DESIGNING AN EFFECTIVE SCS BY TREATING SEDIMENT WITH POLYMERS

by

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BIOGRAPHICAL SKETCH

After earning his doctorate degree in engineering from Utah State University in 1979, Dr. Fifield has worked continuously as a consultant and expert witness. Since 1982 when he started HydroDynamics Incorporated, he has been actively involved with drainage, sediment and erosion control, water rights and nonpoint pollution control. He has authored numerous papers, researched erosion control products, has authored sediment and erosion control manuals for designers and field manuals for inspectors and contractors, and provides expert witness services.

ABSTRACT

If a Sediment Containment System (SCS) is to be effective for capturing a design size particle by gravity, it must allow for the flow of water through the system and provide sufficient time for sediment deposition. Traditionally, attempts at this goal include specifying a capture volume of 252 cubic meters per hectare (3,600 cubic feet per acre) or capturing a design size particle (e.g., 0.02 mm in diameter) found in incoming runoff waters. Unfortunately, practicality usually results in development of a SCS that:

1. Captures only large (e.g., medium silt and larger) diameter particles,
2. Does not prevent colloidal size particles from discharging out of the system,
3. Requires large containment systems to ensure sufficient settling times,
4. Does not address discharges that are larger than design specifications, which results in additional sediment leaving the site, and
5. Has a net effectiveness for capturing sediment that is often much less than 100%.

This paper presents equations and graphs that demonstrate how SCS parameters change when treatment of sediments and inflow waters by a polymer happens. By incorporating the results from laboratory analyses of representative contributing soils samples into equations found in Fifield (2004), an evaluation of vertical terminal velocity and acceleration conditions occurs. Upon developing and applying the new equations to various examples, it is possible to illustrate that when adding polymers to incoming runoff waters in a controlled manner, the net effectiveness for a SCS to remove sediment from runoff waters can approach 100%.

Initial assessment indicate that pond surface areas may be up to 94% smaller with polymer treated sediments when compared to non-treated systems and may need only about one-fourth of the flow path distances. Finally, the equations also provide a method to assess how nephelometric turbidity units (NTUs) will vary for discharge waters when the design of an SCS structure is not adequate.

Key Words: Effectiveness; Sediment Control; Water Quality; Effluent Guidelines; Polymers

1.0 INTRODUCTION

Sediment containment systems (SCSs) are hydraulic controls that function by modifying the storm runoff hydrograph and slowing water velocities to allow for the deposition of suspended particles by gravity. Some of the more common names for these structures are sediment basins, sediment ponds, and sediment traps. When SCSs are designed correctly, they:

- Provide containment storage volume for incoming runoff waters,
- Create relative uniform flow zones within the containment system for disposition of suspended particles, and
- Discharge contained water at a controlled rate.

If a SCS is to be effective for capturing a design size particle by gravity, it must allow for the flow of water through the system and provide sufficient time for deposition of the sediments. One method to accomplish this task is to capture a design size particle (e.g., 0.02 mm in diameter) with no treatment to incoming runoff waters.

2.0 DESIGN OF AN SCS TO CAPTURE UNTREATED SUSPENDED PARTICLES

Fifield (2004) demonstrated that the following equations apply to any SCS:

$$\mathbf{SA_{min} = (SF \times Q) \div V} \qquad \textbf{Equation 1}$$

$$\mathbf{L_{min} = (L{:}W_e \times SA_{min})^{0.5}} \qquad \textbf{Equation 2}$$

$$\mathbf{W_e = SA_{min} \div L_{min}} \qquad \textbf{Equation 3}$$

$$\mathbf{Vol_{min} = Depth \times SA_{min}} \qquad \textbf{Equation 4}$$

$$\mathbf{NEff = AEff \times PEG} \qquad \textbf{Equation 5}$$

Where SA_{min} = Minimum Surface Area of SCS (square meters or *square feet*)

SF = Safety Factor of 120 (SI Units) or *1.2 (English Units)*

Q = Design Discharge from the SCS (cubic meters per second or *cubic feet per second*)

V = Vertical Velocity of Design Particles (centimeters per second or *feet per second*)

L_{min} = Minimum Flow Path Length within the SCS (meters or *feet*)

$L{:}W_e$ = Length to Width Ratio of the SCS (having values that range from 0 to 10)

W_e = Effective Width of the SCS (meters or *feet*)

Vol_{min} = Minimum Containment Volume of the SCS (cubic meters or *cubic feet*)

Depth = Minimum Pond Depth (meters or *feet*)

NEff = Net Effectiveness of an SCS to remove all suspended particles

AEff = Apparent Effectiveness of an SCS to remove design size particles

PEG = Percent of particles that are Equal to or Greater than a design size particle

Equations 1 through 4 are applicable for a large facility (e.g., a detention pond) that is converted into a SCS to capture design size suspended particles and when nearly constant vertical and horizontal flow velocity conditions exist. When a downward acceleration of suspended particles does not exist, then an estimated terminal velocity, V_s, can be calculated using Stokes' Law. Substituting terminal velocity into Equation 1 yields:

$$\mathbf{SA_{min} = (SF \times Q) \div V_s} \qquad \textbf{Equation 6}$$

2.1 EXAMPLE

A sieve and hydrometer analyses on a soil sample found that 35% of the potential contributing sediments will have diameters that are smaller than 0.02-mm (i.e., clay colloidal conditions exist), which indicates that:

PEG = 100% - 35% = 65%.

Thus, 65% of the sediments potentially will have a diameter of 0.02 mm or larger. If a criterion for development of an SCS is to reduce by 80% all incoming suspended particles (i.e., NEff = 80%) entering the system, then Equation 5 indicates:

$$80\% = AEff \times 65\%$$

$$AEff = 123\%$$

However, the apparent effectiveness of an SCS to remove designed size and larger particles entering the system by gravity cannot be greater than 100%. Therefore, the net effectiveness of an SCS to remove suspended particles entering this system by gravity is actually:

$$NEff = 100\% \times 65\% = 65\%$$

and only when a length-width ratio of the system approaches 10 (see Figure 1).

Figure 2 and Figure 3 illustrate how the minimum surface area and flow length, respectively, vary for different discharges from an SCS to achieve a NEff value of 65%. Greater effectiveness of containment systems can be realized by selecting a smaller diameter design size particle, such as 0.01 mm. However, since the terminal velocity of a 0.01 mm diameter particle is about ¼ that of a 0.02 mm diameter particle, the containment system will be at least four times larger. Even then, NEff values will more than likely continue to be less than the desired 80%.

3.0 DESIGNING A SCS TO CAPTURE POLYMER TREATED SUSPENDED PARTICLES

It is known that when runoff waters enter an SCS and discharges occur, the capturing of only large (e.g., medium silt and larger) diameter particles found in the incoming runoff waters happens. Sadly, even when containment systems ensure adequate settling times, the net effectiveness to capture untreated suspended particles often continues to be less than 100%. Thus, there is a need for addition treatment methods that increase the effectiveness of an SCS to capture sediment in runoff waters.

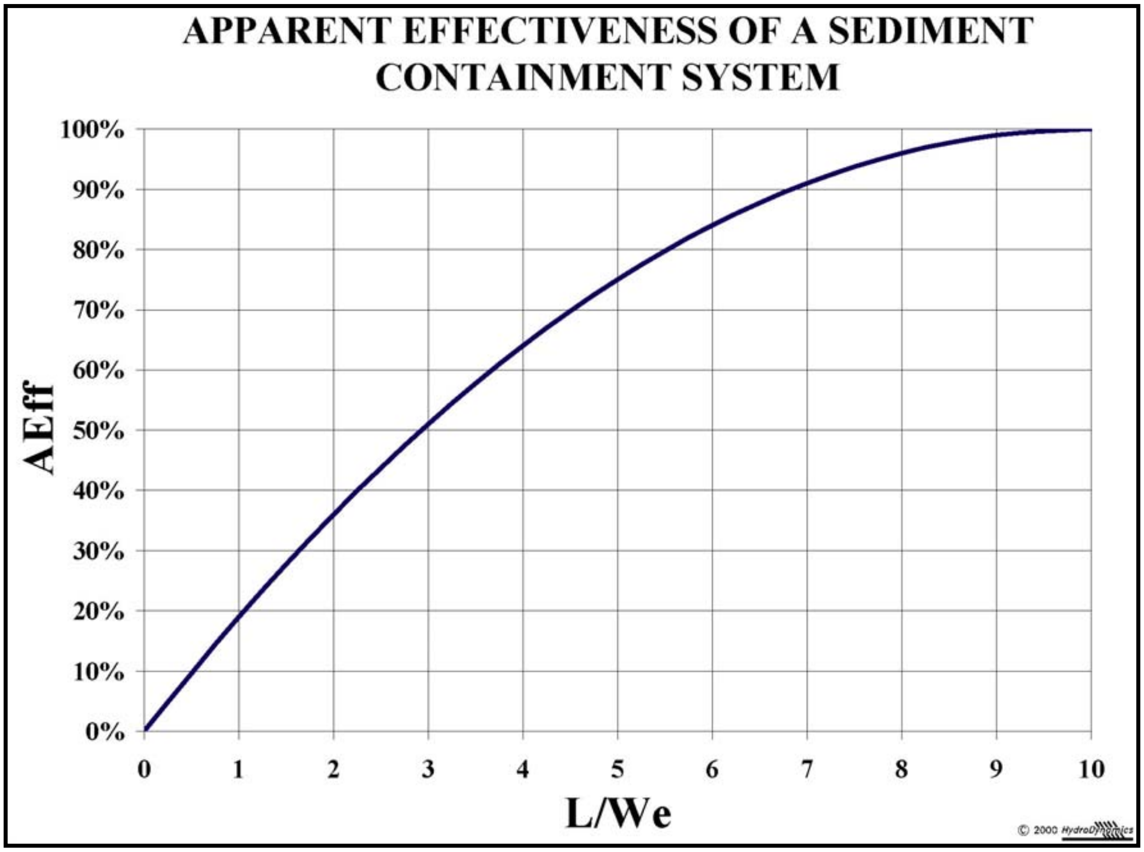

Figure 1. How AEff values vary for different length-width ratios of an SCS.

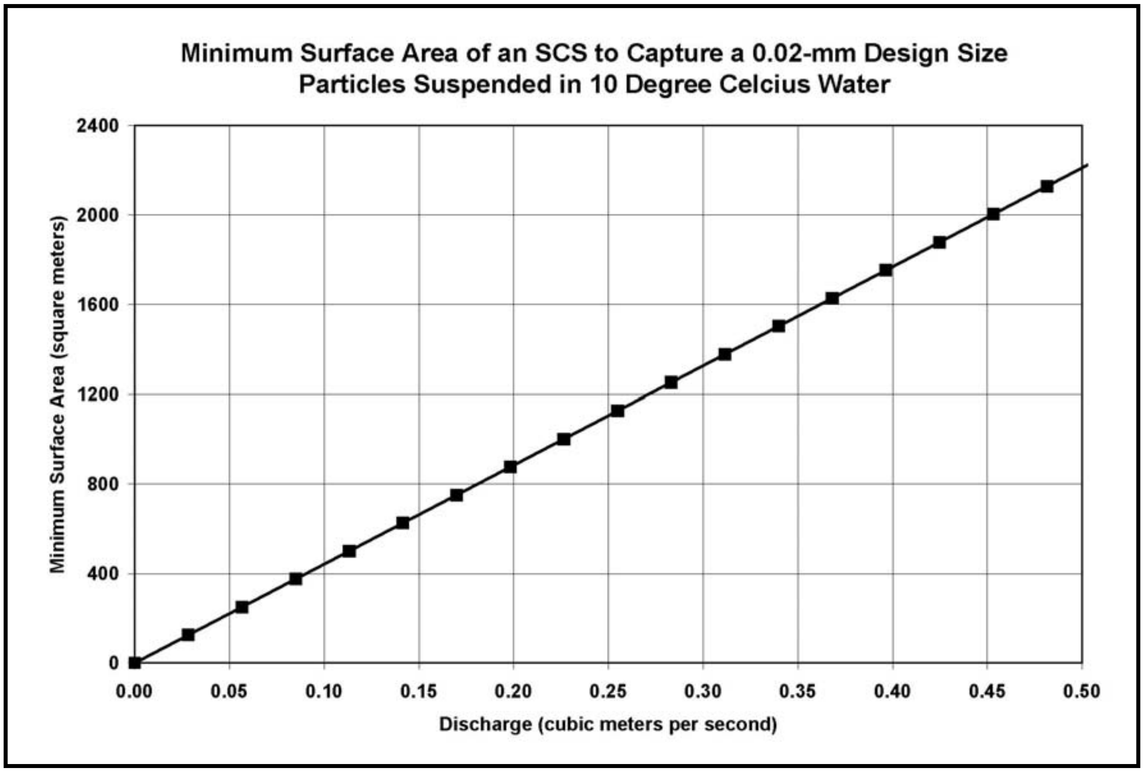

Figure 2. How the surface area of an SCS varies for different discharges.

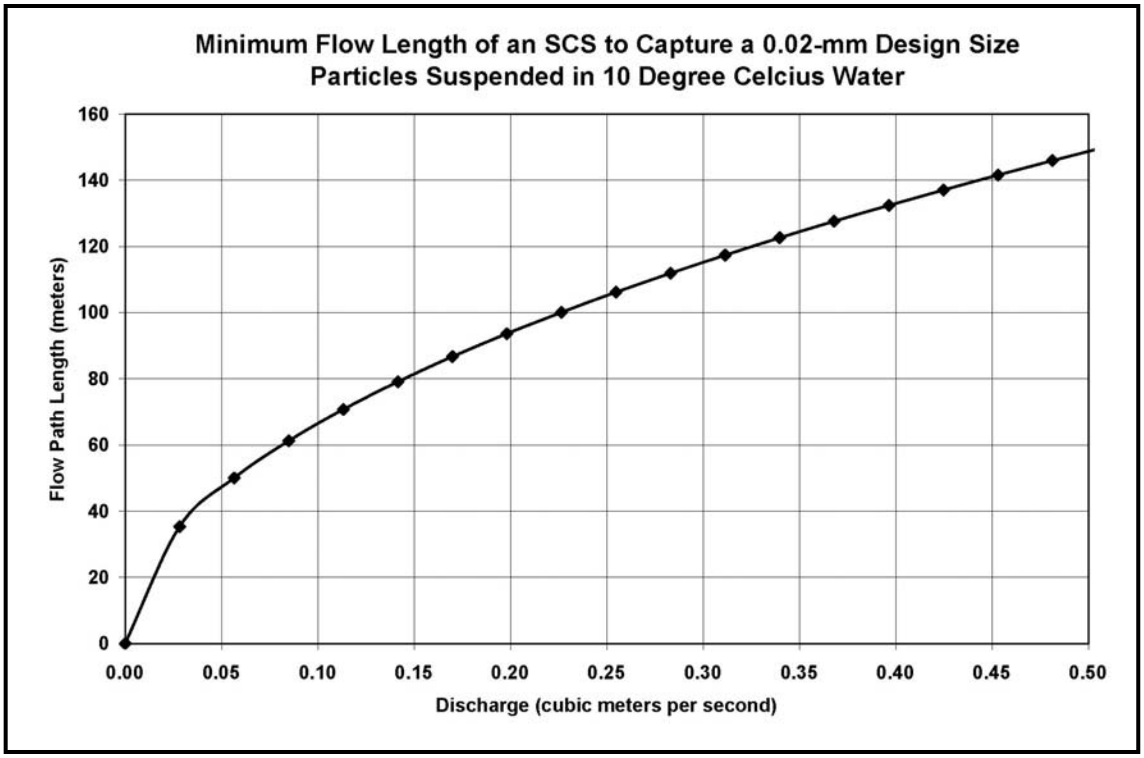

Figure 3. How the flow length of an SCS varies for different discharges.

3.1 USING POLYMERS

EPA (2008) recommends providing containment volume for inflows from a 2-year, 24-hour storm event plus a sediment storage volume of 28 m^3 (1,000 $ft.^3$). They also suggest an alternative storage volume of 252 m^3/ha (3,600 $ft.^3$/ac.), plus storage volume.

As long as discharge conditions do not occur, EPA's suggested containment volume will result in NEff values of 100%. However, designers of an SCS must always anticipate discharge conditions, which can result in turbid outflows containing suspended colloidal particles and accompanying toxic pollutants.

Fortunately, the addition of polymers can reduce turbidity by coagulation, which causes colloids to adhere to each other and form larger particles (a.k.a. flocs). As illustrated in Figure 4, the large polymer treated particulates will have an increase mass, which results in faster deposition times. Once deposition times become less, smaller surface areas and shorter flow path lengths are needed.

What is not known about the deposition of polymer treated particulates is whether they fall through a water column at a terminal or accelerated velocity. What follows below provides an assessment of both conditions.

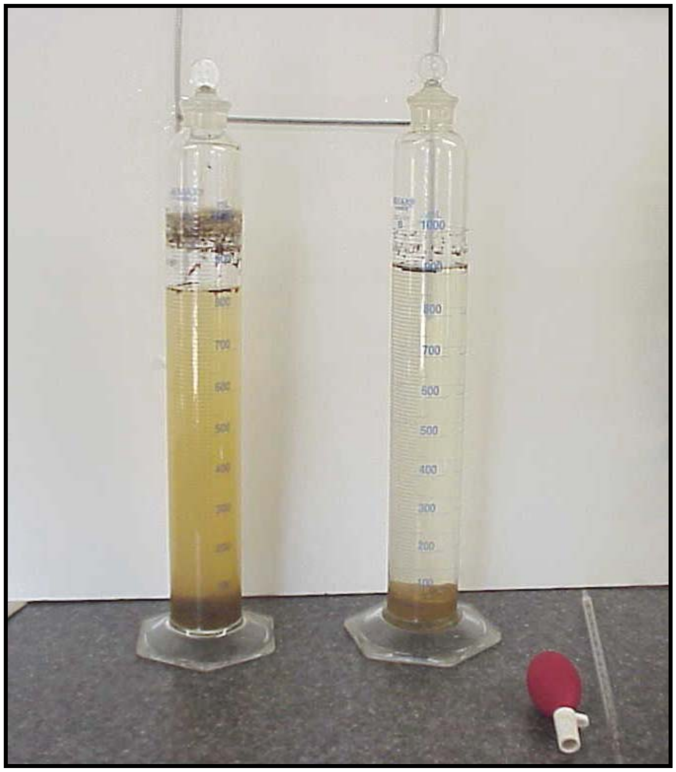

Figure 4. Deposition of sediments for untreated waters (left flask) and polymer treated waters (right flask).

3.2 WHEN TERMINAL VELOCITY CONDITIONS EXIST

By measuring the time polymer treated particulates fall a specific distance within a laboratory-settling flask; it is possible to calculate an average vertical velocity using the following equation:

$$V_{ave} = Y \div T \qquad \textbf{Equation 7}$$

where V_{ave} = Average vertical velocity (meters/second or *ft./sec.*)

Y = Maximum vertical distance a particulate falls in a laboratory flask (meters or *feet*)

T = Time for a particulate to fall a specified distance in the flask (seconds)

Assuming polymer treated particulates falling through water in the flask represents the terminal velocity of suspended particles in an SCS, then Equation 1 becomes:

$$SA_{min} = SF \times Q \div V_{ave} = (SF \times Q \times T) \div Y \qquad \textbf{Equation 8}$$

If the introduction of a polymer causes colloids to adhere to each other, then it can be assumed that capturing nearly all suspended particles is occurring (i.e., PEG ≈ 100%). Thus, the design of an SCS will have a net effectiveness that approaches 100% in removing incoming suspended particles. This means that AEff also approaches 100%, which implies the Length-Width ratio of a SCS must approach 10 (see Figure 1). Thus, Equation 2 can be simplified to:

$$L_{min} = (10 \times SA_{min})^{0.5} \qquad \textbf{Equation 9}$$

3.3 WHEN ACCELERATED VELOCITY CONDITIONS EXIST

As polymer treated particulates fall vertically at an accelerated rate through water in a flask, Newtonian physics dictate that:

$$\mathbf{Y = \tfrac{1}{2} \times A_{fl} \times T^2} \qquad \textbf{Equation 10}$$

where A_{fl} = Net acceleration of the particulates in the flask (meters per second^2 or *feet per second*^{2}). Notice that Equation 10 can be rewritten as:

$$\mathbf{A_{fl} = (2 \times Y) \div T^2} \qquad \textbf{Equation 11}$$

It is also known that when suspended polymer treated particulates accelerate through an SCS water column, the vertical velocity (Vel) after falling a specified Depth can be found by:

$$\mathbf{(Vel)^2 = 2 \times A_{scs} \times Depth} \qquad \textbf{Equation 12}$$

where A_{SCS} = Net acceleration of the particulates in the SCS (meters per second^2 or *feet per second*^{2}).

Assuming polymer treated particles contained within an SCS will accelerate vertically at the same rate polymer treated sediments fall in a laboratory flask, substitution of Equation 11 into Equation 12 yields:

$$\mathbf{Vel = 2 \times (Y \times Depth)^{0.5} \div T} \qquad \textbf{Equation 13}$$

Substituting the results of Equation 13 into Equation 8 yields,

$$\mathbf{SA_{min} = (SF \times Q \times T) \div [2 \times (Y \times Depth)^{0.5}]} \qquad \textbf{Equation 14}$$

3.4 SAFETY FACTORS

What is not known about Equation 8 and Equation 14 are safety factors to compensate for real world conditions. For example, when testing soils samples, laboratory water temperatures may not simulate actual runoff conditions, which impacts the vertical velocity of particulates falling through a water column. Also, adequate flow path lengths within an SCS may not exist to minimize turbulent flow conditions that cause mixing and re-suspension of particulates.

Lastly, it is not known whether terminal or accelerated velocity conditions exist after the introduction of polymers, which dictate the sizing of an SCS. Thus, it is important that efforts take place to determine realistic safety factors to compensate for unknowns variables that exist in the real world.

3.5 EXAMPLE

Consider what happens when clay colloidal particles (see previous example) are treated with a polymer that cause the formation of particulates to fall 330 mm (13 in.) through water in a flask within 44 seconds. Figure 5 and Figure 6 compare how the minimum surface area and flow path length of an SCS will vary for different discharge values when polymer treated particulates fall 1.0 meter and a safety factor of 2 exists.

Analysis of Figure 5 and Figure 6 yields the following:

- The surface area of an SCS necessary to capture polymer treated suspended particles may be as little as 2% to 6% of what is required for <u>untreated</u> suspended particles.
- The flow path length for polymer treated suspended particles to travel within an SCS may be about 13% to 25% of what is required for <u>untreated</u> suspended particles.

Increasing safety factor values does not substantially change the conclusion that introducing polymers into inflow waters significantly changes what is illustrated in Figure 5 and Figure 6. Hence, by properly introducing a polymer (preferably anionic to minimize the potential of aquatic impacts) into inflow runoff waters will result in substantial reductions of surface area and flow length of an SCS.

3.6 IMPORTANT CONSIDERATIONS FOR DESIGNING A SCS USING POLYMERS

Traditional methods for removing sediment from runoff waters require large containment systems, which often have low net effectiveness to remove suspended colloidal particles. However, once a polymer is properly and professionally introduced into runoff entering a containment system, then net effectiveness can approach 100% while employing the use of smaller SCS and ensuring the following occurs:

- Completing a laboratory analysis of representative contributing soils samples that discharge sediment to a containment system when runoff events occur (an analysis of multiple samples may be required),
- Proper design of a SCS (an optimum shape is rectangular), and
- Ensuring discharges out of a SCS occur from the top layer of contained waters.

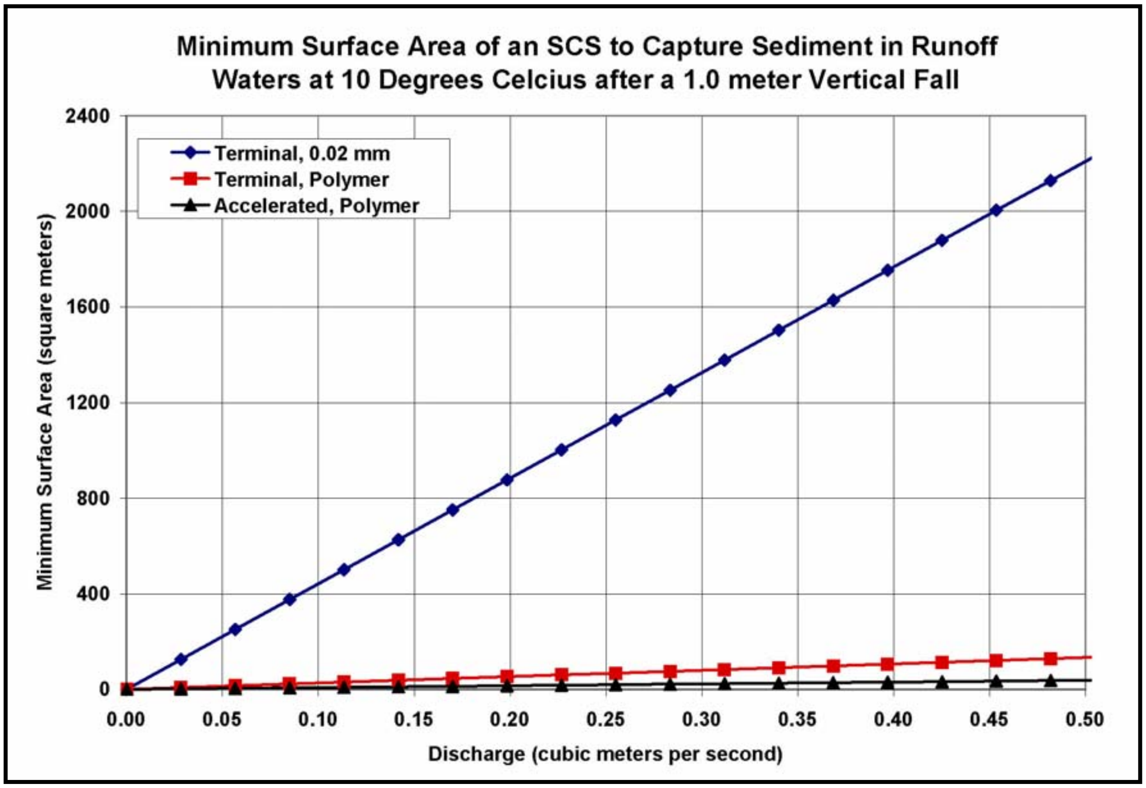

Figure 5. Minimum surface area comparisons for an effective SCS.

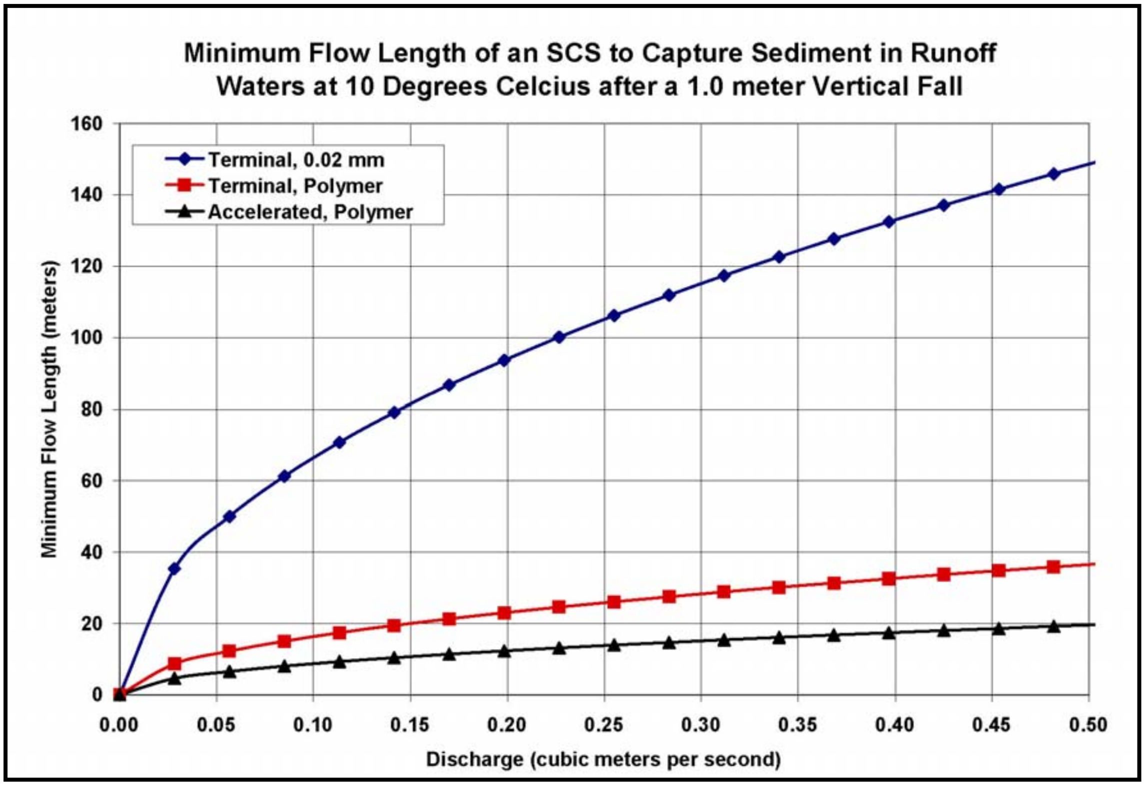

Figure 6. Minimum flow length comparisons for an effective SCS.

4.0 THE EFFECTIVENESS OF AN SCS AND NTU VALUES OF DISCHARGE WATERS

The trouble with relying upon a sieve analysis of upstream soils is that it does not always provide adequate data for what actually becomes suspended within runoff waters. Overcoming this shortcoming can occur by optically measuring the turbidity of suspended particles in runoff waters and expressing the results in nephelometric turbidity units (NTU's).

4.1 PREDICTING NET NTU VALUES

When suspended colloidal particles found in runoff waters are expressed in NTU's, Equation 5 becomes:

$$\mathbf{NEff = AEff \times [1 - (NTU_f \div NTU_o)]} \qquad \textbf{Equation 15}$$

where NTU_f = Final NTU value of polymer treated waters mixed with contributing soil samples

NTU_o = Initial NTU value of untreated waters mixed with contributing soil samples

Since NEff represents the percentage of particulates that are captured, this variable can also be expressed in NTU units as:

$$\mathbf{NEff = 1 - (NTU_{dis} \div NTU_o)} \qquad \textbf{Equation 16}$$

where NTU_{dis} = anticipated NTU value of discharge waters from an SCS and assuming inflow water is represented by NTU_o. Substituting Equation 16 into Equation 15 yields:

$$\mathbf{NTU_{dis} = \{1 - AEff \times [1 - (NTU_f \div NTU_o)]\} \times NTU_o} \qquad \textbf{Equation 17}$$

4.2 EXAMPLE

Consider what happens when laboratory analyzed water samples using contributory soils to an SCS yields NTU_o = 9,300 and NTU_f = 60. Theoretically, an SCS having a length-width ratio of 10 (see Figure 1) should result in AEff = NEff = 100%. However, even when it is assumed that AEff = 100%, Equation 15 indicates that:

$$\begin{aligned} NEff &= AEff \times [1 - (NTU_f \div NTU_o)] \\ &= 100\% \times [1 - (60 \div 9{,}300)] \\ &= 99.4\% \end{aligned}$$

Ironically, while the above clearly demonstrates superior reduction of sediments in discharge waters, an SCS having a NEff value of 99.4% will not meet the proposed November 19, 2008 EPA numeric limitations of 13 NTU for storm water discharges from 12 hectares (30 acres) or larger construction sites. This can only be achieved when NEff = 99.9%, which indicates a need for tertiary treatment of discharge waters.

What will be the optimal dimensions of an SCS to achieve 60 NTU discharge waters when polymers are professionally added to runoff waters from 12 hectares (30 acres) of land and inflow waters are 0.30 m^3/sec (10.5 cfs)? Using data found in Section 3.4, the following dimensions are calculated using the above equations when an average SCS depth of 2.0 meters (6 ft.) and safety factor of 3 exists.

When Terminal Conditions Exist	When Acceleration Conditions Exist
Minimum Surface Area = 120 m^2 (1,290 $ft.^2$)	Minimum Surface Area = 24.4 m^2 (262 $ft.^2$)
Minimum Length = 35 m (115 ft.)	Minimum Length = 15.6 m (51.2 ft.)
Minimum Width = 3.5 m (11.5 ft.)	Minimum Width = 1.6 m (5.1 ft.)
Minimum Volume = 240 m^3 (8, 470 $ft.^3$)	Minimum Volume = 48.8 m^3 (1,722 $ft.^3$)

When comparing the above with EPA's (2008) suggested capture volume of 252 m^3/ha (3,600 $ft.^3$/acre) of untreated runoff waters, plus sediment storage volume, one will find a containment requirement of about 3,052 m^3 (107,700 ft^3 = 2.47 acre-feet).

When containment volume of runoff is retained and no discharges occur it will be possible to realize that NEff = 100%. However, regulatory requirements often require that contained waters drain from an SCS within a specific time period. For example, if the 2-meter deep SCS is to drain within 72 hours, then the following parameters might exist for an SCS having a Length-Width ratio of 10.

Average Discharge = 0.012 m^3/sec (0.41 cfs)

Minimum Surface Area = 1,517 m^2 (16,320 $ft.^2$)

Minimum Length = 123 m (404 ft.)

Minimum Width = 12.3 m (40.4 ft.)

EPA Volume = 3,052 m^3 (107,700 ft^3 or 2.47 acre-feet)

The above examples demonstrate that the size of an SCS can be dramatically reduced when adding polymers to inflow waters while meeting practical numeric NTU effluent limitations.

Only when sediment laden inflow waters consist of sand and larger diameter particles will a containment structure designed using EPA criteria might realize NEff values that approach 100%. However, there is no assurance that 13 NTUs (or lower) discharge waters will also exist for such a structure.

Usually, sediment-laden inflows include clay colloids that are nearly impossible to remove from untreated contained waters before they discharge from an SCS. In the above example, development of an SCS using EPA parameters might capture 0.001 mm (i.e., medium clay) and larger diameter particles. Since clay colloids smaller that 0.001 mm exists, it can be expected that untreated discharge water from the EPA structure will exceed the proposed numeric effluent limitations of 13 NTUs.

Finally, what will be an approximate NTU value of discharge water when the length-width ratio of the SCS is only 5.5 instead of 10? From Figure 1, a length-width ratio is 5.5 yields a value of AEff ≈ 80% ≈ 0.80. Using Equation 17, we see that:

$$
\begin{aligned}
NTU_{dis} &= \{1 - AEff \times [1 - (NTU_f \div NTU_o)]\} \times NTU_o \\
&= \{1 - 0.80 \times [1 - (60 \div 9{,}300)]\} \times 9{,}300 \\
&= 1{,}908
\end{aligned}
$$

Notice that NEff = [1 – (1,908 ÷ 9, 300)] x 100 = 79.5% for this scenario.

5.0 FIELD TESTING

The problem with theory is that the concepts are based upon idealized conditions. Thus, field-testing of the above concepts is necessary to assess different scenarios so that it is possible to quantify the following questions:

- What are appropriate safety factor values when runoff waters enter a SCS with no attempt to establish uniform internal flow conditions?
- What are appropriate safety factor values when runoff waters enter a SCS behind a baffle to create uniform internal flow conditions?
- What is the optimal depth of an SCS to ensure maximum capture of polymer treated suspended particles?
- What are maximum inflow and outflow values to ensure optimal capture of polymer treated suspended particles?

Perhaps the greatest challenge with treating runoff waters with polymers lies with having proper field-testing of the above theories. Equally challenging, however, may be convincing reluctant professionals (and regulatory agencies) that practical numeric NTU limitations for SCS discharges can be met in an economical manner. However, this will require accountability for proper design and implementation of effective containment structures on construction sites, along with ensuring polymers are added in a responsible manner to runoff waters entering an SCS.

6.0 REFERENCES

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