at a cost which is not prohibitive. For example, many of the pieces of equipment consist of individual units which process a given flow. The number of units on line can therefore, theoretically, be increased to handle any specified flow. However, in many cases the cost of such multiple units quickly becomes prohibitive.

Table 11 summarizes the initial costs of the most feasible post-sediment pond equipment. The equipment is grouped according to smallest particle size which each type is capable of removing.

Data presented in Table 11 indicates that as the particle size which is desired to be removed decreases, the equipment cost generally increases. The notable exception to this is the use of hydrocyclones. Hydrocyclones are reported to be capable of removing a large percentage of fine-grained sediment particles at a reasonable cost. Therefore, they would probably be the most useful for fine-grained sediment control in the widest variety of situations.

The investment which one is willing to make in the purchase of post-sediment pond equipment is dependent upon the severity of the fine-grained sediment problem and the total cost of the construction. In some instances, removal of particles less than ten microns in diameter may be required. If total project costs and anticipated future usage justifies the investment, the use of upflow filters, or gravity or inclined tube settlers as post-sediment pond devices is indicated.

In summary, then, if the use of post-sediment pond equipment is indicated, hydrocyclones appear to be able to provide the broadest range of protection against fine-grained sediment pollution at the most reasonable cost. If the removal of particles smaller than ten microns in diameter is required, upflow filters or gravity (inclined tube)

Table 11. COSTS AND REMOVAL EFFICIENCIES OF MOST FEASIBLE POST-SEDIMENT POND EQUIPMENT

Smallest Diameter Particle Removed (μ)	Equipment Type	Approximate Average Initial Cost ($)*
1-10† (clay-silt)	Upflow filters	95,000
	Gravity (inclined tube) settlers	110,000
10-20 (silt)	Hydrocyclones	7,000
20-30 (silt)	Tubular pressure filters/strainers	50,000
30-50 (silt)	Two-stage separator	20,000

*Based on a design inflow of 3780 liters/min (1000 gpm).

†With the addition of a chemical flocculant.

settlers with the addition of chemical flocculants would probably be the most efficient at the most reasonable equipment cost. It is recommended, of course, that the decision to purchase post-sediment pond equipment also take into account the need for the equipment on future construction sites.

SECTION VII

REMOVAL AND DISPOSAL OF SEDIMENT FROM DETENTION PONDS

Removal

When a sediment pond becomes filled, its efficiency for removing sediment decreases. Removal of the sediments accumulated in ponds should, therefore, be done on a periodic basis at any construction site in order to keep the ponds functioning at their maximum efficiency. There are a number of means by which this can be accomplished. The various alternatives are discussed below. The feasibility of utilizing a specific method at a specific site will depend upon site constraints such as the size of the sediment basin, equipment availability, and time constraints.

Conventional Draglines

One of the commonly used methods of cleaning ponds involves the use of a crane with a dragline bucket attached. The crane is located on the bank of the pond. Through rapid rotation of the boom, the bucket is thrown into the pond and then hauled in as it scrapes, from the bottom, a load of sediments. The entrapped material is either piled in windrows along the bank of the pond or loaded directly onto trucks.

The reach of a dragline is usually limited to about 18 meters (60 ft) from the crane. A longer reach can be achieved if a long boom is used; however, this practice results in less efficient use of the bucket. In addition, the long boom can present difficulties in transporting the dragline equipment to the pond site. Thus, the cost per yard removed by a dragline with a conventional boom usually is significantly lower than one with an extra long boom. Sediment removal with a conventional dragline is, therefore, limited to removing the material from ponds up to 36 meters (120 ft) wide, or from the edges of larger ponds. Since the dragline is positioned on the edge of a sediment pond, it can be used to clean ponds with bottoms that are too soft to support other types of cleaning equipment which must enter the pond, after it is drained, to remove the sediment.

The cost of cleaning a sediment pond by dragline is about \$3.20 per cubic meter (\$2.50/yd^3) removed (Ref. 32).

Front-End Loaders

Standard front-end loaders are often used to enter a pond and remove the accumulated sediment. A pond must first be drained prior to cleaning operations to allow enough time for some sediment dewatering and drying to take place. Then, the front-end loader enters the pond and removes the sediment.

This method of sediment removal is less expensive than use of a convertional dragline. However, two important considerations will limit its use:

- The pond must be drained and dewatered beforehand. Thus, use of the pond for sediment retention is lost for a longer period of time than with a conventional dragline operation.

- Specific site and/or pond bottom characteristics may preclude use of this method if the front-end loader cannot enter the pond at all.

Crane-Operated Scrapers

Sediment removal by this equipment involves basically a variation of the conventional dragline approach. This equipment, however, increases the effective reach of a crane to over 300 meters (1000 ft).

Figure 10 shows two different approaches for the use of crane-operated scrapers. Several manufacturers produce scrapers which are compatible with them. Basically, as shown in the figure, the scrapers are hauled in by cranes or winches, but are returned by a cable attached to a "dead man", or support mechanism, located on the bank of the pond, some distance away. As the scraper is being hauled in, it functions in the same manner as a conventional dragline bucket in that it scrapes the bottom and accumulates a load of sediment which it transport toward the crane. The sediment is piled along the side of the pond for subsequent

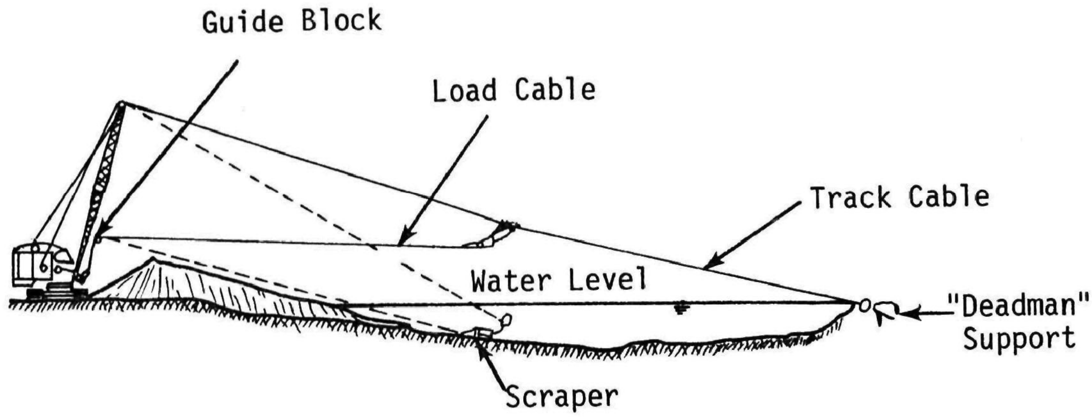


FIGURE 10a. Arrangement for Crane-Operated Scraper.

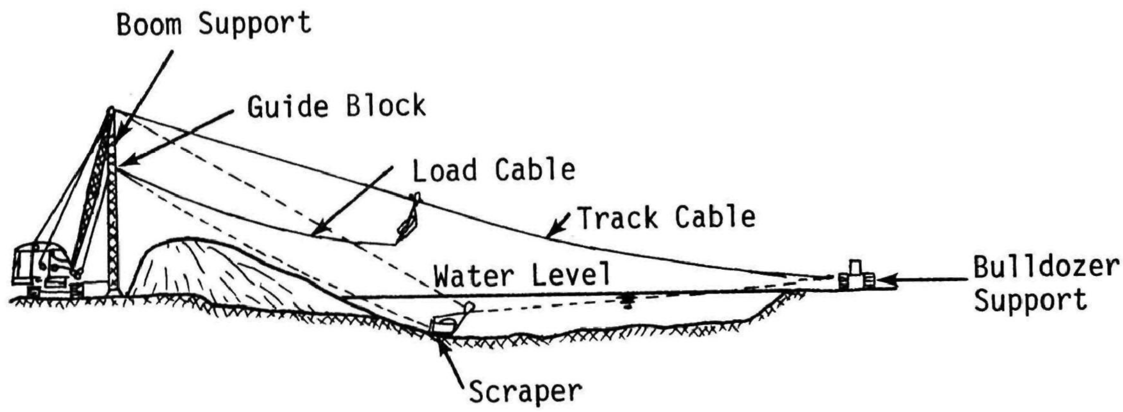


FIGURE 10b. Alternate Arrangement for Crane-Operated Scraper.

removal by front-end loader and truck. Larger scrapers can be used and greater mobility achieved by using a boom support for the crane and a bulldozer for the tail anchor, as shown in Figure 10 b. Like the conventional dragline, they can be used where pond bottoms are too soft to provide a firm foundation for other types of equipment.

Costs for sediment removal are roughly equivalent to those of a conventional dragline, because the economics inherent in the longer reach of the scraper roughly offset the additional initial set up costs and possible additional spoil handling costs.

Hydraulic Dredges

Small hydraulic dredges are available which can be used to clean sediment ponds. Usually, these dredges are equipped with mechanical augers or cutter teeth which loosen the sediment. Sediment is then pumped into a submerged intake pipe attached to or directly behind the auger or cutter teeth. Discharge from the dredge pump is directed to a spoils area for subsequent dewatering. Resuspension of the sediment in the pond is kept to a minimum during the dredging activity since water is continually being drawn into the intake pipe. Some hydraulic dredges are even equipped with shields over the intake pipe to further reduce suspended sediment movement.

One difficulty connected with this method of sediment removal is the problem of the proper disposal of the large quantities of water pumped along with the sediment. Since the solids content of the dredged slurry is sometimes less than 10 percent by weight, adequate containment basins must be provided to dewater, dry, and otherwise handle the dredged material.

Generally, cleaning of a sediment pond by hydraulic dredging becomes more economically feasible as the size of a pond increases. In addition, it must contain water of sufficient depth to float the dredge throughout the sediment-removal operation. Therefore, hydraulic dredging is most likely a feasible alternative for sediment removal in ponds with an area of 0.4 hectare (1 acre) or larger and located across a drainageway which has a constant inflow. Small hydraulic dredges which could be used to clean sediment ponds have a minimum pumping rate of about 0.09 m^3/sec (1500 gpm). Thus, a pond will require at least that amount of inflow to keep them afloat unless discharge water is decanted and recycled after flowing through the containment basin.

Dewatering and Drying Techniques

Once sediment has been removed from a sediment pond, it must be dewatered and/or dried before it can be properly disposed of or reused. If the sediment is removed by equipment other than a hydraulic dredge, much less water is included; as a result, it is much easier to dewater further. If it was removed via hydraulic dredging, up to 90 percent of it by weight could be water, thus causing a more time-consuming dewatering process. Presented here are techniques and alternatives which appear promising for use in the dewatering and drying of fine-grained sediments after they have been removed from a sediment pond.

Use of Drying Beds

With this technique, sediment that is removed from a sediment pond is placed in a drying bed which has a sand/gravel layer at the bottom. It results in downward drainage of water and consequent dewatering of the material. The sand/gravel layer is connected to an underdrain system which carries the water away from the sediment. One drawback to the use of this technique involves the clogging of the sand/gravel layer by the fine-grained sediment.

Some success has been reported on the use of this technique as an aid in dewatering fine-grained sediment which was removed from a pond by a crane-operated scraper. In one study, the use of gravity drainage beds did increase the dewatering rate of fine-grained sediment which was removed from a pond, as compared to simply dumping the removed sediment into a confined disposal area (Ref. 32).

Rehandling of Deposits

Simple rehandling of fine-grained sediment removed from ponds is presently being used by the sand and gravel processing industry as a means of drying and dewatering it before truck transport (Ref. 33). The settled sediment is removed with a crane and dumped into an adjacent containment area. Later, this containment area is cleaned again by the crane. By this time, enough water has drained from the slurry so that it can be cast directly onto the ground, without the need for confining dikes, for further drying. When sufficiently dry, the fine-grained sediment is loaded onto trucks with a front-end loader, and transported off the site.

The main disadvantages of this operation involve the relatively large amount of area required and the relatively long drying period. Sufficient time and area must be provided for dewatering and handling the material. As an aid to dewatering, a gravel filter layer and underdrain system could be used. This could decrease the dewatering times required between handling operations.

Reworking of Deposits

Reworking the top portions of fine-grained sediment deposits which have either been removed from a sediment pond, or remain in the pond after the pond has been drained, has proven to be effective in increasing the dewatering rate. When the surface has been reworked, the water which is brought to the surface evaporates.

Experiments performed on sediment removed from a pond by a crane-operated scraper showed that surface scarification was effective in aiding the immediate drying of the sediment to a depth of approximately 0.3 meter (1 ft) (Ref. 32). The scarification was found to be most effective on the finer-grained materials.

Field trials have been conducted in which a conventional tracked vehicle was used to continually agitate the surface of a containment basin which was filled with sediment deposited via a hydraulic dredge. Consolidation and dewatering was obtained in a much shorter period of time than if the material was allowed to dewater naturally (Ref. 34). The use of a twin helical screw amphibious vehicle to produce continual surface roughening of deposited sediment in order to enhance drying has also been successfully demonstrated (Ref. 35).

Other Techniques

The following dewatering and drying techniques which may be applicable to the fine-grained sediment problem have been identified. They have not been field tested on a large scale and thus are not readily available for immediate application on construction sites.

Thickening Followed by Vacuum Filtration

A potentially useful concept for the dewatering of fine-grained sediment which has been investigated for possible use in the restoration of the clay spoil ponds in the sand and gravel processing industry is shown in Figure 11 (Ref. 33). This method consists of the use of a standard settling tank such as those used in the wastewater treatment industry followed by a rotating drum vacuum filter.

An experimental system was designed to process 0.12 m^3/sec (1950 gpm) of a clay slurry which was to be removed by pumping from the bottom of a pond. This technique shows promise as a means for dewatering fine-grained sediment, as no cranes would be necessary to handle the silt, clay, and water mixture and the use of trucks would be reduced. The cost of such a system, however, is estimated to be over $100,000. Full scale prototype operations are planned to further refine this technique.

Centrifugation

Centrifuges mechanically dewater sediment through the use of centrifugal force. This technique has long been used for the dewatering of sewage sludges, and standard mechanical centrifuges are available. At present, the most commonly-used centrifuge for sludge dewatering is the solid bowl centrifuge. It provides fairly good dewatering and produces solids concentrations of the discharged solids in the range of 15 to 35 percent by weight. The use of centrifuges for dewatering fine-grained sediment deposits is relatively expensive, and thus their practical use on construction sites is probably limited.

Mechanically Drying and Heating of Materials

Large mechanical dryers and heaters, used for a variety of drying tasks in the chemical and mineral processing industries, may be used for sediment dewatering purposes. A common type of dryer is the rotary dryer, in which heat is supplied to a large, continuously-rotating drum. The rotating dryer shell exposes the wet surfaces of the sediment particles to the drying media as they are conveyed at a controlled rate through the dryer. The applicability of this technique to the drying of fine-grained sediment removed from ponds would be limited by the availability of sufficient fuel and power for heating. In addition, capital, operation, and maintenance costs are much higher for this technique than for other standard methods of dewatering or drying.

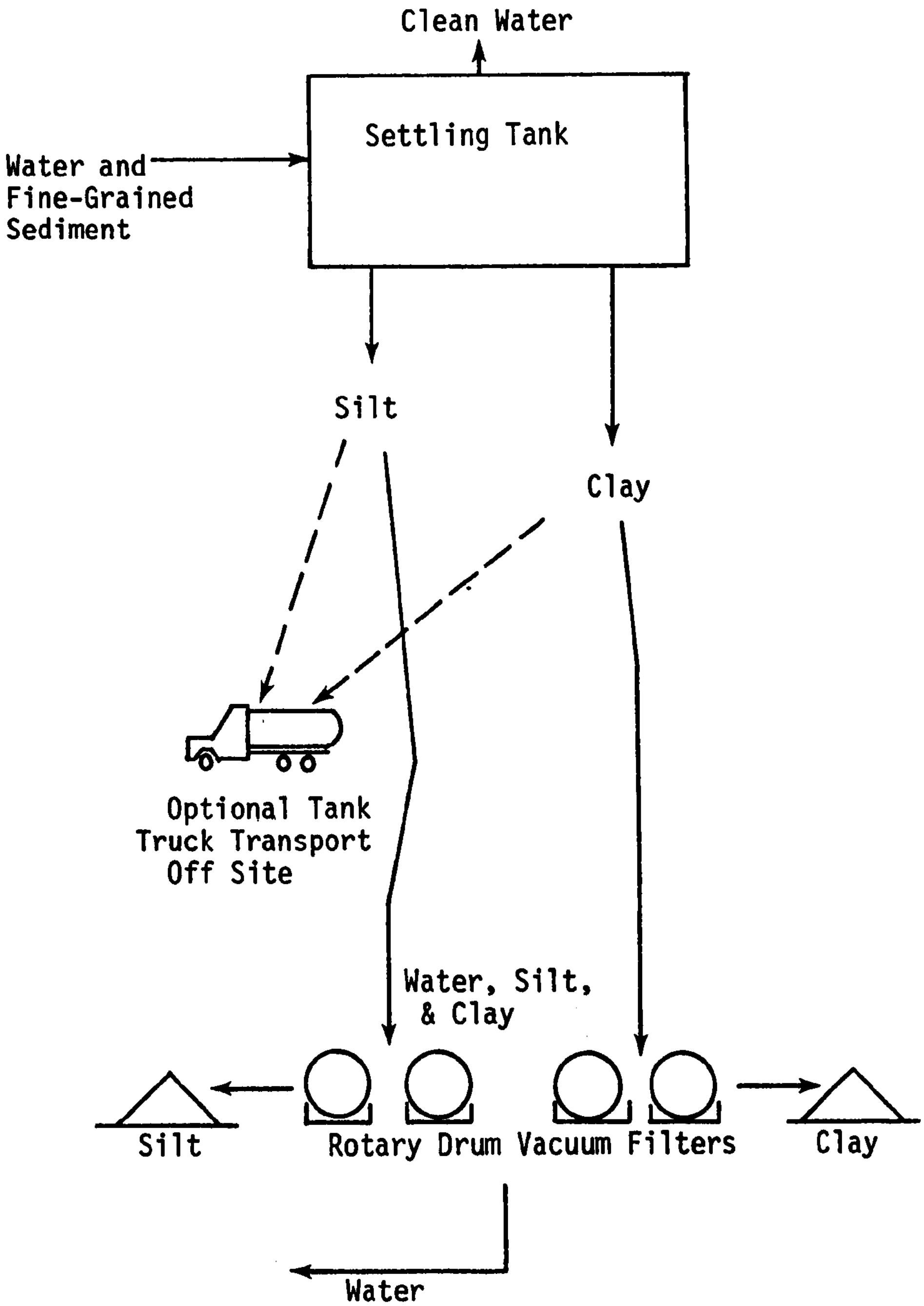


FIGURE 11. Settling Tank - Vacuum Filtration Technique for Dewatering Fine-Grained Sediment.

Capillary Enhancement

Experiments conducted in the past have shown that vertical capillary wicks have the potential for removing water from subsurface zones of dredged material fills, promoting the formation of a surface crust, and increasing the evaporation rate from the material. Further laboratory evaluations are planned if an initial state-of-the-art assessment proves the practicability of the technique (Ref. 36).

Reuse of Sediments

The disposal of fine-grained sediments after they have been removed from a sediment pond and sufficiently dewatered has always been a problem. If space is available, spreading in another area and stabilizing through the establishment of a vegetative cover offers perhaps the most practical solution.

Some research has been performed on the utilization of fine-grained sediments for a variety of other purposes. Some promising results have been obtained regarding the use of dredged sediments for a variety of agricultural purposes such as turf farming and the rehabilitation of eroded and depleted soils. For example, the following utilization procedures were found usable for disposing of sediments which are continuously being removed from the Delaware River and Bay (Ref. 37) during maintenance dredging operations:

- The application of sediments to light sandy soils to improve their agricultural potential at rates of 450 to 670 metric tons per hectare (200-300 tons/acre).
- The application of sediments also to heavier soils without reducing their agricultural potential.
- The additions of sediments to beach sands for establishing vegetative cover.

During another study, the feasibility of enhancing dredged sediments in order to acquire a material with improved characteristics for the growing of grass was investigated. Several low cost and readily available materials were tested for their effectiveness as conditioners for sediment which had been removed from a sediment pond. They include digested sewage sludge, fly ash, woodchips, crushed dolomite, and 10-10-10 fertilizer. Good grass germination and growth were achieved on a number of plots (Ref. 32).

The use of fine-grained sediments as fill material for engineering purposes has often been proposed. The ideal material for this use would probably be clean sand, however, both coarse- and fine-grained sediments have been used (Ref. 38). For most engineering uses, fine-grained sediments will have to be blended with coarser-grained sediment in order to obtain material with acceptable physical characteristics such as shear strength, cohesion, permeability, and plasticity.

Some research has been performed on the utilization of the fine-grained sediments, particularly the clays, for the manufacture of bricks (Ref. 39). The results indicate that although technologically feasible processes can be developed, the immediate commercial feasibility of the clay utilization is limited because of the variability in the quality of the clays obtained.

Overall, the determination as to what possible reuse will be made of the fine-grained sediments removed from a sediment pond will depend upon what alternatives are available in the immediate vicinity of the construction site. A variety of agricultural uses appear to be feasible, but their ultimate use would depend upon the cost of transporting the sediments from the construction site to the point of use. Generally, there is always some need for fill material in the general area surrounding a construction site. Again, the economics of transporting the sediment to its point of need, the physical characteristics of the sediment, and the proposed use of the fill would dictate whether or not this is a feasible alternative.

SECTION VIII

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APPENDIX

SOME POST-SEDIMENT POND EQUIPMENT MANUFACTURERS

Included below is an alphabetical listing of some manufacturers of the post-sediment pond equipment which was selected as being feasible for fine-grained sediment control and removal. Detailed performance and other data is available from them.

Ametek
Process Equipment Division
East Moline, Illinois 61244

C.E. Bauer
The Bauer Bros. Co.
Springfield, Ohio 45501

BIF
A Unit of General Signal
West Warwicke, R.I. 02893

Crane Co.
Cochrane Environmental Systmes
800 3rd Avenue
P.O. Box 191
King of Prussia, PA 19406

Croll-Reynolds Engineering Co., Inc.
1122 Main Street
Stamford, CN 06902

The De Laval Separator Company
Poughkeepsie, NY 12602

DEMCO Incorporated
845 S.E. 29th Street
Oklahoma City, OK

Dorr-Oliver, Inc.
2051 W. Main Street
Stamford, CN 06904

Envirex, A Rexnord Company
Water Quality Control Sales Office
10380 Drummond Road
Philadelphia, PA 19154

Eriez Magnetics
Asbury Road at Airport
Erie, PA 16512

Johns-Manville
Filtration & Minerals Division
Greenwood Plaza
Denver, CO 80217

Laval Separator Corp.
1899 N. Helm Street
P.O. Box 6119
Fresno, CA 93727

Parkson Corp.
5601 N.E. 14th Avenue
Ft. Lauderdale, FL 33334

Roberts-Boze, Inc.
2611 Sharon Street
Kenner, LA 70062

Rotex, Inc.
1230 Knowlton Street
Cincinnati, OH 45223

Serfilco
Division of Service Filtration Corporation
1415 Wankegan Road
Northbrook, IL 60062

Sweco, Inc.
6033 E. Bandini Blvd.
P.O. Box 4151
Los Angeles, CA 90051

Zurn Industries, Inc.
Water and Waste Treatment Div.
Erie, PA 16518

TECHNICAL REPORT DATA

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1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA 440/9-76-026		

4. TITLE AND SUBTITLE "Methods To Control Fine-grained Sediments Resulting From Construction Activity"	5. REPORT DATE 12/15/76 (Approval Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Michael Nawrocki and James Pietrzak	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hittman Associates, Inc. Columbia, Maryland 21045	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-01-3260
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Water Planning and Standards Washington, D.C., 20460	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This publication is the third in a series issued under Section 304(3)(2)(C) of Public Law 92-500 concerning the control of water pollution from construction activity. It was prepared for use by planners, engineers, resource managers, and others who may become involved in programs to effectively provide for sediment control. Standard erosion and sediment control measures are usually effective for preventing the runoff of the total sediment load. The effectiveness of these standard techniques; however, has been found to be relatively poor with regard to preventing the runoff of the fine-grained fractions, such as the silts and clays.

The objective of this study was to research practical, cost-effective methods which would help to reduce specifically the fine-grained sediment pollution derived from construction activities. The prime consideration during this study was the use or adaptation of existing technology, as described in the current literature or data, to the fine-grained sediment pollution problem.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sediment Control, Pollution Abatement Soil Erosion, Water Erosion, Construction	Sediment Control Water Pollution Water Erosion	1312, 0807, 0203, 0201, 1308

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES 75
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA Form 2220-1 (9-73)