Evaluation and Enhancement of the Effectiveness of Sediment Trapping and Retention Devices Installed on the Nevada Side of Lake Tahoe

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ABSTRACT

The gradual decline in the clarity of Lake Tahoe in recent decades has been well documented. Suspended solids in stormwater runoff may contribute to the decline in clarity. Some of the suspended solids originate from sand applied to roadways around the lake during the winter months in order to increase vehicle traction. Another source of suspended solids is the erosion of soil at the base of cut slopes along roadways. In an attempt to reduce the quantities of solids entering the lake, the Nevada Department of Transportation (NDOT) has installed sediment trapping devices along the highways within the Lake Tahoe basin. The devices work by intercepting stormwater runoff and allowing time for particles in the water to settle to the bottom of the traps. Two specific types of sediment trapping devices which are widely used in the basin are the drop inlet and the double can sediment traps. Settled solids are stored in the traps and the water exits and continues to the lake. Research was conducted at the University of Nevada, Reno (UNR) in an attempt to enhance the performance of these sediment trapping devices. Full-scale laboratory models of each trap were constructed and tested in the fluid mechanics laboratory at UNR. Each of the various modifications that were tested to enhance the performance of the traps improved particle removal to varying degrees compared to the performance of the standard traps. The most effective enhancement was the addition of multiple layers of vertically-oriented filter fabrics which resulted in trap efficiencies of greater than 50% for the removal of total suspended solids (TSS). Sand media filtration increased the removal efficiency for TSS in the double can sediment trap to greater than 40%. Arranging additional sediment traps in series was found to increase the removal efficiency of TSS to above 30%. The results and recommendations should

help NDOT devise and implement techniques to economically and efficiently improve the performance, operation, and maintenance of existing sediment traps and to enhance the design of future sediment traps in an effort to help keep Lake Tahoe blue.

ACKNOWLEDGEMENTS

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INTRODUCTION

1.1 Research Objectives and Experimental Approach

The primary objective of the research was to quantify the performance of the double can and drop inlet sediment retention devices installed on the Nevada side of Lake Tahoe. The second objective was to identify cost effective methods to improve the design and/or operational maintenance procedures that could be implemented to enhance the performance of the traps.

Specific tasks for the research began with a literature search, followed by construction of full-scale models of the double can and drop inlet sediment traps in the laboratory. Winter road sand and decomposed granite was introduced into the traps at two different flow and feed rates, creating combinations of four different concentrations. Testing of each individual flow and feed rate condition was repeated several times with the intent to reduce the error and find an average. A continuous stream of effluent from the sediment traps was diverted through a particle counter and a flow through turbidimeter. Grab samples were also taken and tested for turbidity, total suspended solids, pH, and electrical conductivity. The influent and effluent grab samples were analyzed to determine how efficiently the traps removed the particles. Sieve analyses were also performed. Representative sieve samples of the road sand were taken before being introduced to the water, and also from the settled accumulation inside the traps.

Another specific task was to modify the design of the existing sediment trapping devices to increase the particle removal efficiency. Initially, some of the effluent flow from the sediment traps was passed through a small-scale sand filter and then sand filter columns using various filter loading rates. Later, the flow was passed through a single layer of filter fabric before exiting from each sediment trap. Then, the effluent flow was passed through multiple layers of filter fabric before exiting from each sediment trap. The performance of a full-scale media filter was then evaluated, followed by the performance of the sediment traps arranged in series. Finally, the performance of multiple layers of filter fabric installed within each of the sediment traps arranged in series was evaluated.

Chapter 2

LITERATURE REVIEW

2.1 Particle Characteristics

It is important to understand the various characteristics of particles in order to find how they will react in the water. Important characteristics of particles in water include the particle size, particle shape, particle number and distribution, and how cohesive they are (Shaw 1966).

2.1.1 Particle Size

An important particle property of interest is particle size, though natural sediments are irregular in size, making finding of an exact size difficult. There are three terms for diameters as presented by Lane (1947). They are the sieve diameter, sediment diameter, and the nominal diameter. The sieve diameter is the opening size of a square mesh in which a particle will just pass. The sediment diameter is the diameter of a manufactured sphere of same specific weight and terminal settling velocity as a particle in the same fluid. The nominal diameter is the diameter of a sphere of the same volume as the particle. It is common to use sieve diameters, and place the sediments into size classes, or grades (ASCE 1975). The grade chart for comparing sediments to class can be seen in Table 2.1, as given by Lane (1947). The sediment grain diameter determined by sieve analysis is typically smaller than the diameter of an "equivalent-volume" sphere, where Cleasby and Woods (1975) did size comparisons of sand to equivalent volume spheres and found that the sand was five to ten percent larger.

Table 2.1 Sediment size to class comparison (ASCE 1975)

	Size Range				Approximate Sieve Mesh Openings per inch	
	Millimeters					
Class name (1)	(2)	(3)	Microns (4)	Inches (5)	Tyler (6)	United States standard (7)
Very large boulders		4,096-2,048		160-80		
Large boulders		2,048-1,024		80-40		
Medium boulders		1,024-512		40-20		
Small boulders		512-256		20-10		
Large cobbles		256-128		10-5		
Small cobbles		128-64		5-2.5		
Very coarse gravel		64-32		2.5-1.3		
Coarse gravel		32-16		1.3-0.6		
Medium gravel		16-8		0.6-0.3	2-1/2	
Fine gravel		8-4		0.3-0.16	5	5
Very fine gravel		4-2		0.16-0.08	9	10
Very coarse sand	2-1	2.000-1.000	2,000-1,000		16	18
Coarse sand	1-1/2	1.000-0.500	1,000-500		32	35
Medium sand	1/2-1/4	0.500-0.250	500-250		60	60
Fine sand	1/4-1/8	0.250-0.125	250-125		115	120
Very fine sand	1/8-1/16	0.125-0.062	125-62		250	230
Coarse silt	1/16-1/32	0.062-0.031	62-31			
Medium silt	1/32-1/64	0.031-0.016	31-16			
Fine silt ~ 15μm	1/64-1/128	0.016-0.008	16-8			
Very fine silt	1/128-1/256	0.008-0.004	8-4			
Coarse clay	1/256-1/512	0.004-0.0020	4-2			
<16nm Medium clay	1/512-1/1,024	0.0020-0.0010	2-1			
Fine clay	1/1,024-1/2,048	0.0010-0.0005	1-0.5			
Very fine clay	1/2,048-1/4,096	0.0005-0.00024	0.5-0.24			

When looking at gradation, aggregates can have various characteristics of distribution, such as one sized, open, gap, and dense (Mamlouk and Zaniewski 1999). In one-sized distribution, the majority of aggregates passing one sieve are being retained on the next smaller sieve. In this case, the aggregates have the majority of the same diameter and create good permeability. Gap-graded aggregates are missing one or more sizes of material. Open graded aggregates are missing small aggregate sizes that would block the voids between the larger aggregates (Administration 1988).

2.1.2 Particle Shape

Particle shape is also an important particle property and is important for helping to determine particle movement in a liquid. Schulz *et al.* (1954) has examined particle shape factors, concluding with the equation:

$$S_p = \frac{c}{(ab)^{1/2}} \tag{2-1}$$

Where 'a' is the longest mutually perpendicular axes through the particle, 'b' is the intermediate, and 'c' is the shortest. Naturally worn quartz particles have an average shape factor of 0.7.

2.1.3 Cohesive Sediments

Cohesive sediments, as given by ASCE (1975) are as the name sounds, fine particles that cohere or join together (e.g., silt and clay). The rate of erosion depends on the bond between the particles, where the stronger bond prevents erosion, requiring a high velocity for initial movement. The resisting bonds of the particles may be much greater than individual particle characteristics, and therefore may dominate particle movement.

2.1.4 Noncohesive Sediments

ASCE (1975) describes noncohesive sediments as discrete particles (e.g., sand and gravel). The erosion and settling of these particles depends on properties such as size, shape, and density of the individual particles. The movement of noncohesive sediments also depends on the relative position of the particle with respect to the position of surrounding particles.

2.2 Movement of Noncohesive Sediments

Sedimentation involves the processes of erosion, entrainment, transportation, deposition, and the compaction of sediment through geological time. The entrainment, transportation, and deposition of sediment depend on both the flow and the particle properties (ASCE 1975). The process of erosion begins with the initial movement of the particles, and therefore initial movement must be considered.

2.2.1 Incipient Motion

Incipient motion is important to understand since the concept of particle movement is based off of the idea that the sediment was originally put into motion at particular flow conditions and water characteristics. Most incipient motion criteria are based off of the shear stress or fluid velocity (Yang 2003). The following forces are those acting on a grain of sediment lying in a bed of similar grains over which a fluid is flowing. Seen in Figure 2.1, they are the gravity forces of weight and buoyancy, hydrodynamic lift normal to the bed, drag parallel to the bed (Yang 2003), and resistance force of the bed (ASCE 1975).

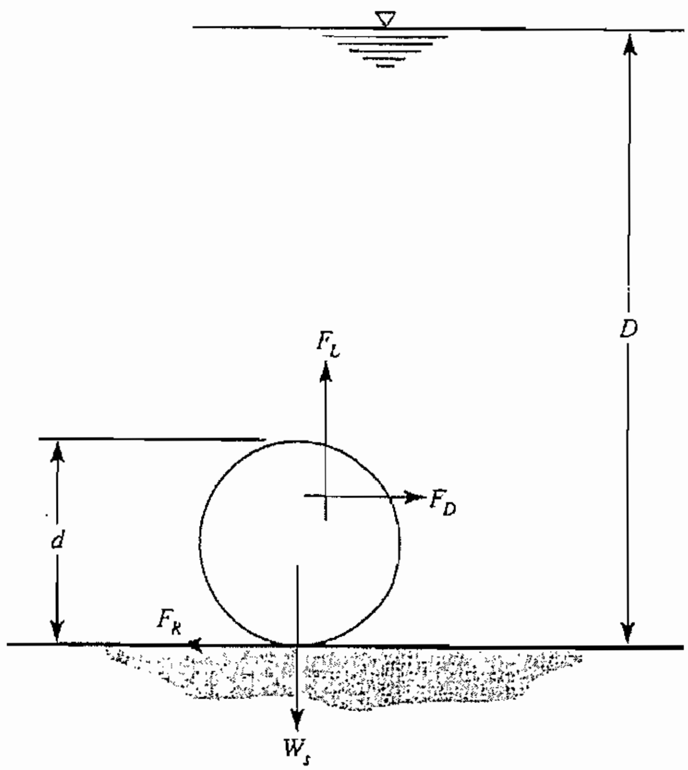


Figure 2.1 Forces acting on a sediment particle (modified from (Yang 2003))

As seen from the free body diagram of Figure 2.1, the particle is at the point of incipient motion when it is at three certain states. Yang (2003) explains that the first is when the lift force (F_L) is equal to the submerged weight (W_S). The second is when the drag force (F_D) is equal to the resistance force (F_R). The third is when the overturning moment (composed of the drag and resistant forces), is equal to the resisting moment (composed of the lift and submerged weight).

2.2.2 Critical Shear Stress

When initial movement is about to occur, the particle is at its critical bed shear stress (τ_c). Shields (1936) applied dimensional analysis to establish the equation for incipient motion. The important factors that are applied are the shear stress (τ_c), sediment (ρ_s) and fluid (ρ_f) densities, diameter of the particle (d), kinematic viscosity (ν), and gravitational acceleration (g). These quantities produce the following dimensionless quantities:

$$d\frac{(\tau_C / \rho_f)^{1/2}}{\nu} = \frac{dU_*}{\nu} \tag{2-2}$$

$$\frac{\tau_C}{d(\rho_S - \rho_f)g} = \frac{\tau_C}{d\gamma[(\rho_S / \rho_f) - 1]} \tag{2-3}$$

The relationship between the parameters in Equations 2-2 and 2-3 are then determined experimentally. The relation of the experimental data by Shields and other investigators is displayed in the Shields diagram (Yang 2003). Later research came up with equations to find the critical shear stress. Miller *et al.* (1977) developed a shear stress equation for quartz sediment particles that have diameters greater than 1,000 μm and that behave in a cohesionless manner:

$$\tau_C = 4.14d \tag{2-4}$$

Where (d) is the diameter of the non-cohesive particles, and (τ_c) is the shear stress acting on the particles. This is also true for particles ranging from 400 to 1,000 μm. Particles that are between 40 and 400 μm erode differently due to cohesive characteristics, and the equation is:

$$\tau_C = 2.75d^{0.4} \tag{2-5}$$

2.2.3 Critical Velocity

The first observations of critical conditions pertaining to sediment particles in water are reported in terms of velocity. In recent years, though, velocity has been abandoned for shear stresses to obtain more satisfactory quantities (ASCE 1975). Mavis and Laushey (1966) showed that the critical bottom velocity (u_{oc}) for sands can be calculated by:

$$u_{oc} = 0.5(\frac{\gamma_S}{\gamma} - 1)^{1/2} d_S^{4/9} \tag{2-6}$$

Where (d_S) is the mean size of the sediment in millimeters, (γ_S) is the specific weight of the sediment, (γ) is the specific weight of the liquid, and (u_{oc}) is in feet per second and was developed by fitting a curve to observed data.

2.3 Transport of Sediment in Water

At very low velocities no sediment will move, but after incipient motion has begun, grains will roll and slide intermittently along the bed. As the velocity and turbulence of the fluid increases, some grains will make short jumps and leave the bed for a short time and return to the bed. If flow velocity is increased even more, some sediment will be swept into the main body of flow and turbulence will cause the sediment to remain suspended for a considerable length of time (ASCE 1975).

2.3.1 Bed-Load Transport

If the sediment particles are rolling, sliding, or jumping short distances along the bed, the process is called bed-load transport. Looking at the shear stress approach, Shields (1936) extended flow condition relationships to obtain the flow condition corresponding to incipient motion. This produced the equation:

$$\frac{q_b \gamma_S}{q \gamma S} = 10 \frac{\tau - \tau_C}{(\gamma_S - \gamma) d} \tag{2-7}$$

Where (q_b) is the bed-load, (q) is the water discharge per unit channel width, (d) is the sediment particle diameter, (τ_c) can be obtained from Shields diagram, (S) is the slope, (γ_S) is the specific weight of the sediment, (γ) is the specific weight of the liquid, and (τ) is the product of specific weight, water depth, and slope of the channel.

2.3.2 Suspended Load

Suspended load refers to sediment particles that become suspended and remain suspended for a great amount of time due to turbulent conditions. Lane and Kalinske (1941) provided an equation to find the suspended load, (q_{sw}):

$$q_{sw} = qC_a P_L \exp(\frac{15\omega a}{U_* D}) \qquad (2\text{-}8)$$

Where (q) is the water discharge and (C_a) is the suspended sediment concentration at distance (a) above the bed. P_L is the depth-integrated average sediment concentration per sediment concentration at distance (a) as seen in Figure 2.2. (ω) is the fall velocity corresponding to (d_{50}), (D) is the water depth, and (S) is the slope for the shear velocity:

$$U_* = (gDS)^{1/2} \qquad (2\text{-}9)$$

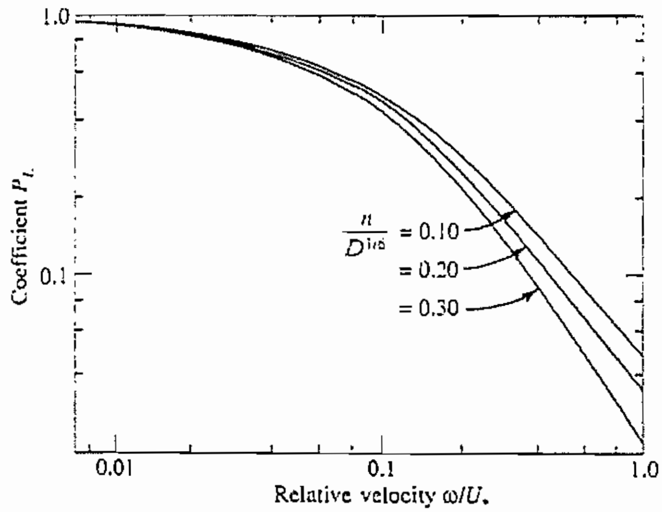


Figure 2.2 Relationship between suspended load coefficients (Lane and Kalinske 1941)

2.3.3 Particle Settling

In order for a particle to settle, its velocity downward must overcome the effects of the water. Fall velocity is a function of the size, shape, surface roughness, and specific gravity of the particle, as well as the viscosity of the fluid (Yang 2003). The types of settling are separated into classes, and equations are present to represent particle settling based off of spherical particles. As explained in MWH (2005), by using Newton's law the forces acting on a particle as it settles in a fluid can be evaluated and a momentum balance on the particle done. A positive settling velocity means that the particle settles and a negative settling velocity means the particle will rise since it is less dense than water.

2.3.4 Particle Classes

Particles are separated into four classifications based on their concentration and morphology. Type I particles are discrete and settle without influencing other particles since the concentration is low and they do not flocculate (MWH 2005). The classifications can be seen in Figure 2.3.

In Type II settling, particles flocculate either by velocity gradients in the sedimentation basin or by differential settling. At very high concentrations, Type III, or hindered settling can occur by creating a blanket of particles that traps particles below it as it settles. The blanket settling velocity depends on the suspended solids concentration, with velocity decreasing with increasing concentration (MWH 2005). MWH 2005 also describes Type IV as compression settling where water is displaced as particles compress, resulting in increased particle compaction.

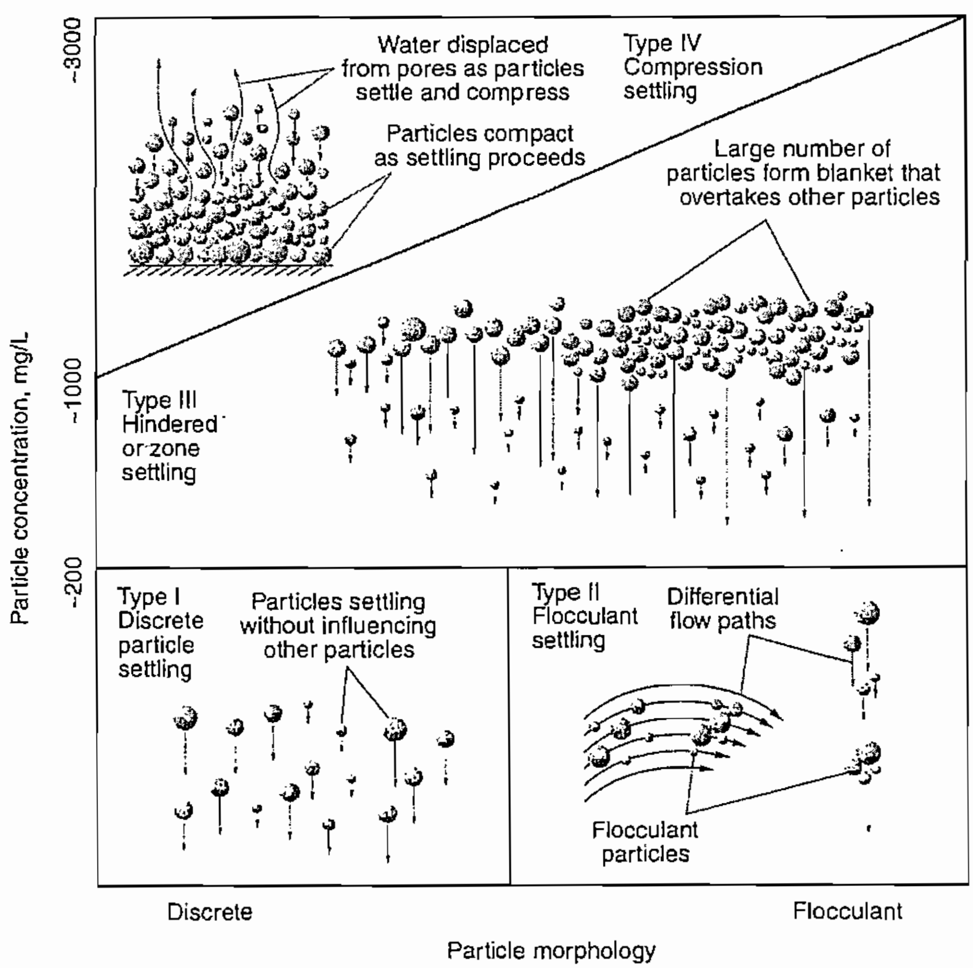


Figure 2.3 Particle classifications (MWH 2005)

If there are only a few closely spaced coarse particles in a fluid, they will fall in a group at a higher velocity than that of a single particle. In contrast, if the particles are dispersed throughout the fluid, then their fall velocity will experience hindered settling (McNown and Lin 1952). Haushild *et al.* (1961) explained that the increase of fine particles into the water could increase the characteristics of the liquid medium mixture, and most importantly the viscosity and specific weight. Therefore, increasing fine sediment concentration could in turn increase the rate of sediment transport.

2.3.5 Stokes' Law

Stokes' law is for settling of particles in quiescent conditions. It is based off of the concept that a sediment particle is spherical, which is not the case in the real world. The equation is still used, though, for a representation. Stokes' (1851) equation can be used for a sphere with diameter (d) and specific weight (γ_S) with the specific weight of water (γ) to find velocity (ω):

$$\omega = \frac{4gd}{3C_D}\left(\frac{\gamma_S - \gamma}{\gamma}\right) \tag{2-10}$$

Reynolds number (Re), with kinematic viscosity (ν) as:

$$\mathrm{Re} = \frac{\omega d}{\nu} \tag{2-11}$$

The fall velocity of particles in laminar flow, having a Reynolds number less than 1.0 can be represented using the equation for the coefficient of drag, (C_D):

$$C_D = \frac{24}{\mathrm{Re}} \tag{2-12}$$

The coefficient of drag for turbulent flow observed after Camp (1946), having a Reynolds number between 1.0 and 10,000 can be expressed as given by MWH (2005):

$$C_D = \frac{24}{\text{Re}} + \frac{3}{\sqrt{\text{Re}}} + 0.34 \tag{2-13}$$

Figure 2.4 can also be used to find the drag coefficient by using the value obtained by the relation of Rouse (1938):

$$\frac{W_S}{\rho \upsilon^2} \tag{2-14}$$

Where (W_S) is the submerged weight of the spherical sediment given by:

$$W_S = \frac{\pi d^3}{6}(\gamma_S - \gamma) \tag{2-15}$$

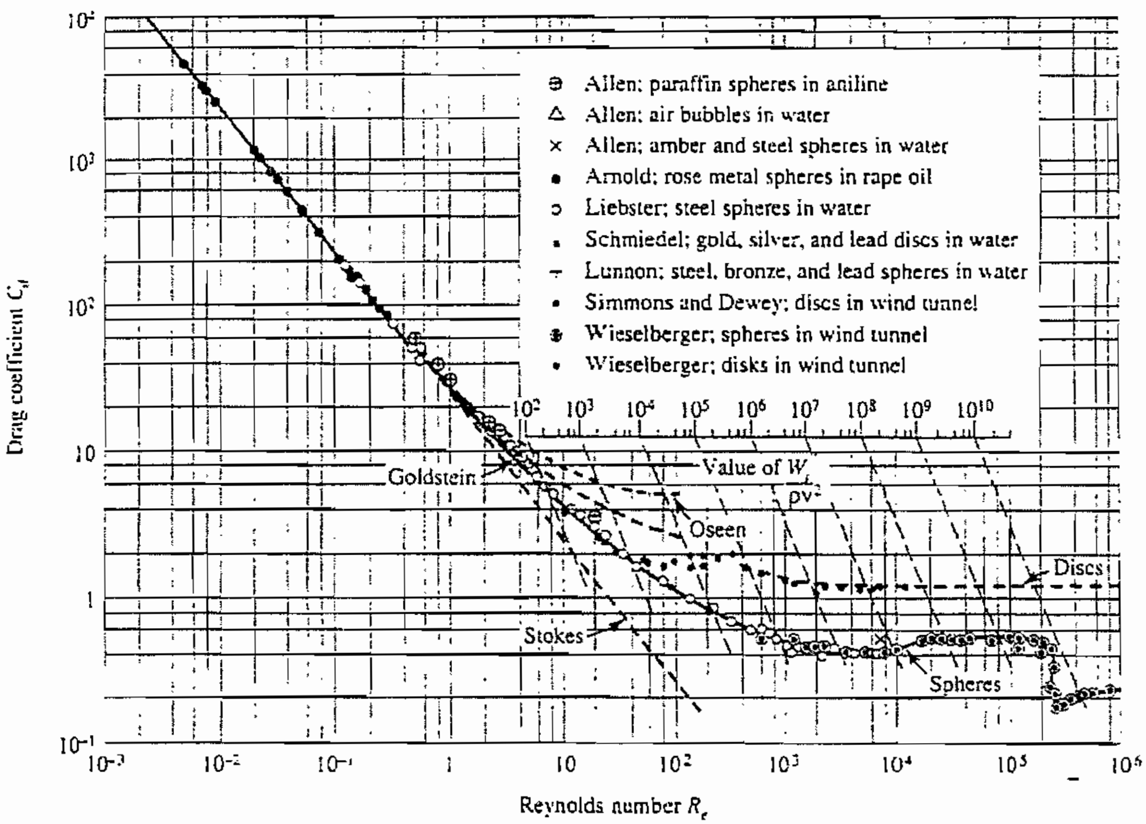


Figure 2.4 Drag coefficient as a function of Reynolds number (Rouse 1938)

2.3.6 Settling in Turbulent Conditions

As described in MWH (2005), turbulence can be considered as a cascade of energy from large eddies to small eddies. This is done after kinetic energy is given to the water through physical means. The structure of water is such that as the large eddies move around, the energy is transferred to smaller eddies until inertial forces are overcome by the viscous nature of water to become no smaller. Field (1968) and Houghton (1968) made theoretical studies on spherical particles in oscillating fluids to find the effects on fall velocity. Field (1968) confirmed by experiment that particles settled more slowly in a fluid oscillating in the vertical direction than one at rest. Both agreed that the reduction in fall velocity was a result of nonlinear relation between drag on the particles and their velocity relative to the fluid.

2.3.7 Particle Size and Settling Velocity

The sedimentation of a particle will vary with specific weight, density, and viscosity of the fluid. This has led to the introduction of the definition of standard fall velocity and diameter as defined by the Interagency Committee (1957). The standard fall velocity is the average rate of fall that a particle would attain if falling alone in distilled water of infinite extent at a temperature of 24°C. The standard fall diameter of a particle is the diameter of a sphere that has the same specific weight and has the same standard fall velocity as the given particle.

2.4 Particle Settling in a Basin

The volume of sediment deposited in a reservoir, or sedimentation basin depends on the efficiency of the trapping device, fall velocity of the particles, size and shape of the reservoir, and flow through the reservoir. The trap efficiency of a reservoir is the ratio of the quantity of deposited sediment to the total sediment inflow (Yang 2003).

2.4.1 Settling Zones

Camp (1946) developed the rational theory for the removal of discrete, or Type I particles in a sedimentation basin by dividing a basin into four zones. These zones are the inlet, sludge, settling, and outlet zones, as seen in Figure 2.5.

There were five assumptions for Camp's (1946) theory. The first was to consider plug flow conditions in the settling zone. The second was to assume uniform horizontal velocity in the settling zone. The third was to assume there is uniform concentration of all size particles across a vertical plane at the inlet end of the settling zone. The fourth was to assume particles are removed once they reach the bottom of the settling zone. And the fifth was to assume that particles settle discretely without interference from other particles at any depth.

There are two components to particle trajectories in the settling zone of a sedimentation basin. This includes the settling velocity of the particles (ω) and the fluid velocity (ω_f) as seen in Figure 2.6 of a rectangular sedimentation basin.

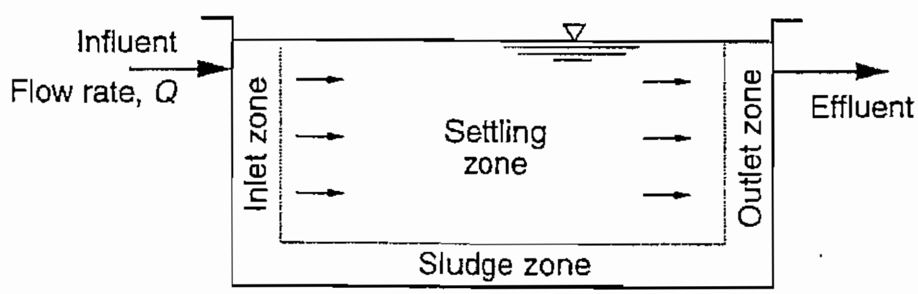


Figure 2.5 Settling zones of a sedimentation basin (MWH 2005)

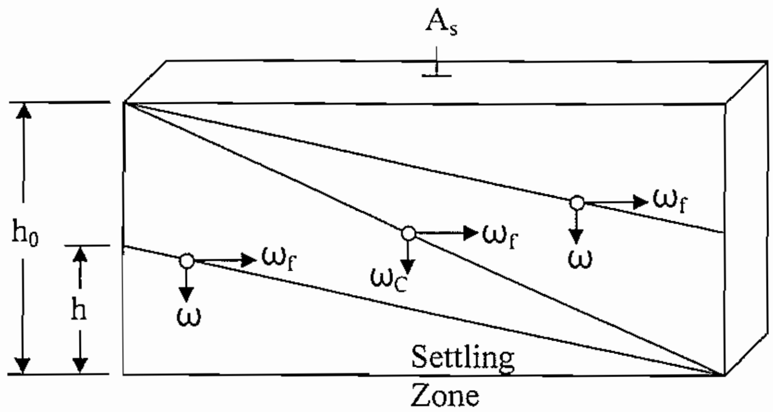


Figure 2.6 Particle trajectories in the settling zone of a sedimentation basin (modified from (MWH 2005))

Camp (1946) also described that a particle from the inlet zone enters at the top of the sedimentation basin and settles at a constant rate to the sludge zone. When this happens just before the outlet it is referred to as the critical settling velocity, or (ω_c) given by the equation:

$$\omega_C = \frac{h_O}{\theta} = SOR = \frac{Q}{A_S} \tag{2-16}$$

Where SOR is the surface overflow rate, (h_O) is the depth, (θ) is the hydraulic detention time, (Q) is the flow rate, and (A_S) is the surface area of the sedimentation basin, as seen in Figure 2.6. Camp (1946) also gave that particle trajectories are linear. Because of this, particles entering the settling zone at any height (h) above the tank floor, with settling velocities (ω) greater than the critical settling velocities will be removed because of their trajectories. The fraction of particles removed (R_2) can be found by:

$$R_2 = \frac{\omega}{\omega_C} = \frac{h}{h_0} \tag{2-17}$$

Particles with settling velocities less than the critical velocity may still be removed depending on their position at the inlet and the height of entrance.

2.5 Rapid Media Filtration

Using rapid media filtration is another way in which particles may be removed from the water. It is important to understand the composition of the media, the process of filtration, and the mechanisms of particle removal.

2.5.1 Filter Media

MWH (2005) described that naturally occurring granular minerals are used for filter media. These include sand, anthracite coal, and garnet and are described in ANSI/AWWA B100-01 Standard for Filtering Material (AWWA 2001a). The size distribution is determined by sieve analysis (ASTM 2001a) through calibrated sieves (ASTM 2001b), where the weight of material retained on each sieve is measured, and the cumulative weight retained is plotted as a function of sieve size.

Media uniformity allows the filters to operate at a higher hydraulic loading rate with lower head loss. Because of this, the size distribution of naturally occurring material is broader than desirable for filter media. As a result, filter materials are processed to remove the largest (by sieving) and smallest (by washing) grain sizes, producing a narrower size distribution, as seen in Figure 2.7 (MWH 2005).

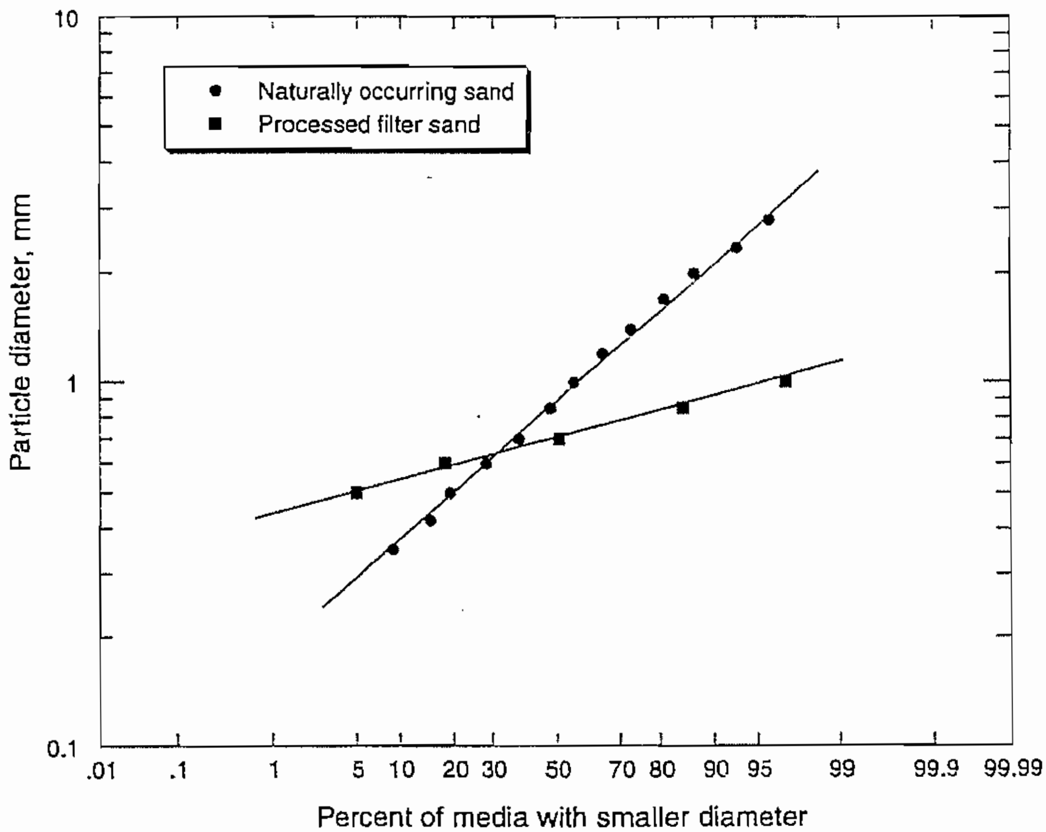


Figure 2.7 Size distribution of media filter sand (MWH 2005)

2.5.1.1 Uniformity Coefficient

Because filter media stratifies during backwash, a low uniformity coefficient (UC) is an important factor in the design of rapid media filters (MWH 2005). As described by Reynolds (1996), the effective size, or d_{10} is the sieve size that will pass ten percent by weight of the media. The uniformity coefficient is composed of d_{60}, which is the sieve size passing sixty percent. The uniformity coefficient is defined as:

$$UC = \frac{d_{60}}{d_{10}} \tag{2-18}$$

Fair *et al.* (1971) explained that the hydraulic resistance of an unstratified granular bed tends to be unaffected by size variation as long as the effective size remains constant.

2.5.2 Filtration Processes

Filter effluent turbidity during the filter run follows a pattern that includes three distinct segments which are ripening, effective filtration, and failure (MWH 2005). Ripening is a process of media conditioning and occurs as the clean media captures particles. By catching more particles, they become more efficient at collecting additional particles. Some investigators have shown that ninety percent of the particles that pass through a well-operating filter do so during the initial stages of filtration (Amirtharajah 1988). Effective filtration is the time duration in which optimal particle removal is occurring. Failure can be caused two ways, by breakthrough or excessive head loss. Breakthrough occurs when the filter contains so many particles that it no longer filters effectively and there is a rise in the effluent particle concentration. The head loss can increase beyond the point of available designed head, at which point the filter fails (MWH 2005). This is shown in Figure 2.8, where the filter design is optimum when both the breakthrough and head loss events occur simultaneously (Reynolds and Richards 1996).

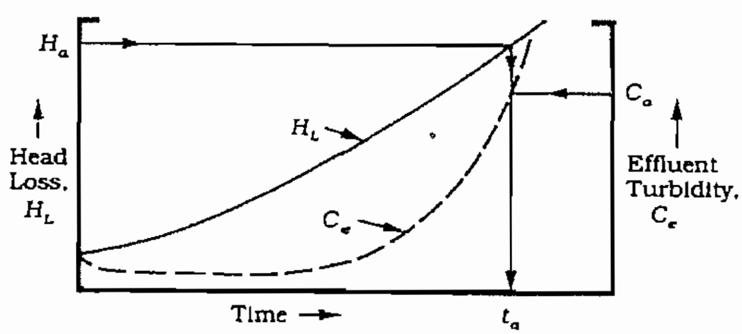


Figure 2.8 Head loss and effluent turbidity vs. time in media filtration (Reynolds and Richards 1996)

2.5.3 Particle Removal Mechanisms

Filters remove particles from water through a variety of mechanisms. When particles are larger than the void spaces in the filter, they are removed by straining (MWH 2005). When particles are smaller than the voids, they can be removed if they are transported to the filter media to contact and stick (Yao, Habibian, and O'Melia 1971). Transport to the media surface occurs by interception, diffusion, inertial forces, and gravitational forces. Attachment then occurs by attractive close-range molecular forces such as van der waals forces (MWH 2005).

2.5.3.1 Straining

When particles are larger than the void spaces in the filter, they are removed by straining. This causes a cake to form at the surface of the filter bed that can improve particle removal efficiency, but also increases head loss across the filter (MWH 2005). Figure 2.9 shows a representation of straining.

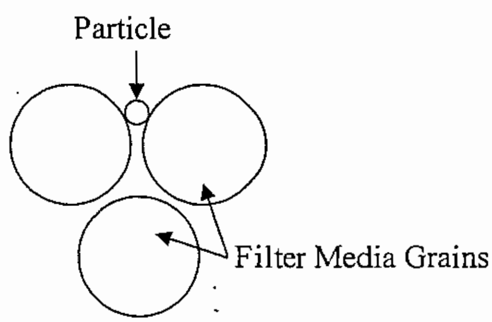


Figure 2.9 Particle straining during media filtration (modified from MWH 2005)

A bed of granular media can strain particles smaller than the filter media grain size. For spherical media, a close-packed arrangement will cause straining when the ratio of particle diameters is greater than 0.15. Particles that are smaller than this can pass through the media, making straining insignificant for particles smaller than about thirty to eighty micrometers for many cases (MWH 2005).

2.5.3.2 Filtration Model

Having media uniformity in a filter bed creates void spaces significantly larger than the particles being filtered, which in turn results in straining not being the dominant removal mechanism. Instead, particles are removed when they adhere to the filter grains or previously deposited particles (MWH 2005). For water treatment applications, Yao *et al.* (1971) have presented a model with a theory based on the accumulation of particles on a single filter grain, or collector. The accumulation on a single collector is defined as the rate at which particles enter the region of influence of the collector multiplied by transport and attachment efficiency factors.

The particles must come in contact with the collectors, and the modes for transporting particles to the collector surface are interception, sedimentation, and diffusion (Yao, Habibian, and O'Melia 1971). For laminar flow, spherical particles, and spherical collectors, Yao *et al.* (1971) gave the equation for particle transport by interception, (η_I):

$$\eta_I = \frac{3}{2}\left[\frac{d_P}{d_C}\right]^2 \qquad (2\text{-}19)$$

Where (d_P) is the particle diameter, and (d_C) is the collector diameter. Yao *et al.* (1971) also gave that the collector efficiency due to sedimentation (gravity), or (η_G) is found to be the ratio of Stokes settling velocity to the superficial velocity, shown by:

$$\eta_G = \frac{g(\rho_s - \rho_f)d_P^2}{18\mu v_f} \tag{2-20}$$

Where (v_f) is the filtration rate, or superficial velocity. Particles are influenced by Brownian motion and will deviate from the fluid streamlines due to diffusion. The transport efficiency by diffusion, (η_D) is given by Levich (1962) as:

$$\eta_D = 4Pe^{-2/3} \tag{2-21}$$

Where (Pe) is the Peclet number, which after using Stokes-Einstein equation is found to be (Clark 1996):

$$Pe = \frac{3\pi\mu d_P d_C v_f}{k_B T} \tag{2-22}$$

Where (k_B) is Boltzmann constant, 1.381 x 10^{-23} J/K and (T) is the absolute temperature in Kelvin. Yao *et al.* (1971) assumed that the transport mechanisms are additive, giving the equation:

$$\eta_T = \eta_I + \eta_G + \eta_D \tag{2-23}$$

The effect of particle diameter on each mechanism is shown in Figure 2.10. Figure 2.10 predicts that the lowest removal efficiency occurs for particles at about 1 μm in size and has been verified experimentally (Yao, Habibian, and O'Melia 1971).

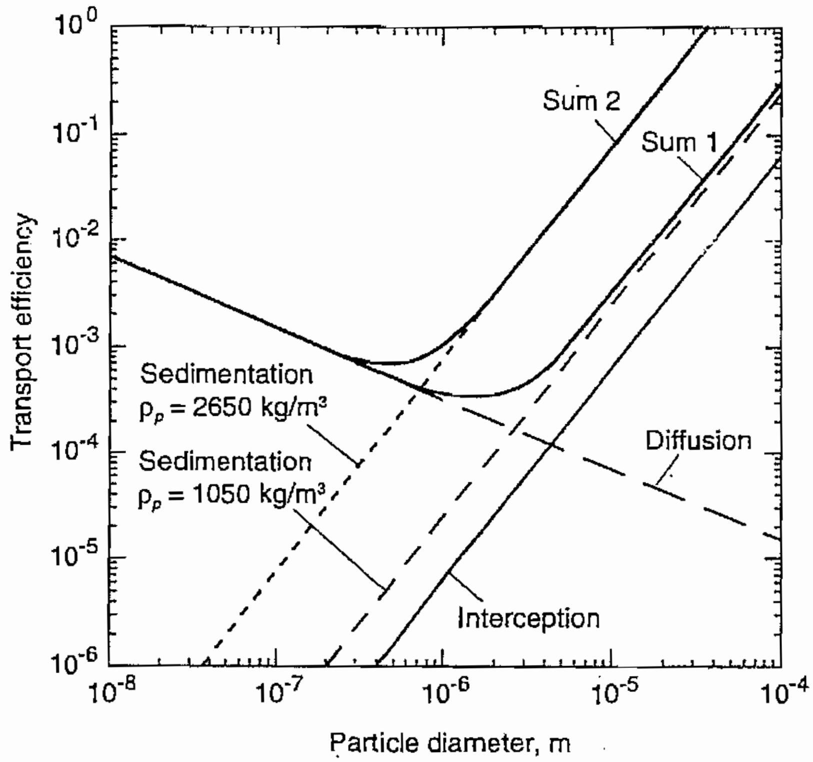


Figure 2.10 Particle size vs. transport efficiency (d_c = 0.5 mm, v = 5 m/h, T = 25°C) (MWH 2005)

2.6 Plate Settlers

Plate settlers were developed to improve the efficiency of conventional rectangular settling basins by relying on settling area rather than detention time. The plates are designed to keep the water velocity smaller than the settling velocity of the particles (AWWA and ASCE 1990). This allows the particles to settle onto and slide off of the plate surfaces to accumulate on the basin floor. Problems do arise, though, because of scouring action re-suspending particles if the water travels at a high velocity (AWWA and ASCE 1990). Performance of the plate settlers can also be greatly reduced due to conditions such as poor flocculation, poor inlet flow distribution, scaling, and algal growth (MWH 2005).

There are three different ways in which to design plate settlers in a basin: 1) cross-flow, 2) co-current, and 3) countercurrent. For countercurrent settlers, assuming a uniform velocity, the equation for the fluid velocity in the channel, ($v_{f\theta}$) is:

$$v_{f\theta} = \frac{Q}{NdW} \tag{2-24}$$

Where (d) is the distance perpendicularly between two parallel plates, (Q) is the flow rate, (N) is the number of channels, and (W) is the width of the channels (MWH 2005). As stated above, the water velocity needs to be smaller than the particle settling velocity. Therefore, for design purposes it is desirable to find the point at which the settling time is equal to the time the particle is in the plates, given by:

$$\omega_s \geq \frac{v_{f\theta} d}{L_p \cos\theta + d \sin\theta} \tag{2-25}$$

Where (ω_s) is the particle settling velocity, (L_P) is the length of the plate, and (θ) is the inclination angle in degrees of the plates from the horizon. The particles with settling velocities equal to or larger than the right side of Equation 2-25 will be removed from the water (MWH 2005).

2.7 Previous Investigations in the Tahoe Basin

Other research has been done in the Tahoe Basin in order to try to turn back the declining rate of clarity in Lake Tahoe. Studies pertaining to the geology of the surrounding area will give some insight into the natural materials around the lake. The California Department of Transportation (Caltrans) has also supported research.

2.7.1 Geological Investigations

The lay of the land, or the relief, in the Tahoe Basin influences soil formation through its effect on drainage and erosion. Most of the slopes in the basin are steep, favoring rapid runoff, good to excessive drainage, and a high erosion potential. The soils of the flood plains are low lying and subject to poor drainage conditions (Rogers 1972). The natural sediments originally came from many parent materials, formed in material weathered from granitic, metamorphic, and basic igneous rock, glacial deposits and outwash, and in alluvium of mixed sources (Rogers 1972).

2.7.2 Caltrans Studies in the Tahoe Basin

Caltrans maintains over 68 miles of roadways in the Tahoe Basin as well as several maintenance and material storage yards (Caltrans 2000). Because the stormwater runoff and snow management activities from these facilities need to be watched and maintained, Caltrans has undergone testing in order to understand the characteristics of the stormwater in the Tahoe Basin (Caltrans 2001).

2.7.2.1 Tahoe Basin Stormwater Monitoring

The Tahoe Basin Stormwater Monitoring Program was initiated due to various problems in the Tahoe Basin. The report is given during the period of July 2000 to April 2001 (Caltrans 2001). According to Caltrans (2001), the three different runoff conditions in the Tahoe Basin are summer thunderstorms, winter/spring snow melt, and transitional conditions with snow/rain mix. For the runoff conditions, precipitation water quality samples were collected at two-highway runoff monitoring stations during events. Along

with the testing of precipitation was the collection of stormwater runoff to identify and characterize sediments and other pollutants found in highway runoff.

According to Caltrans (2001), the list of analytical constituents for precipitation water quality monitoring was determined from the constituents of the runoff samples. These pollutants in the precipitation were analyzed by priority, in which conductivity, pH, and others were included. Table 2.2 includes some of the analytical data taken from runoff from summer thunderstorms, rain or mixed rain/snow, and snowmelt, and the Caltrans data analysis tool (DAT) was applied to generate the statistical values listed (Caltrans 2001).

The water quality data generated from the summer thunderstorm season provided examples of runoff quality without the impact of the sand and salt. This is shown in Table 2.3, showing conductivity and TSS were lower (Caltrans 2001).

The State of California Regional Water Quality Control Board has established water quality limits for all stormwater discharges to surface waters and infiltration systems in the Tahoe Basin (Caltrans 2001). For turbidity of surface discharges, the stormwater limit is 20 NTU, and for infiltration systems is 200 NTU (Region 1994).

Table 2.2 Related runoff water quality data from the Tahoe Basin (modified from Caltrans, 2001)

Constituent / Parameter	Units	Reporting Limit	Sample Size	Range		Mean	Median	Std. Dev.
				Min	Max			
pH	pH	0.1	22	5.6	8.5	7.3	7.3	0.8
EC	umhos/cm	1	22	39	16200	2400	1026	4027
TSS	mg/L	1	22	25	5100	989	608	1334
Turbidity	NTU	0.05	19	8	8	575	493	644

Table 2.3 Summer thunderstorm data (modified from Caltrans, 2001)

Constituent / Parameter	Units	Summer Thunderstorms		
		Station 3-202 8/03/00	Station 3-203 8/03/00	Station 3-203 8/30/00
pH	pH	6.6	6.34	5.6
EC	umhos/cm	39	55	169
TSS	mg/L	48	263	25
Turbidity	NTU	39	138	66

2.7.2.1.1 Double Barrel Sediment Trap

The double barrel sediment traps were also tested during the Tahoe Basin Stormwater Monitoring Study (Caltrans 2001). The characteristics were evaluated by comparing the mass of material collected in the traps to the particle size distribution of the sediment, and identifying the chemical content of various particle size fractions (Caltrans 2001).

Filter fabric bags and sheets were installed in the double barrel sediment traps and used as a passive filtration collection system to collect sediments for characterization of particle size distribution, chemical composition, and mass. Any material that settled to the bottom would fall into the bag. The filter sheets were installed in a stacked filter box that received the outflow from the sediment traps. Mass was calculated for dry weight and ASTM D422 was used to determine the particle size distribution, shown in Figure 2.11 (Caltrans 2001).

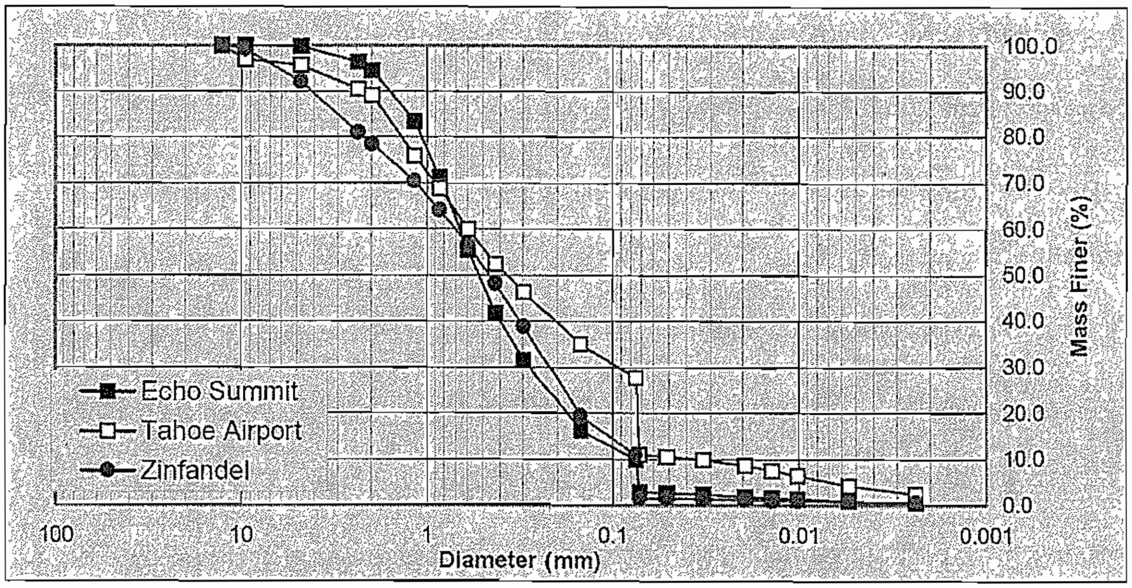


Figure 2.11 Grain size distribution (Caltrans 2001)

In general, results indicate that most of the total sediment mass is retained in the sand traps. The results from the sites with sediment traps indicate that the larger sediments ranging between about 0.07 – 5.0 mm were retained by the up gradient barrels during both monitoring periods (Caltrans 2001).

2.7.2.2 Highway 267 Filter Fabric Sand Trap Pilot Study

Caltrans (2006) installed filter fabric sand traps along Highway 267 that used a two-stage treatment process that consisted of settling followed by filtration through filter fabrics. The main goal of the study was to evaluate the treatment effectiveness of two sand traps for reducing total suspended solids (TSS) and turbidity from storm water runoff. Another goal was to assess operation and maintenance requirements at the two sand traps under the various environmental conditions that occur in the Tahoe Basin.

According to Caltrans (2006), the first sand trap was set up where the runoff flowed into a sedimentation chamber where it was detained for a short period to allow the coarse sediments to settle out. After the sedimentation chamber filled with water it overflowed into the filter chamber. The filter chamber was lined with a triple layer of non-woven geotextile. The runoff passed through the fabric and was collected in an underdrain piping beneath. The effluent was then discharged to the surface as shown in Figure 2.12. The second sand trap was similar to the first until it entered the filter chamber. At that point there were then two perforated riser pipes covered with a triple layer of non-woven geotextile. The runoff passed through the fabric and was then collected in the underdrain piping system beneath. The effluent was then discharged to the surface, as shown in Figure 2.13. Automatic samplers were employed to collect representative samples of the influent and effluent. The apparent opening size of the filter material for both traps was 0.150 mm, and the flow rate for the material was 2,037 L/min/m^2.

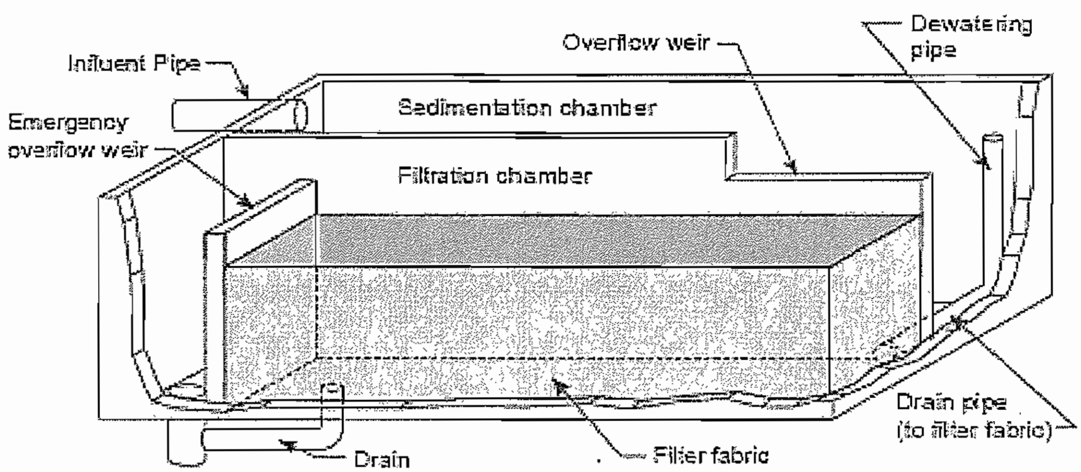


Figure 2.12 Drawing of Sand Trap 1 (Caltrans 2006)

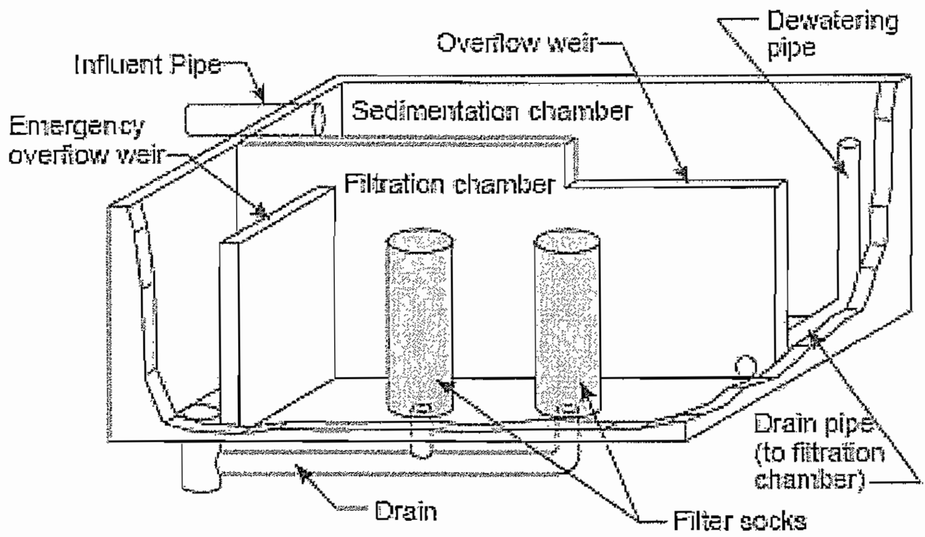


Figure 2.13 Drawing of Sand Trap 2 (Caltrans 2006)

Most of the sediment accumulation was in the sedimentation chamber, as found by visual observation and representative measurements. Sediment accumulation was also observed in the filtration chamber, but not at a measurable depth (Caltrans 2006). Results were compiled to determine the quality of influent and effluent at the sites and to evaluate the performance of each sand trap. Table 2.4 shows mean concentrations of influent constituents and percent removal (Caltrans 2006). The findings of the study were that the filter fabric did not clog and that sand traps were more effective at treating higher influent TSS concentrations (Caltrans 2006).

Table 2.4 Sand trap removal effectiveness (Caltrans 2006)

		Mean Influent Concentration		Mean Effluent Concentration		Percent Removal	
	Units	3-301	3-304	3-302	3-305	Sand Trap #1	Sand Trap #2
Turbidity	NTU	773	823	251	306	68	63
Total Suspended Solids	mg/L	397	768	160	171	60	78

2.7.2.3 Geotextile Fabric Filter Laboratory Testing

Caltrans conducted laboratory testing of geotextile filter fabrics. This was in order to evaluate the ability of various geotextiles and cloth fabrics for the removal of turbidity and total suspended solids (TSS) from synthetic storm water, also taking into account head loss (Caltrans 2004).

The filter fabrics were installed inside four inch diameter filter columns at vertical and horizontal orientations and were continuously loaded with roughly 2.2 gpm/ft^2 of synthetic storm water. The fabrics were selected based on apparent size opening, material type, cost, availability, and manufacturer. The apparent opening size (AOS) ranged from 0.010 mm in some of the cloth-based fabrics up to 0.60 mm for some of the woven material. Fabrics were tested based primarily on AOS and thickness (Caltrans 2004).

The synthetic stormwater was made to represent typical Tahoe Basin runoff, where turbidity and TSS are two major determinants. The target values were to have a TSS of 500 mg/L and a turbidity of 450 NTU, having a ratio of TSS to turbidity equal to 1.1 (Caltrans 2004).

According to Caltrans (2004), many filter fabrics were tested, but the BP Amoco 4510 and 4516 will be described in this review. It was concluded from the graphs that horizontal filters performed better than vertical filters when Amoco 4516 was used. When Amoco 4510 was used, sometimes the horizontal filter was better, sometimes the vertical, sometimes they were equal. As observed with turbidity removal, the fabrics tested did not always perform the same in each run. As for hydraulic performance, the filters tested had head losses exceeding the maximum during a representation of a one inch storm event. This means that the filters can not get close to operating for one year of full-scale operation without hydraulic failure. The relationship of turbidity versus time can be seen in Figure 2.14.

Rate of head loss buildup was faster for horizontally-oriented filters than for vertically-oriented filters for Amoco 4516. For Amoco 4510, there was no significant difference in head loss buildup for horizontal and vertical units, the vertical head buildup is shown in Figure 2.15 (Caltrans 2004). To simulate real life scenarios upon the fabrics, they were washed or scraped and re-tested (Caltrans 2004).

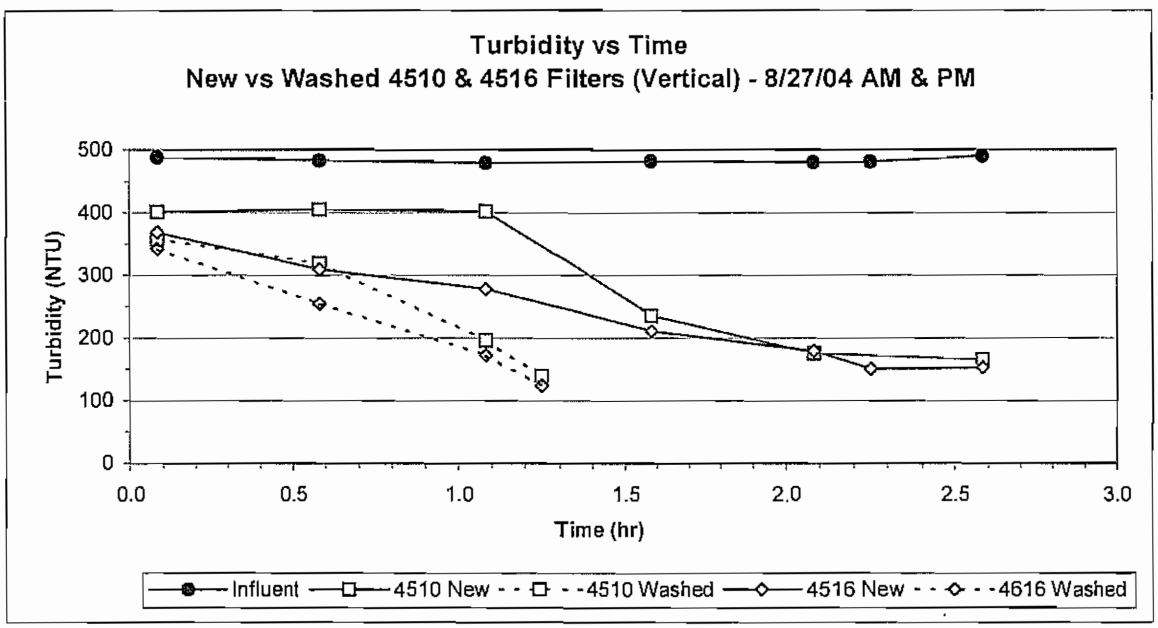


Figure 2.14 Filter fabric analysis of turbidity vs. time (Caltrans 2004)

As shown in Figure 2.14 and Figure 2.15, the used and washed fabrics had a higher rate of head loss buildup, but had better turbidity removal than the new fabrics.

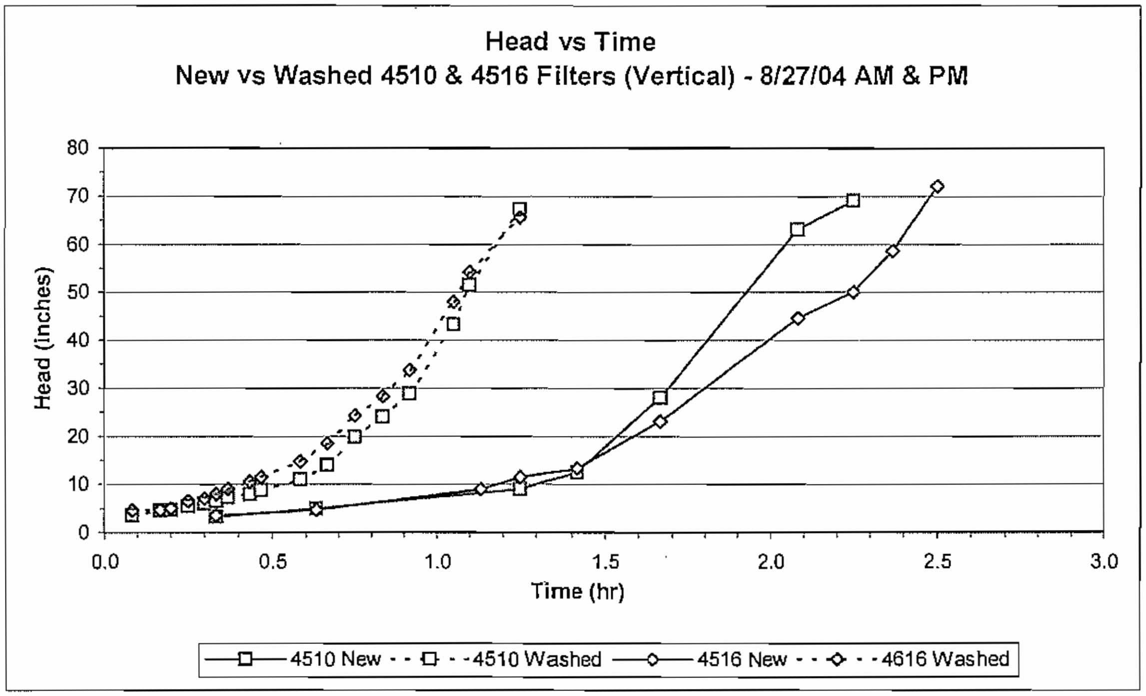


Figure 2.15 Filter fabric analysis of head vs. time (Caltrans 2004)

Chapter 3

EXPERIMENTAL MATERIALS AND METHODS

3.1 Overview

The experimental methods are given in this chapter to show how the sediment and traps were prepared for each test, as well as how the tests were run. The methods also explain how the flow and feed rates were determined, how the sediment traps were set up in the laboratory, and how they were enhanced.

3.2 Testing Methods

Testing in the laboratory allowed for tests to be repeated under the same conditions, and allowed for changes while constraining existing properties (e.g., keeping flow constant while changing sediment concentration). Each test was repeated at least three times under the same conditions to obtain an average and standard deviations. Each test included the following steps.

- Trap Cleaning and Preparation
- Sediment Preparation
- 30 Minute Trap Test
- Data Collection and Sample Analysis
    - Turbidity
    - Particle Counting
    - pH and Electrical Conductivity
    - Total Suspended Solids Test

- Sieve Analysis

3.2.1 Sediment Preparation

The sediments were prepared to ensure constant feed rates into the traps by funnels without hindrance. Both the decomposed granite and the road sand were prepared prior to testing using a two step process. They were first air dried to a visual dryness. They were then sieved through a quarter inch screen to remove large particles or agglomerations of sediment or salt crystals. For the mixed sediment, the mixture was 75% road sand and 25% decomposed granite. For this, three buckets of road sand were combined with one bucket of decomposed granite and mixed with a shovel to visual consistency.

3.2.2 Trap Cleaning and Preparation

For consistency, each trap was prepared before testing to keep the initial volumes and enhancements similar for repetitive testing. Sediments deposited during testing were removed from the traps, and filters were replaced or cleaned when necessary.

3.2.3 Thirty Minute Test

Testing of the sediment traps involved a constant inflow of a suspension of concentrated sediment over a thirty minute time interval. Sediment feed began at the five minute mark which gave time for the influent flow to stabilize. A submersible pump (PE-1 Series, Little Giant, Oklahoma City, Oklahoma) located at the outlet of each trap enabled the water to be continuously fed to a Hach 2200 PCX Particle Counter and a Hach SC100 1720E Low Range Turbidimeter. Every five minutes the flow through turbidity and temperature were recorded. Grab samples of the influent and effluent water were collected in glass jars after ten minutes had elapsed. This allowed sufficient time for the traps to fill with water and start flowing at the outlet. Grab samples were also taken at the beginning, middle, and end of the thirty minute test at a location of the pipe before the trap influent. This was to obtain background water information to know the contamination of the stored water. Samples of dried sediment for sieve analyses were taken before it was introduced into the traps, and from inside the traps after the end of each thirty minute test. The samples were placed in one gallon plastic bags and labeled accordingly.

3.2.4 Data Collection and Sample Analysis

Following each thirty minute test, the turbidity of the grab samples were measured using a Hach 2100N Turbidimeter (Loveland, CO). Then the electrical conductivity and pH of each sample was measured using a Fisher Scientific Accumet Model 20 pH/conductivity meter (Denver, CO). A total suspended solids test was done according to Section 2540 D of Standard Methods (Association *et al*, 1998). The jars were inverted eight times before testing to allow for consistent resuspension. Sediment from the traps were dried in an oven at 103°C in accordance with ASTM C136, and sieve analyses were also done on the dried sediment samples according to ASTM C136 (Mamlouk and Zaniewski 1999).

3.3 Testing Flows

Hydrographs from Caltrans (2003) were analyzed in locations closest to Nevada, with the locations indicated in Figure 3.1 as Snow Creek at Station #3-219 and Tahoe

Meadows at Station #3-201. Testing of the sediment traps was performed at two different flow rates. Because of the volume of the traps and the thirty minute duration of the tests, the low flow was chosen to ensure a definite effluent flow within ten minutes of elapsed time.

As seen from the hydrograph for Tahoe Meadows in Figure 3.2, some peak flows can be represented by 675 liters per minute (L/min), which is roughly 175 gallons per minute (gpm). Some low flows can be represented at 475 L/min (roughly 125 gpm), as seen in Figures 3.2 and 3.3. Considering the storage capacity of the sump in the laboratory, the capacity of the pump supplying water, and the trap capacities, the flows chosen were 675 L/min and 475 L/min for the high and low flows, respectively.

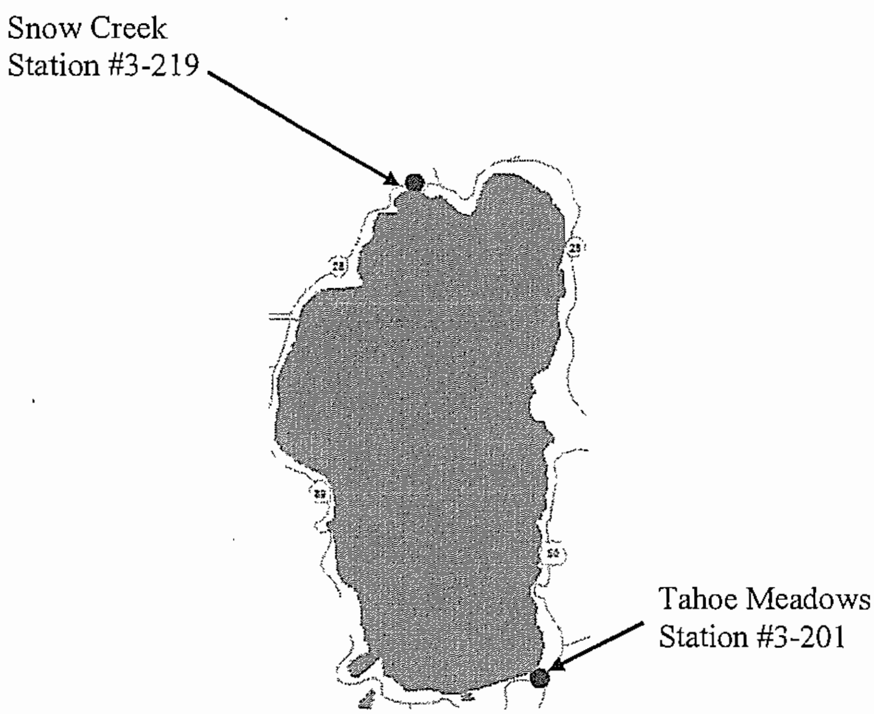
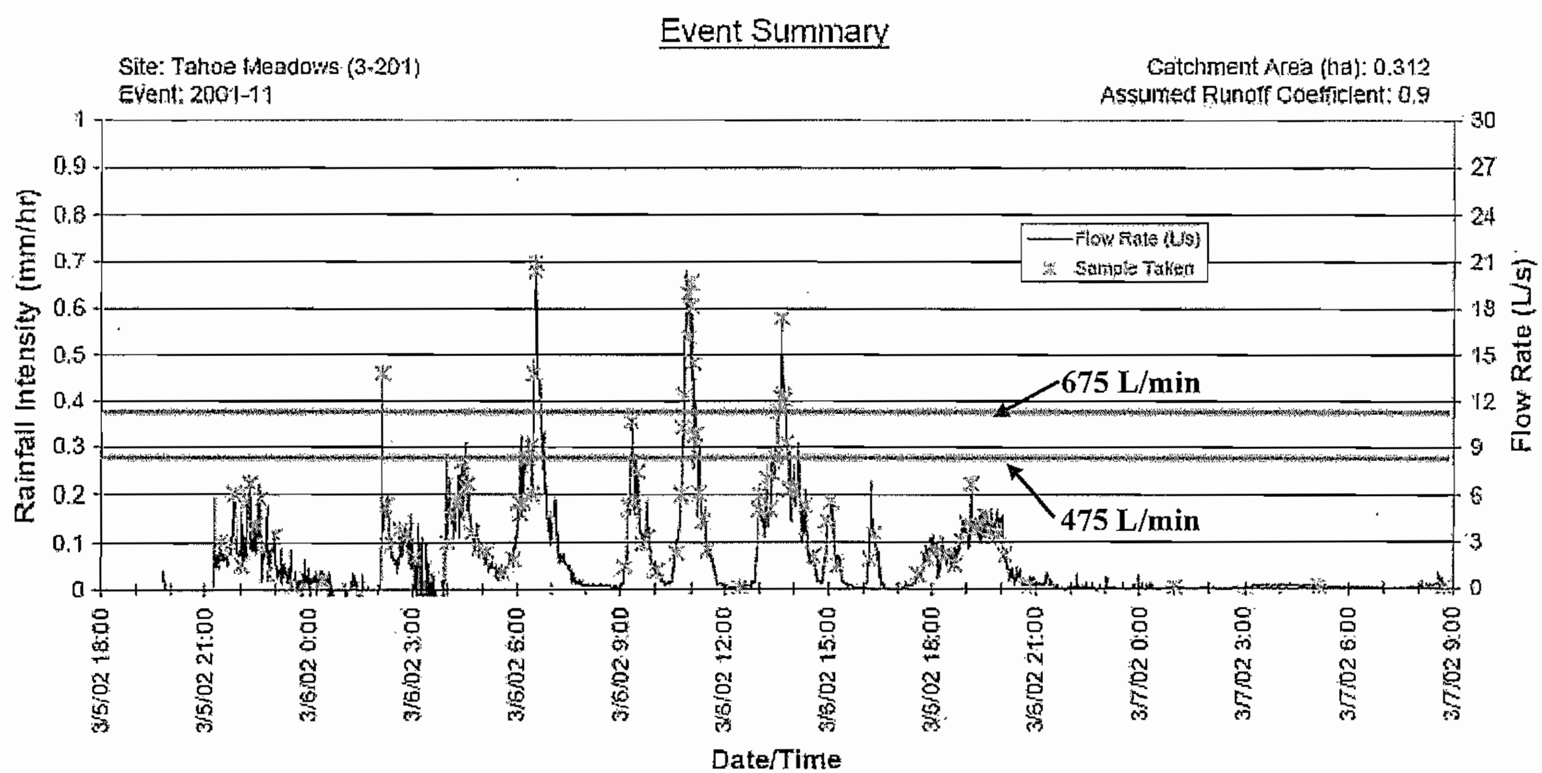


Figure 3.1 Lake Tahoe testing stations (modified from Caltrans, 2003)



Runoff Data		*Sample Data*	
Start Date/Time:	03/05/02 19:46	Start Date/Time:	03/05/02 21:26
Stop Date/Time:	03/07/02 08:46	Stop Date/Time:	03/07/02 08:45
Total Flow Volume (L):	236033	Estimated Percent Capture:	90%
Peak Flow (L/s):	20.95	Successful Aliquots:	105

Notes: Rain/snow mix event. Snowmelt runoff begain at approximately 9 am. This runoff was not sampled. Bottle was replaced three times.

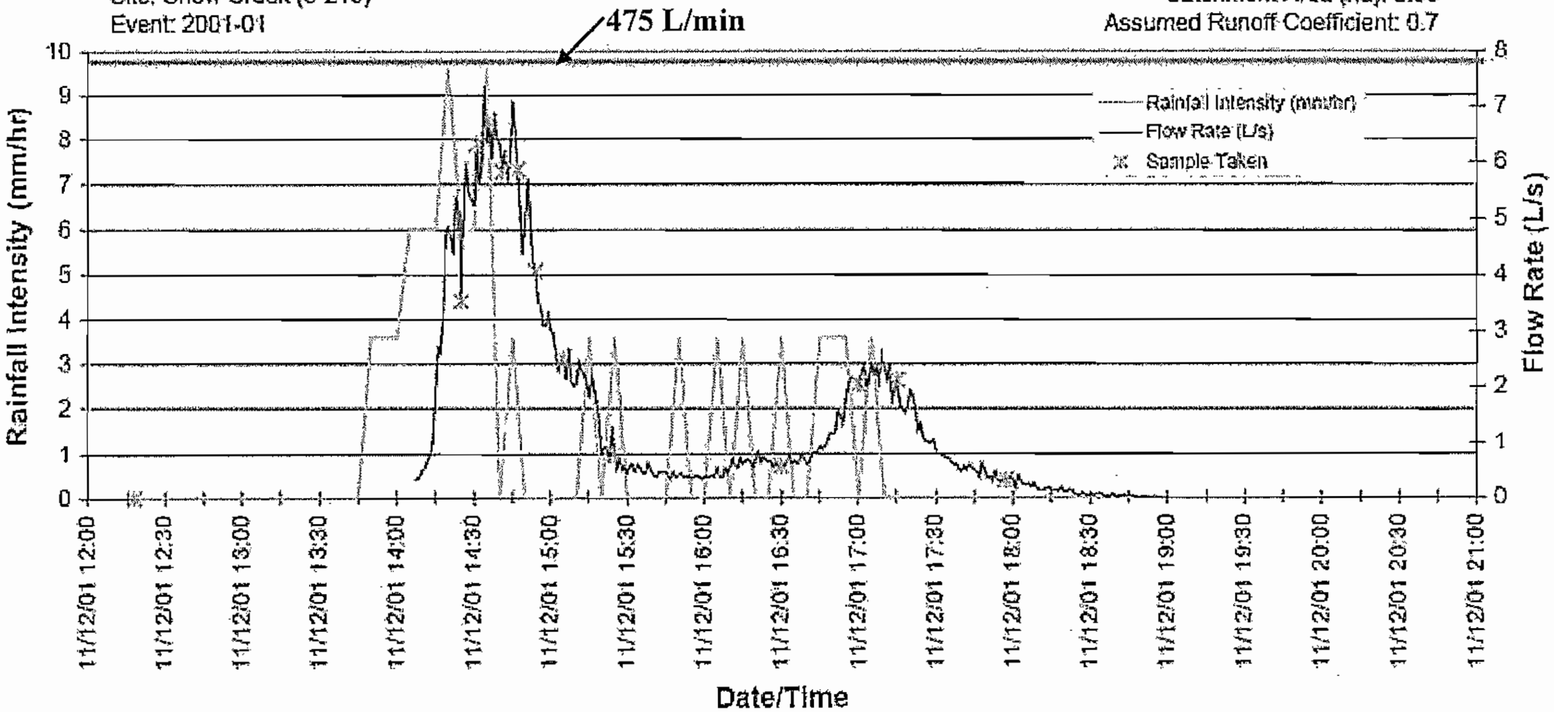
Figure 3.2 Tahoe Meadows hydrograph (Caltrans 2003)

Figure 3.3 Snow Creek hydrograph (Caltrans 2003)

Event Summary

Site: Snow Creek (3-219)
Event: 2001-01

Catchment Area (ha): 0.83
Assumed Runoff Coefficient: 0.7



Rain Data		*Runoff Data*		*Sample Data*	
Start Date/Time:	11/12/01 13:50	Start Date/Time:	11/12/01 14:07	Start Date/Time:	11/12/01 12:18
Stop Date/Time:	11/12/01 19:05	Stop Date/Time:	11/12/01 19:06	Stop Date/Time:	11/12/01 17:57
Event Rain (mm):	8.30	Total Flow Volume (L):	25324	Estimated Percent Capture:	99%
Max Intensity (mm/hr):	9.60	Peak Flow (L/s):	7.35	Successful Aliquots:	13
		Observed Runoff Coefficient:	0.368		

Notes: Sampling period extends outside of flow period. Last recorded rainfall time used as end time.

3.4 Testing Concentrations

Road sand or decomposed granite was introduced into the water feeding the sediment traps through two funnels of different sizes. The resulting suspended solids concentrations of both the road sand and decomposed granite are shown in Table 3.1. The testing was performed to the matrix in Table 3.2.

Table 3.1 Suspended solids concentrations of sediments

Road Sand Concentration (kg/min)				Decomposed Granite Concentration (kg/min)			
High Sediment Feed Rate		Low Sediment Feed Rate		High Sediment Feed Rate		Low Sediment Feed Rate	
475 L/min	6.8	475 L/min	4.4	475 L/min	5.6	475 L/min	3.3
675 L/min	6.8	675 L/min	4.4	675 L/min	5.6	675 L/min	3.3

Mixed Sediment Concentration (kg/min)	
High Sediment Feed Rate	
475 L/min	4.0

Table 3.2 Testing matrix

	675 L/min	***475 L/min***
High Sediment Feed Rate, Road Sand (RS)	675 L/min, High Sediment Feed Rate, RS	475 L/min, High Sediment Feed Rate, RS
Low Sediment Feed Rate, Road Sand (RS)	675 L/min, Low Sediment Feed Rate, RS	475 L/min, Low Sediment Feed Rate, RS
High Sediment Feed Rate, Decomposed Granite (DG)	675 L/min, High Sediment Feed Rate, DG	475 L/min, High Sediment Feed Rate, DG
Low Sediment Feed Rate, Decomposed Granite (DG)	675 L/min, High Sediment Feed Rate, DG	475 L/min, High Sediment Feed Rate, DG

A mix of three parts of road sand to one part of decomposed granite was used for some testing to more appropriately simulate field conditions. The mixed sediment was introduced at a suspended solids concentration measured to be 4.0 kg/min. Testing was also performed with a high sediment feed rate and a low water flow resulting in the highest concentrations of suspended solids in the influent, as seen in Table 3.2 (475 L/min with 6.8 kg/min road sand, 475 L/min with 5.6 kg/min decomposed granite, 475 L/min with 4.0 kg/min mixed sediment).

3.5 Sieve Analyses

Sieve analyses were used to quantify the size fractions of the sediment before it was introduced into the system (feed) and of the sediment retained within the traps (retained). The gradation curves are particle size distribution curves that quantify the particle sizes entering, exiting, and remaining in the trap. Sieve analyses were performed only for the road sand. The more cohesive nature of the decomposed granite resulted in the formation of small clumps that were difficult to sieve and resulted in inconsistent size fractions. The flow and feed rate for the field samples is unknown. The flow for the laboratory tests given was 475 L/min, and the sediment feed rate was 6.8 kg/min.

3.5.1 Sieve Sample Field Data

The sieve analyses of samples taken from within the sediment traps used in the laboratory are compared in Figure 3.4 to sieve analyses of field samples collected from sediment traps located along U.S. Highway 50 (US 50) and Nevada State Route 28 (SR 28). For the field samples, Sample 1 was collected from a single drop inlet sediment trap along US 50 going northbound near Borens Meadow. Sample 2 was collected from a

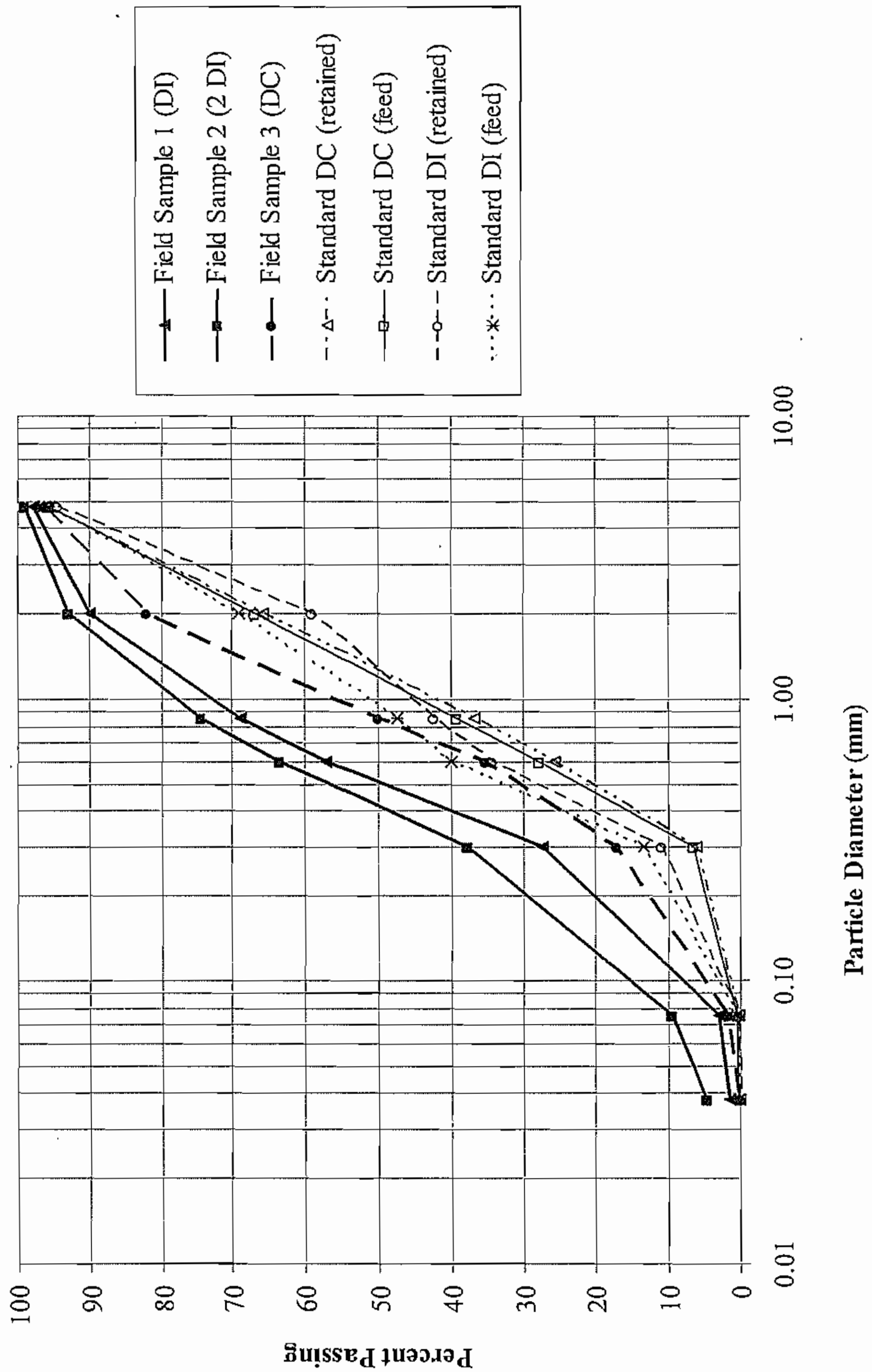


Figure 3.4 Field sample analyses for the double can and drop inlet sediment traps (475 L/min, and 6.8 kg/min road sand for laboratory samples)

double drop inlet sediment trap along US 50 going northbound near Borens Meadow. Sample 3 was taken from a double can sediment trap along SR 28 going southbound.

For Field Sample 1, the percentage of particles passing 1.00 millimeter (mm) in diameter was about 73%, where the percentage of particles passing 0.10 mm in diameter was about 8%. For Field Sample 2, the percentage of particles passing 1.00 mm in diameter was about 78%, where the percentage of particles passing 0.10 mm in diameter was about 15%. Field Sample 2 for the double drop inlet was finer than Field Sample 2 for the drop inlet. For Field Sample 3, the percentage of particles passing 1.00 mm in diameter was at about 55% and the percentage of particles passing 0.10 mm in diameter was about 5%. Thus, Field Sample 2 was the finest sediment sample collected while Field Sample 3 was the coarsest. The finest particles for the laboratory testing of the feed standard sediment traps were retained in the standard drop inlet sediment trap where the percentage of particles passing 1.00 mm in diameter was about 52% and the percentage of particles passing 0.10 mm in diameter was about 4%.

3.5.2 Sieve Analyses of Sediment Samples from Laboratory Testing

Sieve analyses were performed on representative samples of the sediment that was fed into the sediment traps and on sediment retained within the sediment traps. Gradation curves for samples of the road sand that was used during typical tests in the standard sediment traps, sediment traps with single filter fabrics, and sediment traps with multiple filter fabrics are compared in Figure 3.5. In each of these samples, the percentage of particles passing 1.00 mm in diameter was about 40% to 50% and the percentage of particles passing 0.10 mm in diameter was about 2% to 5%. Ideally, the

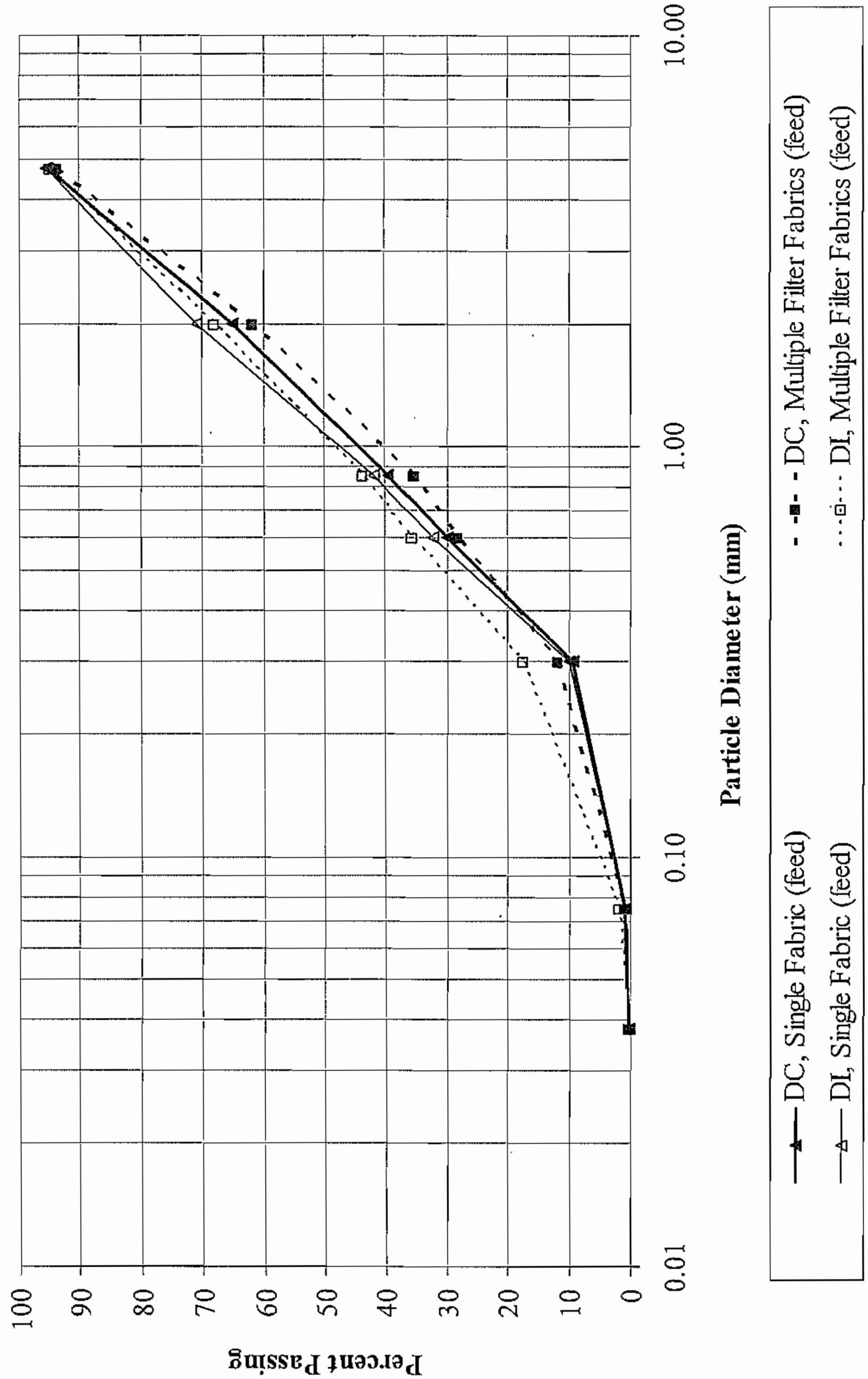


Figure 3.5 Sieve analyses of feed sediment used for tests in the double can and drop inlet sediment traps (475 L/min, and 6.8 kg/min road sand)

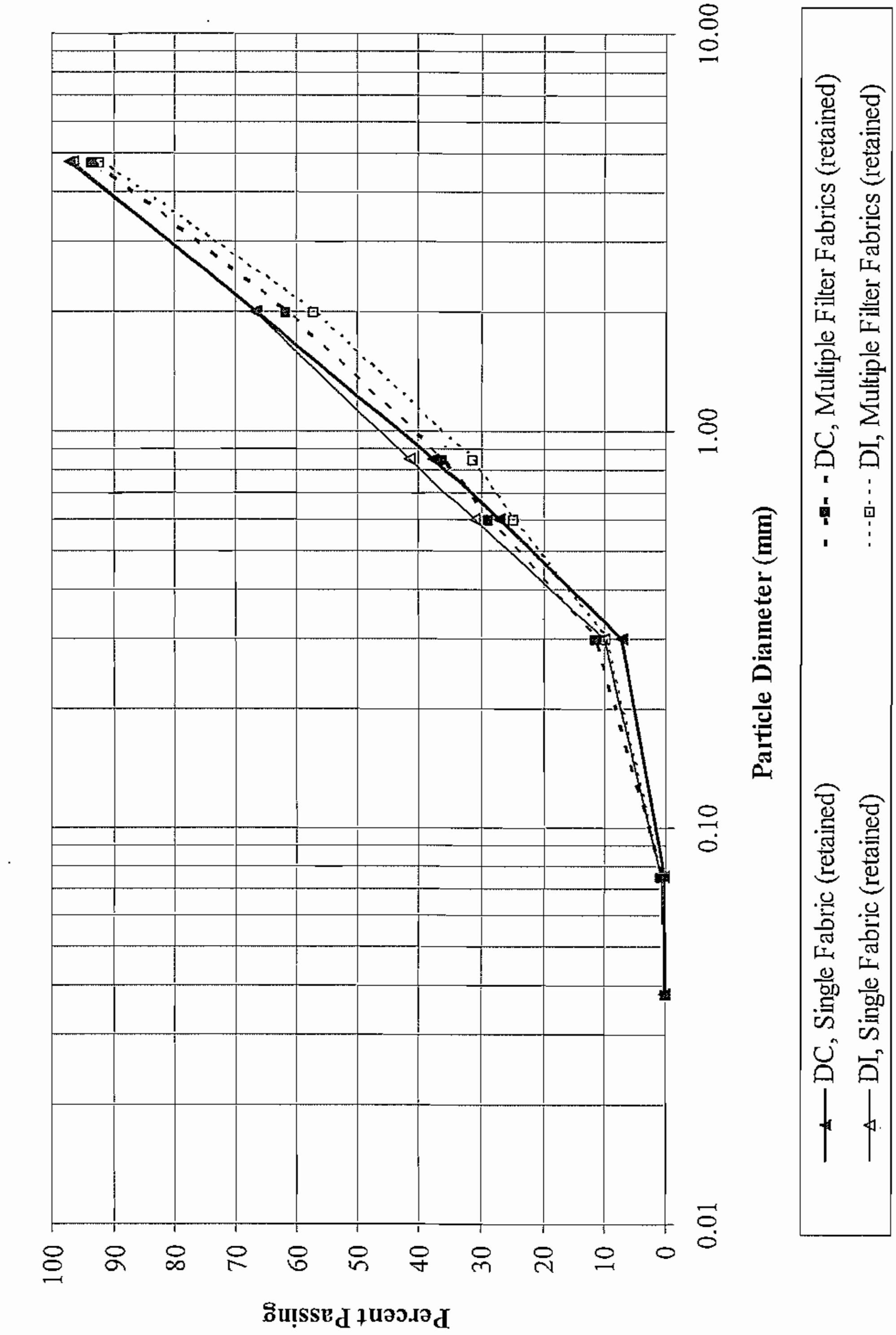


Figure 3.6 Sieve analyses of sediment retained within (retained) the double can and drop inlet sediment traps (475 L/min, and 6.8 kg/min road sand)

gradation curves for the various samples of road sand should have been identical since the sediment source and preparation techniques were identical. However, differences were most likely due to variations in the lack of sediment uniformity and varied slightly over the course of testing.

Figure 3.6 shows a representative gradation of the sediments that were retained within the sediment traps during a typical test. For the double can sediment trap with multiple filter fabrics, the percentage of particles passing 1.00 mm in diameter was about 40% while the percentage of particles passing 1.00 mm in diameter for the drop inlet with multiple fabrics was about 36%. This was less than in the tests with a single layer of filter fabric, making the multiple fabric sediment samples coarser. The gaps between the multiple and single fabrics for both traps decreases as the particle diameters decrease. At a particle diameter of 0.10 mm, the percent passing varies little at about 3% passing. The range of data at 1.0 mm of particle diameter is about 35% to 45%.

3.6 Laboratory Setup

The laboratory installation was set up to allow for the most effective placement of the full-scale sediment traps, as seen in Figure 3.7. The laboratory had two five-foot deep by four-foot wide sumps. One sump was drained to allow placement of the traps and the other sump used was to store water for testing. The water was pumped by a submersible pump (Goulds Pumps, Seneca Falls, New York) at the desired flow rates through a four-inch polyvinyl chloride pipe (PVC) regulated by gate valves. The dry sediment was fed through a funnel into the piping system. The resulting suspension was discharged onto ramps that emptied into the sediment traps. The ramps simulated the pavement from the

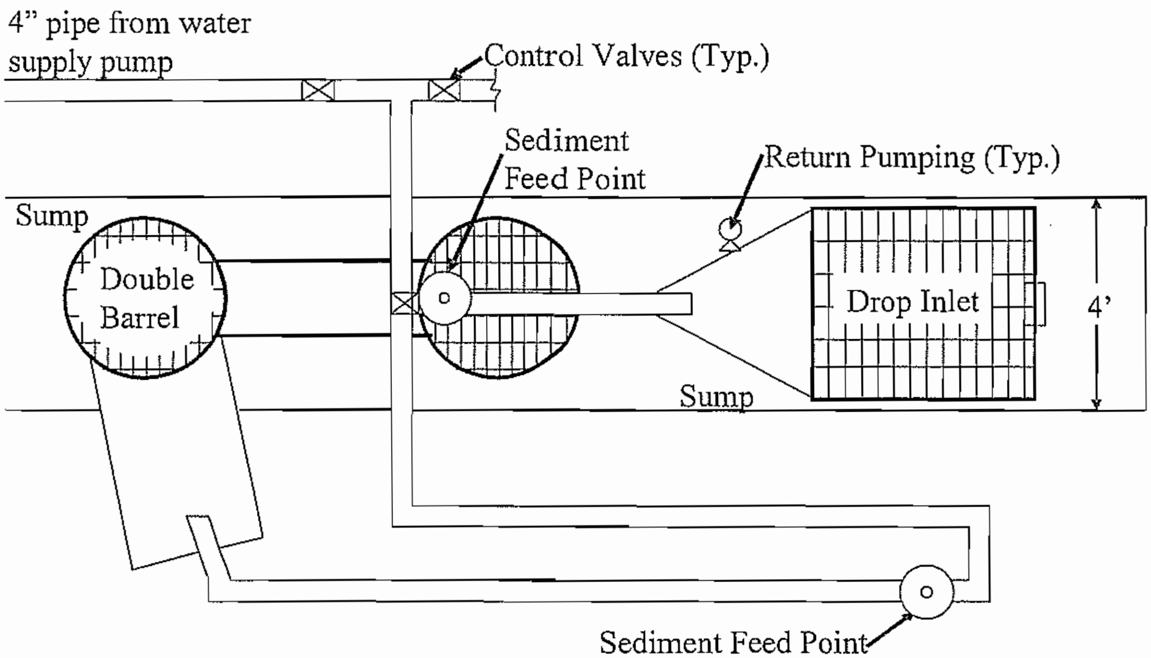


Figure 3.7 Laboratory setup of the double can and drop inlet sediment traps

roadway gutters entering the sediment traps. Effluent from the sediment traps was pumped back to the water storage sump.

3.6.1 Drop Inlet Sediment Trap

The drop inlet sediment trap was modeled after a four-foot (122 cm) by four-foot square by 76-inch (193 cm) deep reinforced concrete drop inlet. The drop inlet sediment trap that was constructed was 48" x 46" x 76" deep, which was required to fit inside the 48" wide sump. The trap was constructed out of water sealed plywood that was lined on the inside with concrete. The water exited the trap through a six inch PVC pipe, which was also the location from which water was continuously pumped to the turbidimeter and particle counter instruments and where grab samples were collected. A standard grate provided by NDOT was placed over the top of the trap. The drop inlet sediment trap can be seen in Figure 3.8.

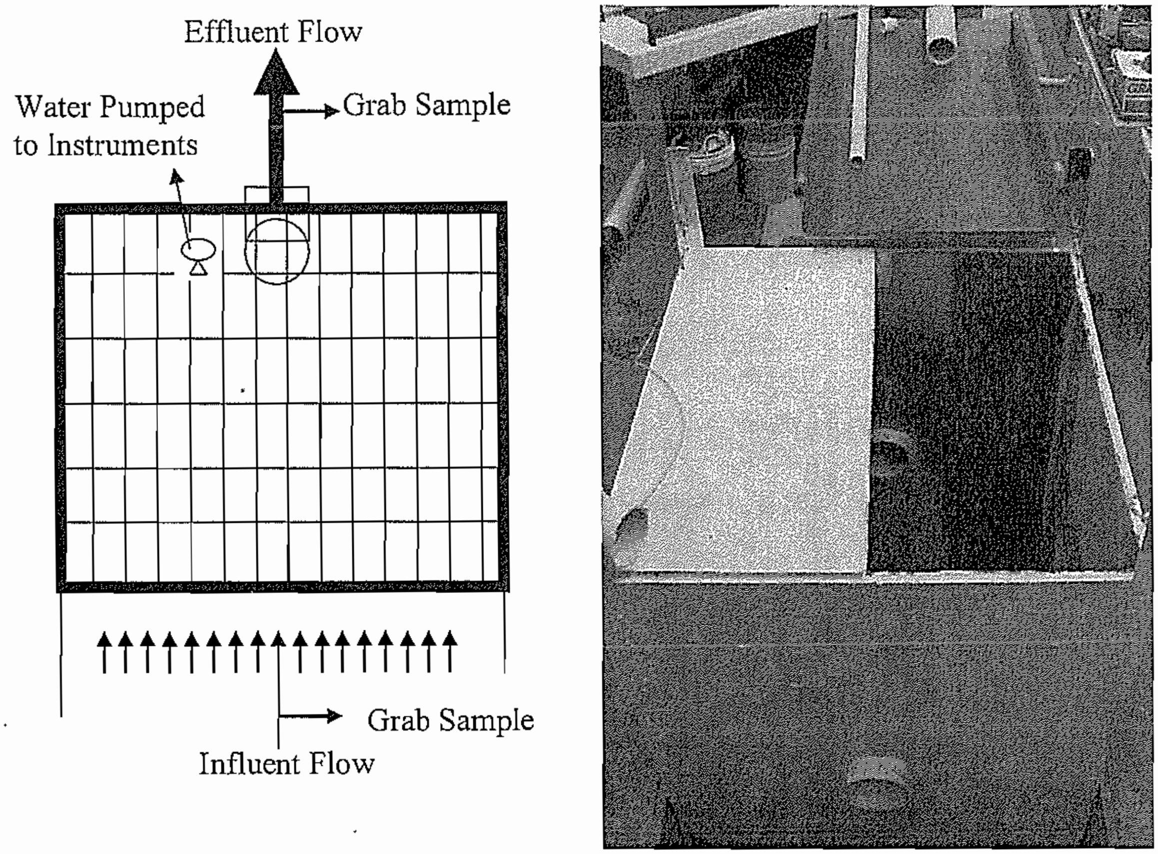


Figure 3.8 Plan view (left) of drop inlet sediment trap, photograph (right) of drop inlet sediment trap with no grating

3.6.2 Double Can Sediment Trap

The double can sediment trap consisted of two 36" diameter vertically oriented corrugated metal pipes (CMPs) provided by CONTECH Construction Products, Incorporated. An 18" diameter CMP that was eight feet long spanned perpendicularly from the one 36" CMP to the other. The invert of the 18" CMP was 5 feet above the bottom of the 36" pipe. The water entered from a ramp through the grating into the first 36" CMP. The water then progressed to the second 36" CMP by passing through the 18" CMP and discharged through a notch cut into the sidewall of the 36" CMP, creating a weir effect. The water exited the trap through the notch, which was also the location from which the water was continuously pumped to the turbidimeter and particle counter instruments, and also where grab samples were collected. The double can sediment trap can be seen in Figure 3.9.

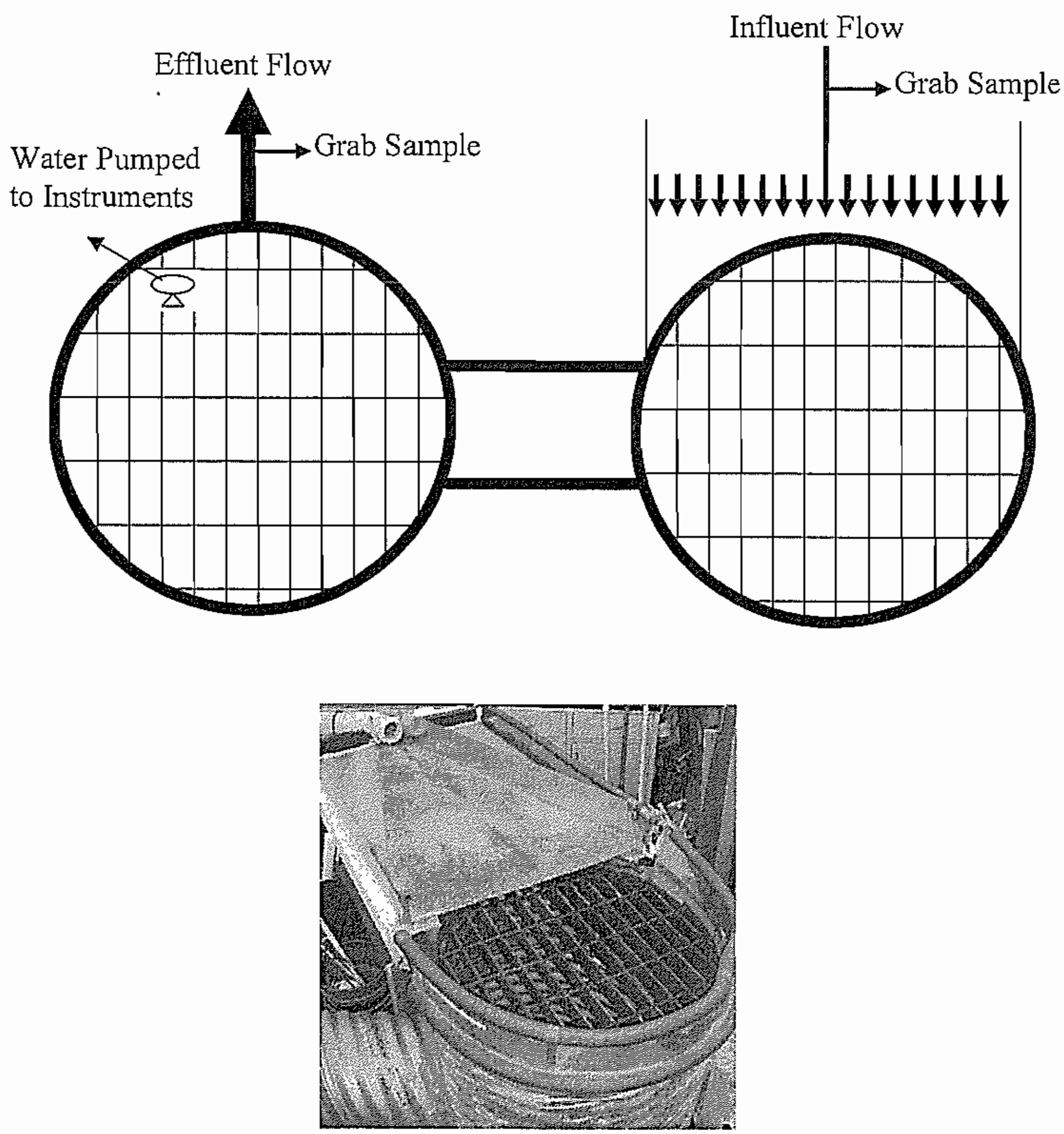


Figure 3.9 Plan view (above) of the double can sediment trap, photograph (below) of first can

3.7 Enhancements

A number of potential enhancements to improve the effectiveness of the drop inlet and double can sediment traps were considered. Each enhancement was tested in both traps to determine the effectiveness. The configuration varied slightly based on the two types of sediment traps. The specific enhancements which were tested included the installation of filter fabric, the construction of a rapid media filter, and the installation of plate settlers. Some testing was done with the use of an additional can or drop inlet arranged in series to find how variations in the detention time influenced particle removal efficiency. As extra testing, filter fabrics were also evaluated without being changed between tests to find how they would perform under repetitive testing. The two types of filter fabrics were also compared to one another. Another concern was the performance of the traps when they were not maintained in the field. To evaluate the performance of this, sediment was added to both traps until 4 inches below the effluent to be tested at near full conditions.

3.7.1 Filter Fabric Filtration

The use of various geotextile filter fabrics to enhance the efficiency of particle removal was evaluated. The filter fabrics were tested in vertical and generally perpendicular orientations with respect to the path of the water. This required all of the water to travel through the fabric to exit the trap, filtering out particles larger than the fabric apparent opening size (AOS).

3.7.1.1 Filter Fabric Information

The filter fabrics used in the project were selected based on a literature search described in Section 2.7.2.3. The fabrics were distributed by ACF West Inc., Geosynthetic Products. The fabrics which were evaluated were Propex 4516 and 4510, polypropylene nonwoven needle punched fabrics. The fabrics were non-biodegradable and able to resist ultraviolet degradation, mildew, insects, and pH conditions below two and above thirteen (Amoco, 2004). Specifications for Propex 4516 and 4510 the fabrics are summarized in Table 3.3 and Table 3.4, respectively. When comparing the apparent

Table 3.3 Propex 4516 specifications (modified from Amoco, 2004)

Property	Test Method	Minimum Average Roll Value (English)	Minimum Average Roll Value (Metric)
Unit Weight	ASTM-D-5261	16 oz/yd^2	542 g/m^2
UV Resistance	ASTM-D-4355	70% at 500 hrs	70% at 500 hrs
AOS	ASTM-D-4751	100 Sieve	0.15 mm
Permittivity	ASTM-D-4491	0.7 sec^{-1}	0.7 sec^{-1}
Flow Rate	ASTM-D-4492	50 gpm/ft^2	2035 L/min/m^2
Coefficient of Permeability	ASTM-D-4493	0.08 in/sec	0.20 cm/sec
Thickness	ASTM-D-5199	115 mils	2.90 mm

Table 3.4 Propex 4510 specifications (modified from Amoco, 2004)

Property	Test Method	Minimum Average Roll Value (English)	Minimum Average Roll Value (Metric)
Unit Weight	ASTM-D-5261	10 oz/yd^2	339 g/m^2
UV Resistance	ASTM-D-4355	70% at 500 hrs	70% at 500 hrs
AOS	ASTM-D-4751	100 Sieve	0.15 mm
Permittivity	ASTM-D-4491	1.2 sec^{-1}	1.2 sec^{-1}
Flow Rate	ASTM-D-4492	85 gpm/ft^2	3460 L/min/m^2
Coefficient of Permeability	ASTM-D-4493	0.08 in/sec	0.20 cm/sec
Thickness	ASTM-D-5199	85 mils	2.15 mm

opening size (AOS) of 0.15 mm for the fabrics to the finest gradation curve in Figure 3.4 (Field Sample 2), the corresponding diameter has a percent passing of roughly 20%. This suggests that 80% or more of the particles should be retained behind the fabric.

3.7.1.2 Filter Fabric Frame Design

Two design configurations of the filter fabric frames were considered. For the first design, one layer of filter fabric was firmly attached to an aluminum frame and placed in the trap. The frame was composed of two vertical one inch square aluminum columns connected by aluminum cross bracings that formed a rectangular frame. The

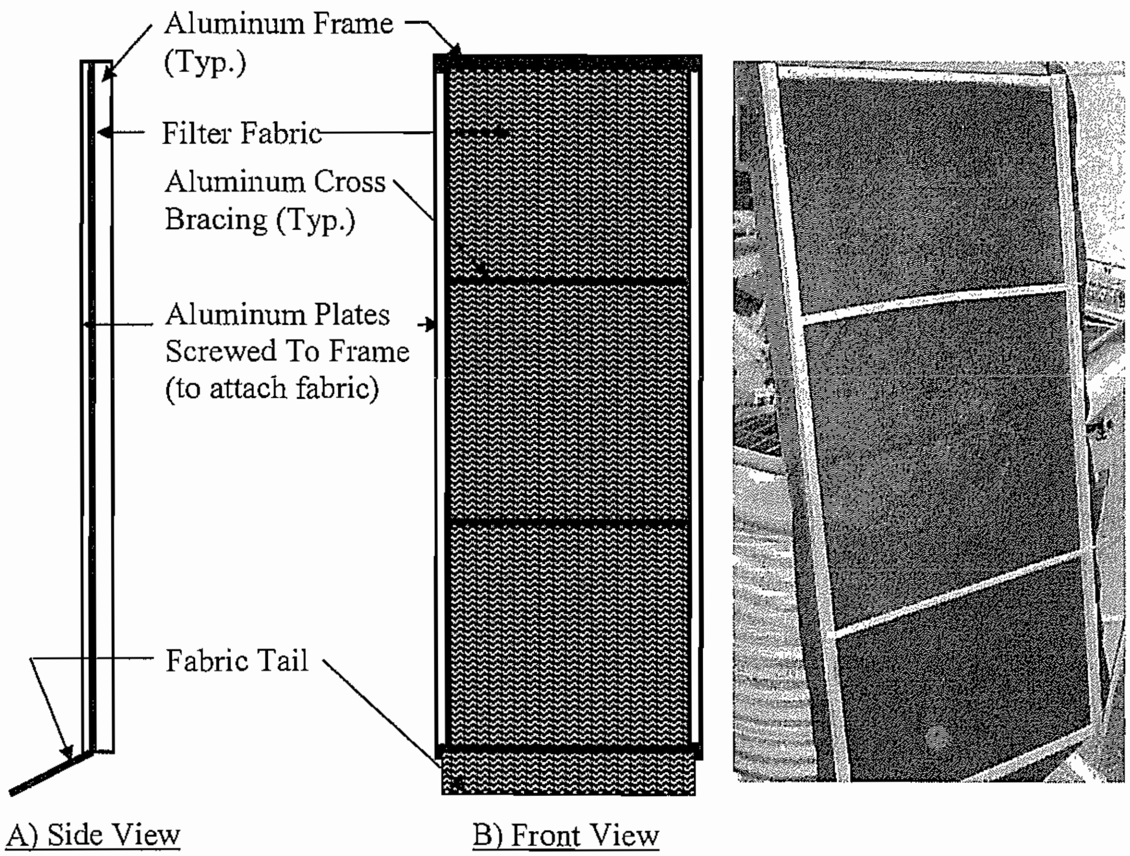


Figure 3.10 Design 1 for filter fabric frame (left), photograph of filter fabric frame Design 1 (right).

filter fabric was cut to fit each frame, extruding one inch extra on each of the sides and six inches on the bottom. One inch wide by 1/8" thick plates were placed over the fabric to hold it in place, as seen in Figure 3.10.

A second filter fabric frame design involved two, two-inch deep "L's" screwed together to form a vertical channel. This was attached to another by one-inch square tube cross bracings at two-foot intervals. The fabric was wrapped around the frame and attached with one inch wide by 1/8" thick aluminum plates that were screwed on top. This allowed for a rectangular box setup that was placed back-to-back with another filter, allowing for three distinct layers of filter fabric (with one doubled up) as seen in Figure 3.11.

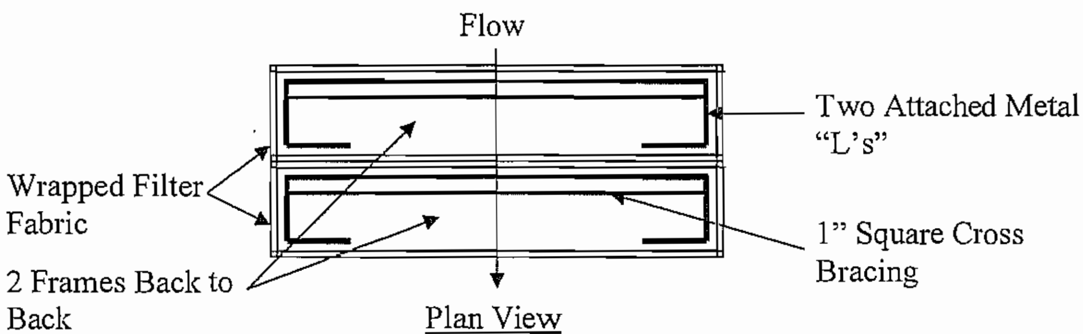


Figure 3.11 Design 2 for filter fabric frame

3.7.1.3 Filter Fabric Installation

The performance of the filter fabrics was evaluated in three different phases for each trap. Phase 1 for the double can, as seen in Figure 3.12, allowed for the attachment of small aluminum "L's" to the side of the CMP pipe. The CMP ribs were filled with a foam sealant to prevent short circuiting of the flow. One frame containing one sheet of fabric that was 35" wide by 80" tall was placed in the second can. The configuration resulted in the placement of 5 filter fabrics. During Phase 2 the same aluminum “L” frame and sealant were used, and two Design 2 frames were placed back-to-back within the second can, and a Design 1 was placed in the first can, as shown in Figure 3.13.

Phase 3 evaluated the performance with the addition of a third can. In this configuration, there were two Design 2 frames in the third can, as in Phase 2, but there was also one Design 2 frame placed in the second can, and one Design 1 frame placed in the first can. The configuration resulted in the placement of 7 filter fabrics. The second can was a high density polyethylene (HDPE) can that had no ribs on the inside, making for a better seal on the edges of the frame. A Phase 3 sediment can be seen in Figure 3.14.

For Phase 1 of the drop inlet sediment trap two, two-inch wide “L’s” were screwed into each side of the drop inlet to position the frame. One Design 1 frame was placed into the trap, as seen in Figure 3.15. For Phase 2, two Design 2 frames were placed in the trap back-to-back against the “L’s”, allowing for three distinct layers of filter fabric as seen in Figure 3.16. The configuration resulted in the placement of 4 filter fabrics. During Phase 3 of the evaluation of two drop inlet sediment traps arranged in series, two Design 2 fabric frames were placed into the second drop inlet as in Phase 2. One Design 1 fabric frame was placed in the first, as seen in Figure 3.17. The configuration resulted in the placement of 5 filter fabrics.

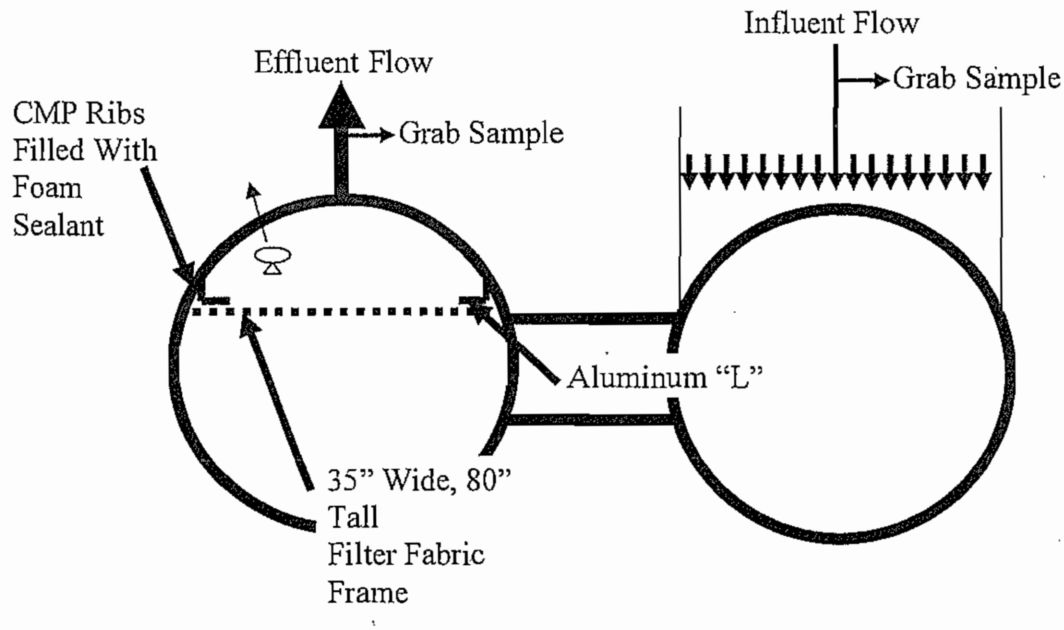


Figure 3.12 Double can Phase 1: Single filter fabric

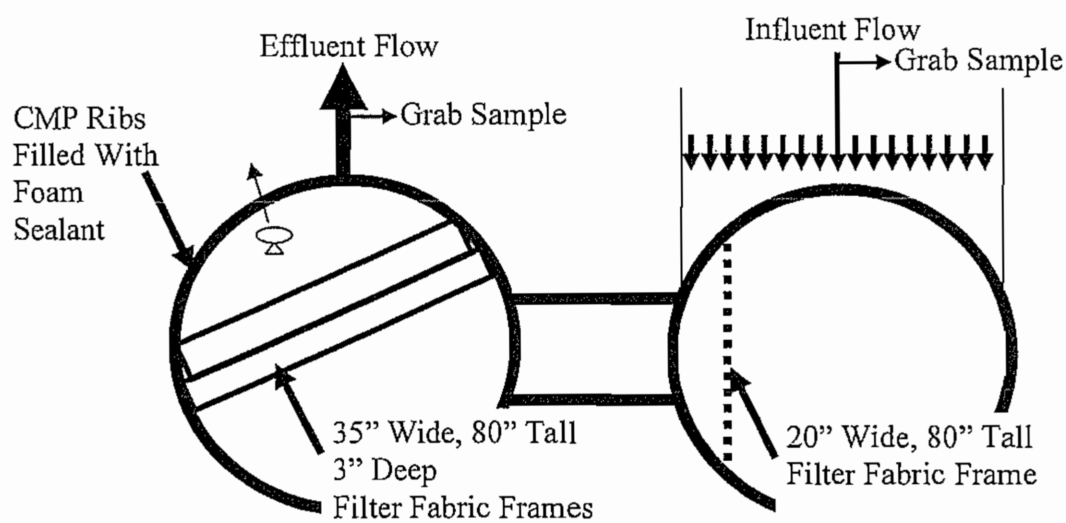


Figure 3.13 Double can Phase 2: Multiple fabrics

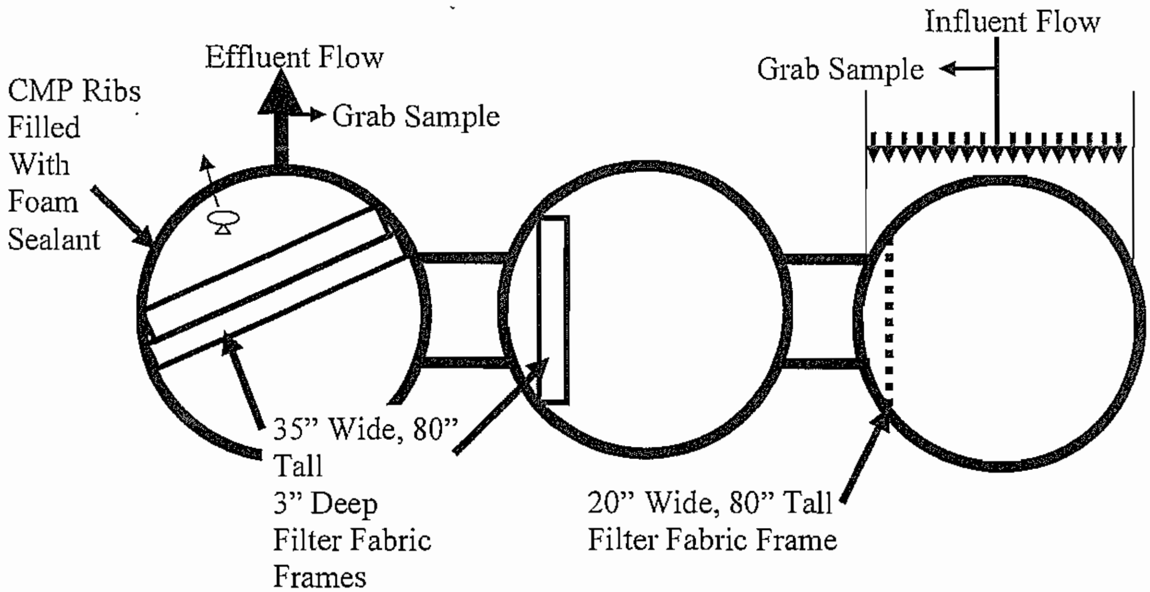


Figure 3.14 Triple can Phase 3: Multiple fabrics

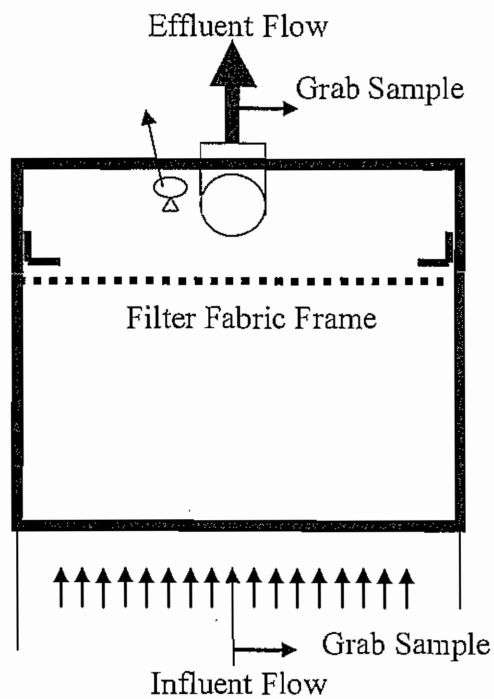


Figure 3.15 Drop Inlet Phase 1: Single filter fabric

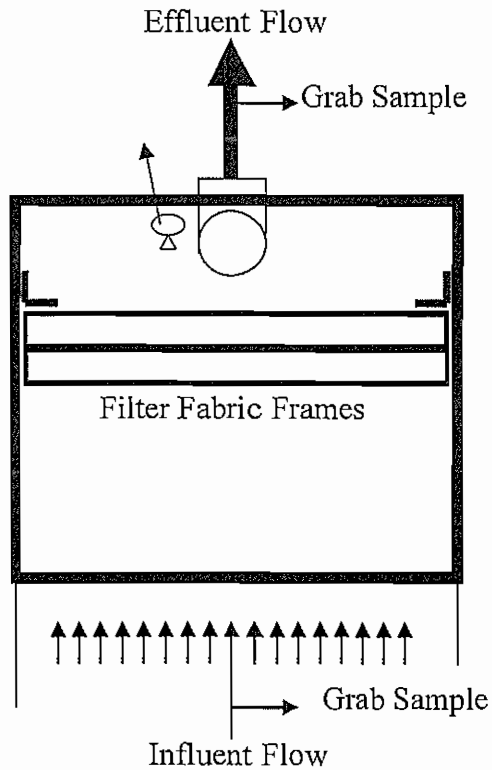


Figure 3.16 Drop Inlet Phase 2: Multiple fabrics

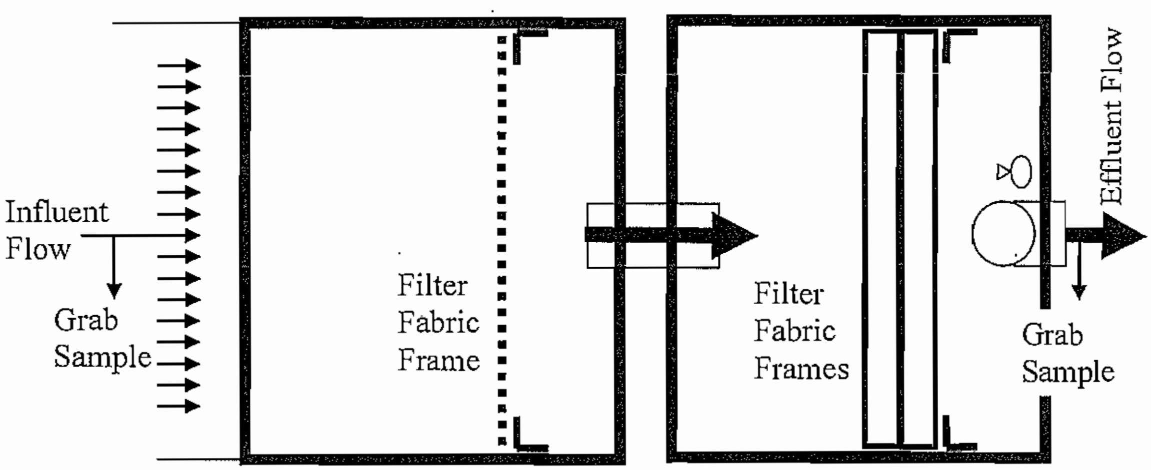


Figure 3.17 Double drop inlet Phase 3: Multiple fabrics

3.7.2 Rapid Media Filtration

The performance of a rapid media filtration device was evaluated as another technique to enhance trap efficiency. The primary media was silica sand, where a sub-base of pea gravel was used in the initial filter testing. The gradation of the silica sand is shown in Figure 3.18. The gradation was found according to ASTM C136 (Mamlouk and Zaniewski 1999).

Similar to the filter fabric evaluation, the evaluation of the rapid media filtration included three distinct phases: 1) initial filter testing; 2) filter column testing; 3) full-scale filter testing.

3.7.2.1 Phase 1: Initial Filter Testing

Phase 1 of the filter testing was performed to determine whether rapid media filtration was feasible. A bench-scale filter was evaluated at a loading rate of approximately 48 L/min/m^2, which corresponded to the maximum filter influent flow a Little Giant 3E series submersible pump would discharge. For the setup, two layers of filter fabric were placed between four inches of silica sand. The silica sand was sitting on two more layers of filter fabric and three to four inches of quarter-inch pea gravel. A perforated underdrain pipe wrapped with a 1/16" square opening fine mesh screen was placed in the gravel for the system effluent. In order to clean the filter, the system was backwashed with tap water at a rate of 408 L/min/m^2 following each test. The backwash water flowed over a weir. A schematic of the bench-scale media filter is shown in Figure 3.19.

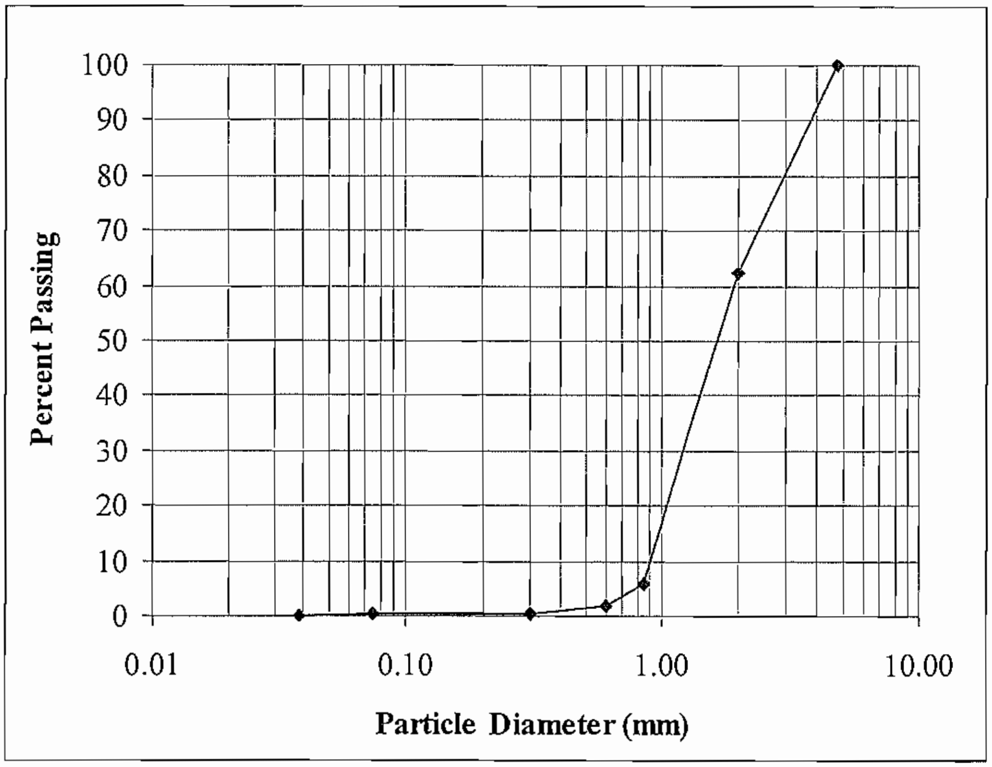


Figure 3.18 Silica sand gradation curve

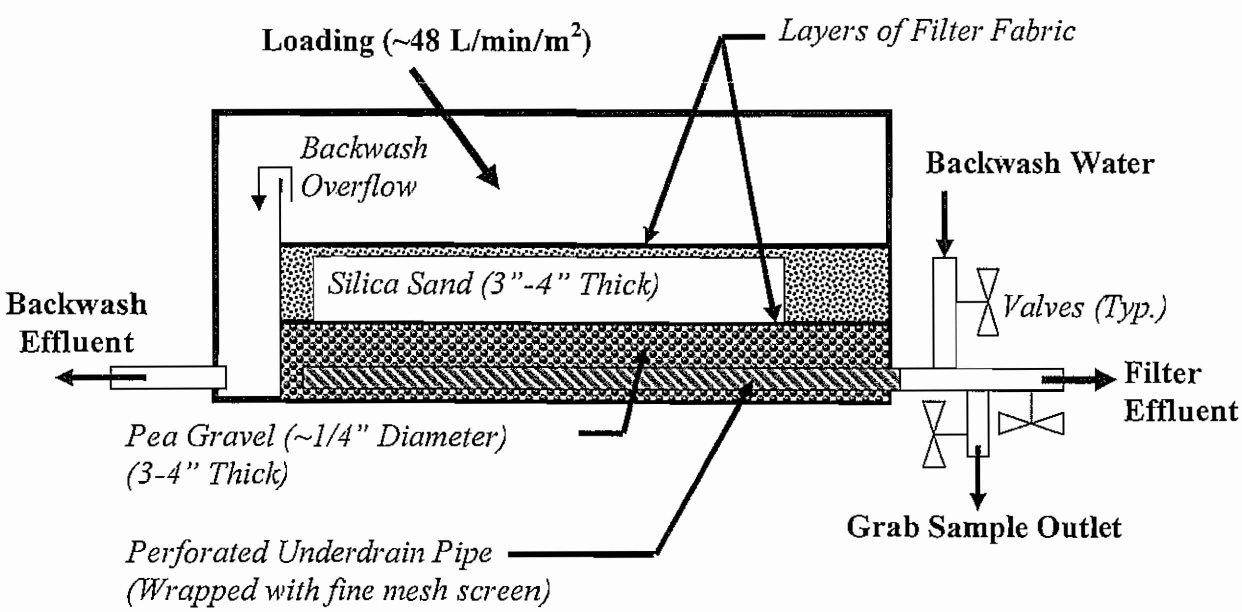


Figure 3.19 Phase 1: Initial filter testing design

3.7.2.2 Phase 2: Filter Column Testing

During Phase 2, the performance of rapid media filtration was evaluated using two different filter loading rates with two different media depths. Filter influent water was pumped by a Little Giant 3E series submersible pump through a rubber hose and distributed among four 2" diameter clear plastic filter columns. The influent flow to each filter was controlled using a flow meter (either 0 to 19 liters per hour (L/hr) or 0 to 38 L/hr) and the two loading rates were 80 L/min/m^2 and 160 L/min/m^2. Two of the filter columns were filled with 8 inches of silica sand and the other two were filled with 16 inches of silica sand. A schematic of the filter columns is shown in Figure 3.20. The water level within each filter was maintained about one inch above the media surface using a needle valve. Following each test, each column was backwashed with 408 L/min/m^2 of water until the backwash water was visibly clean.

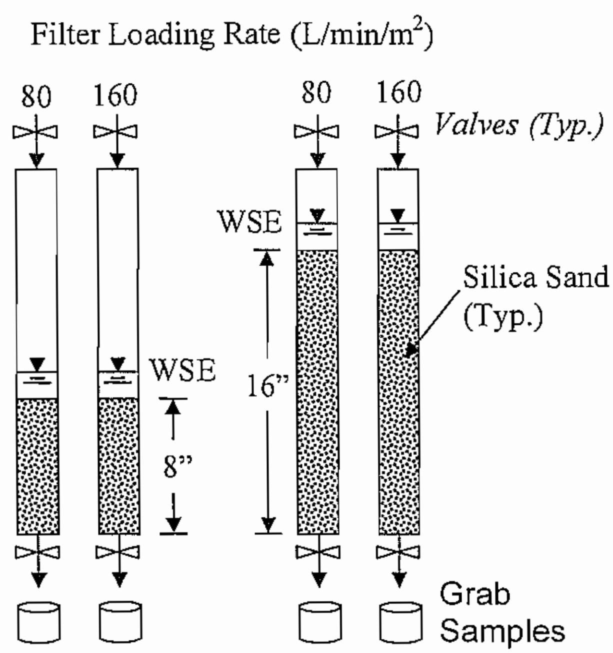


Figure 3.20 Phase 2: Filter columns

3.7.2.3 Phase 3: Full-scale filter

During Phase 3 of the evaluation of rapid media filtration, a full-scale filter was tested at a loading rate of 159 L/min/m^2 for the 475 L/min flow rate. The setup of the system was a wood box that was eight feet wide by four feet deep, having sides that were twenty-four inches tall. Inside the box was a network of four inch diameter perforated pipes with three 1/2" diameter holes at four inch spacing on the underside of the pipes. A schematic of the piping system is shown in Figure 3.21. A 1/16" screen was wrapped around the pipes to keep the media from being flushed out. The media was roughly eight inches deep from the floor of the box and was composed of silica sand. The pipes discharged to the same location, where grab samples were taken and the Little Giant pump was located to pump the water to the flow through turbidimeter and particle counter. Grab samples were also taken at the effluent of the traps and the filter for

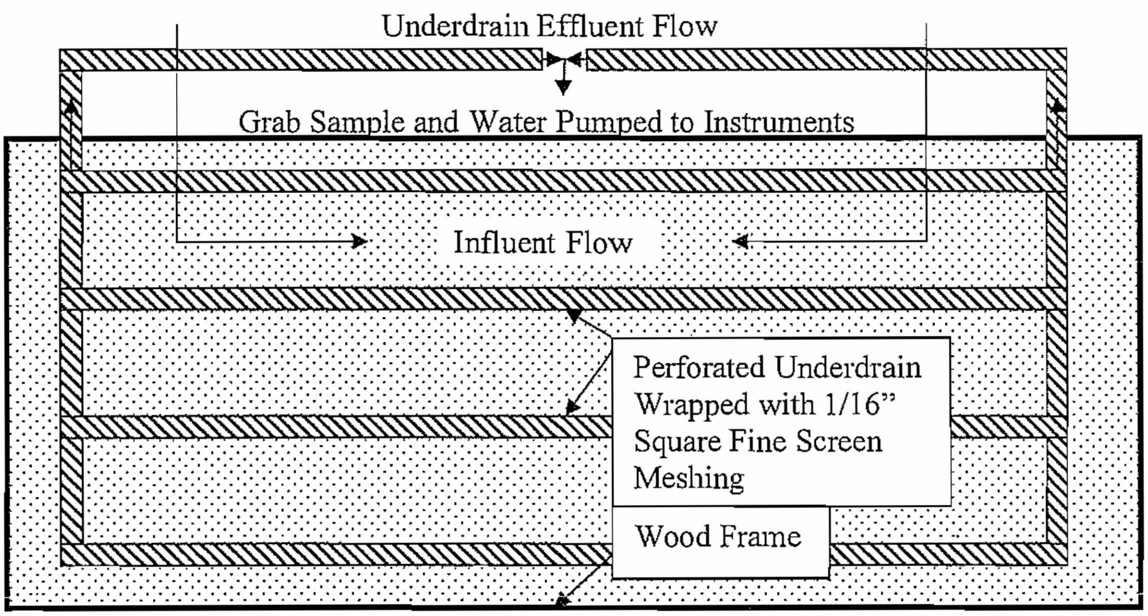


Figure 3.21 Phase 3: Full-scale filter

influent and effluent measurements. Between tests, the top layer of the filter was removed and washed if necessary to remove the fine top layer buildup.

3.7.3 Plate Settlers

A plate settler was tested in order to find its potential for particle removal. The settler was a countercurrent setup and was created out of aluminum bracing and zinc coated sheet metal. Because of the way the plate settler was required to fit into the existing traps, the plate lengths varied and were averaged to find a representative removal velocity. The numbers given in Table 3.5 are for the drop inlet plate settler and the double can plate settler. Particles with settling velocities greater than or equal to those given in the tables would theoretically settle onto the plates and slump off to the bottom of the traps.

Table 3.5 Drop Inlet plate settler (left), double can plate settler (right)

Plate Length (ft)	2.2
Plate Width (ft)	2.5
Number of Plates	20
Settling Velocity Removal (ft/s)	0.00665

Plate Length (ft)	2
Plate Width (ft)	3.7
Number of Plates	21
Settling Velocity Removal (ft/s)	0.00472

Chapter 4

RESULTS AND DISCUSSION

4.1 Overview

The overall objectives of this research were: 1) to quantify the efficiency of particle removal in the standard double can sediment trap and the standard drop inlet sediment trap and 2) to modify the traps in an economical manner in order to enhance particle removal. The performance of the traps was tested for two types of sediments: 1) decomposed granite and 2) sand applied to the roadways around Lake Tahoe by the Nevada Department of Transportation (NDOT) during winter months. The sediment traps were tested under two flow conditions (475 L/min and 675 L/min) at two different concentrations of total suspended solids for both sediments. The performance was also tested when two traps were arranged in series. In an attempt to enhance the performance of the sediment traps, the effects of various modifications were evaluated. Some of the modifications included the installation of plate settlers and various filter fabrics. In addition, the effluent flow from the traps was passed through a rapid sand filter.

Parameters that were routinely monitored during the experiments included total suspended solids, turbidity, particle counts, and sieve analyses. The performance of the traps was quantified based on the removal efficiency of particles which was determined from:

$$Efficiency = \frac{C_{In} - C_{Out}}{C_{In}} * 100 \qquad (4.1)$$

where C_{In} and C_{Out} represent the influent and effluent concentrations of particles entering and exiting the traps, respectively.

The average values of the various parameters that were monitored in the background water, the influent flow, and the effluent flow are given in Table 4.1 to Table 4.3. The background data were monitored since the trap effluent water was stored in the laboratory sump and recycled as influent water during multiple tests before being replaced.

Table 4.1 Typical background water quality (n = 468)

Background Parameter	Minimum	Maximum	Average	Standard Deviation
pH	8.2	11.9	10.0	0.2
Conductivity (µS/cm)	1.1	286.0	20.4	1.5
Turbidity (NTU)	7	177	63	7.9
TSS (mg/L)	3	287	55	14.8

Table 4.2 Typical influent water quality (n = 468)

Influent Parameter	Minimum	Maximum	Average	Standard Deviation
pH	8.7	12.1	10.2	0.1
Conductivity (µS/cm)	1.1	305.0	24.0	1.6
Turbidity (NTU)	2	246	104	8.67
TSS (mg/L)	50	765	220	29.95
Temperature (^{o}C)	11	19	16	0.70

Table 4.3 Typical effluent water quality (n = 468)

Effluent Parameter	Minimum	Maximum	Average	Standard Deviation
pH	8.6	11.9	10.2	0.1
Conductivity (µS/cm)	1.0	296.0	23.1	1.1
Turbidity (NTU)	13	216	93	7.3
TSS (mg/L)	25	884	157	22.6

4.2 Evaluation of the Removal of Total Suspended Solids

The removal of total suspended solids (TSS) within the sediment traps was monitored. Results for the standard sediment traps are discussed first, followed by the results for the enhanced sediment traps.

4.2.1 Removal of Total Suspended Solids within the Standard Double Can Sediment Trap

The results of testing for the removal of TSS in the standard double can sediment trap are summarized in Table 4.4. In general, the concentrations of TSS increased gradually with elapsed run time, which can be attributed to changes in the background water quality. For example, the tests using road sand at a flow of 475 L/min and a sediment feed rate of 4.4 kg/min, the average concentrations of TSS in the background water increased from 23 mg/L to 44 mg/L during the tests. Water used to perform the tests was stored in a sump. The increase in concentration was expected since water was recirculated back to the storage sump after passing through the sediment traps. In addition, particles that settled in the storage sump between tests were also resuspended as the water levels in the sump fluctuated during testing.

During the standard thirty-minute run time for each test, the average influent TSS concentrations for every test were greater than the effluent TSS. When testing road sand at a flow of 475 L/min and a sediment feed rate of 4.4 kg/min, the average influent TSS concentration was 102 mg/L, and the effluent was 90 mg/L, as summarized in Table 4.4. Thus, the average removal efficiency for TSS was approximately 10%±9%, as summarized in Table 4.5. The highest average influent TSS concentration was 167 mg/L which occurred for the tests using road sand at a flow of 475 L/min at a sediment feed rate of 6.8 kg/min. In contrast, the lowest average influent TSS concentration was 89 mg/L which occurred for the tests using road sand at a flow of 675 L/min at a sediment feed rate of 4.4 kg/min. The concentrations of TSS were greater for the decomposed granite tests, where the highest concentration was 385 mg/L which was achieved when the flow was 475 L/min at a sediment feed rate of 3.3 kg/min.

As expected, the highest influent concentration of TSS corresponded with the lowest flow rate and the highest sediment feed rate. Similarly, the lowest influent concentration of TSS corresponded with the highest flow rate and the lowest sediment feed rate. Since the water used during testing was recirculated during the tests, the concentration of TSS in the background gradually increased over the elapsed run time. Little settling occurred within the storage sump while testing was being conducted since the water was continually being recirculated.

The TSS removal efficiencies within the standard double can sediment trap for the various test conditions arc summarized in Table 4.5. The results can be used to evaluate the effectiveness of the standard double can sediment trap for the removal of road sand and decomposed granite under various flows and sediment feed rates. In general, it can also be seen from Table 4.5 that the most efficient road sand test was observed for the high flow and low sediment feed rate (675 L/min, 4.4 kg/min) at 21%±10%. The least efficient road sand test was observed to be 10%±9% at a flow rate of 475 L/min and a sediment feed rate of 4.4 kg/min. Removal effectiveness of the decomposed granite is greater than that of the road sand. The highest decomposed granite removal efficiency was 36%±7% for a flow of 675 L/min and a feed rate of 5.6 kg/min.

Table 4.4 Variation of TSS with elapsed run time in the standard double can sediment trap for road sand (Sand) and decomposed granite (DG)

Sample Location	Elapsed Run Time (min)	Averaged TSS (mg/L) for Flow and Sediment Feed					
		475 L/min 4.4 kg/min (Sand)	675 L/min 4.4 kg/min (Sand)	475 L/min 6.8 kg/min (Sand)	675 L/min 6.8 kg/min (Sand)	475 L/min 3.3 kg/min (DG)	675 L/min 5.6 kg/min (DG)
Background	*1*	23	32	37	15	54	77
	17	34	24	23	39	44	86
	32	44	32	45	56	132	134
	Average:	***34***	***29***	***35***	***37***	***77***	***99***
Influent	*11*	76	77	152	102	400	288
	16	95	93	164	115	380	346
	21	98	92	175	122	315	439
	26	106	85	169	147	383	350
	31	133	99	173	146	449	399
	Average:	***102***	***89***	***167***	***126***	***385***	***364***
Effluent	*10*	73	75	140	98	214	259
	15	82	68	131	93	256	246
	20	99	69	138	109	225	259
	25	92	68	146	112	264	294
	30	104	71	144	143	271	315
	Average:	***90***	***70***	***140***	***111***	***246***	***275***

Table 4.5 TSS removal efficiency with elapsed run time in the standard double can sediment trap for road sand (Sand) and decomposed granite (DG)

Test Conditions	Elapsed Run Time (min)					Avg.	Std. Dev.
	11	*16*	*21*	*26*	*31*		
475 L/min, 4.4 kg/min (Sand)	4%	14%	-2%	13%	22%	10%	9%
675 L/min, 4.4 kg/min (Sand)	3%	27%	25%	20%	28%	21%	10%
475 L/min, 6.8 kg/min (Sand)	8%	20%	21%	14%	17%	16%	5%
675 L/min, 6.8 kg/min (Sand)	4%	19%	10%	24%	3%	12%	9%
475 L/min, 3.3 kg/min (DG)	10%	29%	41%	16%	21%	23%	12%
675 L/min, 5.6 kg/min (DG)	47%	33%	29%	31%	40%	36%	7%

4.2.2 Removal of Total Suspended Solids within the Standard Drop Inlet Sediment Trap

The results of testing for the removal of TSS in the standard drop inlet sediment trap are summarized in Table 4.6. In general, the concentrations of TSS increased gradually with elapsed run time, which can be attributed to changes in the background water quality. This was explained in more detail earlier in Section 4.2.1.

During the standard thirty-minute run time for each test, the average influent TSS concentrations for every test were greater than the effluent TSS concentrations. When testing road sand at a flow of 675 L/min and a sediment feed rate of 4.4 kg/min, the average influent TSS concentration was 96 mg/L, and the effluent was 80 mg/L. Thus, the average removal efficiency for TSS was approximately 16%±7%, as summarized in Table 4.7. The highest average influent road sand TSS concentration was 167 mg/L which occurred for the tests using road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min. In contrast, the lowest average influent TSS concentration was 96 mg/L which occurred for the tests using road sand at a flow of 675 L/min and a sediment feed rate of 4.4 kg/min. The concentrations of TSS were greater for the decomposed granite tests, where the highest concentration was 499 mg/L which was achieved when the flow was 475 L/min at a sediment feed rate of 3.3 kg/min.

As expected, the highest influent concentration of TSS corresponded with the lowest flow rate and the highest sediment feed rate. Similarly, the lowest influent concentration of TSS corresponded with the highest flow rate and the lowest sediment feed rate. Since the water used during testing was recirculated during the tests, the

Table 4.6 Variation of TSS with elapsed run time in the standard drop inlet sediment trap for road sand (Sand) and decomposed granite (DG)

Sample Location	Elapsed Run Time (min)	Averaged TSS (mg/L) for Flow and Sediment Feed					
		475 L/min 4.4 kg/min (Sand)	675 L/min 4.4 kg/min (Sand)	475 L/min 6.8 kg/min (Sand)	675 L/min 6.8 kg/min (Sand)	475 L/min 3.3 kg/min (DG)	675 L/min 5.6 kg/min (DG)
Background	*1*	48	19	32	33	175	74
	17	52	43	26	45	89	101
	32	67	45	41	57	120	162
	Average:	***56***	***36***	***33***	***45***	***128***	***112***
Influent	*11*	117	84	194	130	464	491
	16	103	97	133	124	455	475
	21	133	92	162	131	529	541
	26	127	97	174	130	552	374
	31	117	110	173	139	495	565
	Average:	***119***	***96***	***167***	***131***	***499***	***489***
Effluent	*10*	102	75	115	93	432	316
	15	107	76	123	95	371	421
	20	121	85	149	104	426	374
	25	121	81	136	119	372	389
	30	104	82	119	113	413	413
	Average:	***111***	***80***	***128***	***105***	***403***	***383***

concentration of TSS in the background was monitored during each test. Little settling occurred within the storage sump while testing was being conducted since the water was continually being recirculated.

The TSS removal efficiencies within the standard drop inlet sediment trap for the various test conditions are summarized in Table 4.7. The results can be used to evaluate the effectiveness of the standard drop inlet sediment trap for the removal of road sand and decomposed granite under various flows and sediment feed rates. In general, it can also be seen from Table 4.7 that the most efficient road sand test was observed for the low

Table 4.7 TSS removal efficiency with elapsed run time in the standard drop inlet sediment trap for road sand (Sand) and decomposed granite (DG)

Test Conditions	Elapsed Run Time (min)					Avg.	Std. Dev.
	11	*16*	*21*	*26*	*31*		
475 L/min, 4.4 kg/min (Sand)	13%	-4%	9%	5%	11%	7%	7%
675 L/min, 4.4 kg/min (Sand)	11%	22%	8%	16%	25%	16%	7%
475 L/min, 6.8 kg/min (Sand)	41%	7%	8%	22%	31%	22%	15%
675 L/min, 6.8 kg/min (Sand)	29%	24%	20%	8%	19%	20%	8%
475 L/min, 3.3 kg/min (DG)	7%	18%	20%	33%	17%	19%	9%
675 L/min, 5.6 kg/min (DG)	36%	11%	31%	1%	27%	21%	14%

flow and high sediment feed rate (475 L/min, 6.8 kg/min) at 22%±15%, meaning that the greatest efficiency was during the greatest expected concentration. The least efficient road sand test was observed to be 7%±7% at a flow rate of 475 L/min and a sediment feed rate of 4.4 kg/min. The greatest removal effectiveness of the decomposed granite efficiency was 21%±14% for a flow of 675 L/min and a feed rate of 5.6 kg/min.

4.2.3 Removal of Total Suspended Solids within the Enhanced Double Can Sediment Traps

As described in Chapter 3, Section 7, various enhancements were made to both the standard double can and the standard drop inlet sediment traps in an effort to improve the removal of total suspended solids (TSS). Initially, some of the effluent flow from the sediment traps was passed through a small-scale sand filter or sand filter columns using various filter loading rates. Later, the flow was passed through a single layer of filter fabric before exiting from each sediment trap. Then, the effluent flow was passed through multiple layers of filter fabric before exiting from each sediment trap. The performance of a full-scale media filter was then evaluated, followed by the performance of the sediment traps arranged in series. Finally, the performance of multiple layers of filter fabric installed within each of the sediment traps arranged in series was evaluated.

The results obtained when testing the enhanced double can sediment trap with road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min are summarized in Table 4.8 and Figure 4.1. This combination of flow and sediment feed rate resulted in the highest TSS concentration that was tested. These results are compared to those obtained for the standard double can sediment trap with no enhancements. Similar to the standard sediment trap, each value analyzed is the average TSS concentrations for a thirty-minute test as a whole.

The lowest overall removal efficiency of TSS was achieved in the standard double can sediment trap at 16%±5%. The next lowest average removal efficiency of TSS was achieved with the single filter fabric at 24%±13%, while the efficiency of multiple filter fabrics was 54%±15%, roughly doubling the average efficiency of the single fabric. Analysis of the efficiencies for the fabrics over time suggests that the multiple filter fabrics are superior to single filter fabrics at removing particles.

Table 4.8 TSS removal efficiency with elapsed run time for the enhanced double can sediment trap (475 L/min, 6.8 kg/min road sand)

	Elapsed Run Time (min)						**Std.**
Test Conditions	***11***	***16***	***21***	***26***	***31***	**Avg.**	**Dev.**
2 Can / No Enhancements	8%	20%	21%	14%	17%	16%	5%
3 Can / No Filter	35%	19%	28%	36%	34%	30%	7%
2 Can / Media Filter	42%	46%	32%	47%	43%	42%	6%
2 Can / Single Filter Fabric	45%	24%	12%	12%	24%	24%	13%
2 Can / Multiple Fabrics	63%	63%	57%	58%	28%	54%	15%
3 Can / Multiple Fabrics	63%	63%	66%	63%	62%	63%	2%
2 Can / Plate Settler	38%	15%	32%	20%	31%	27%	10%

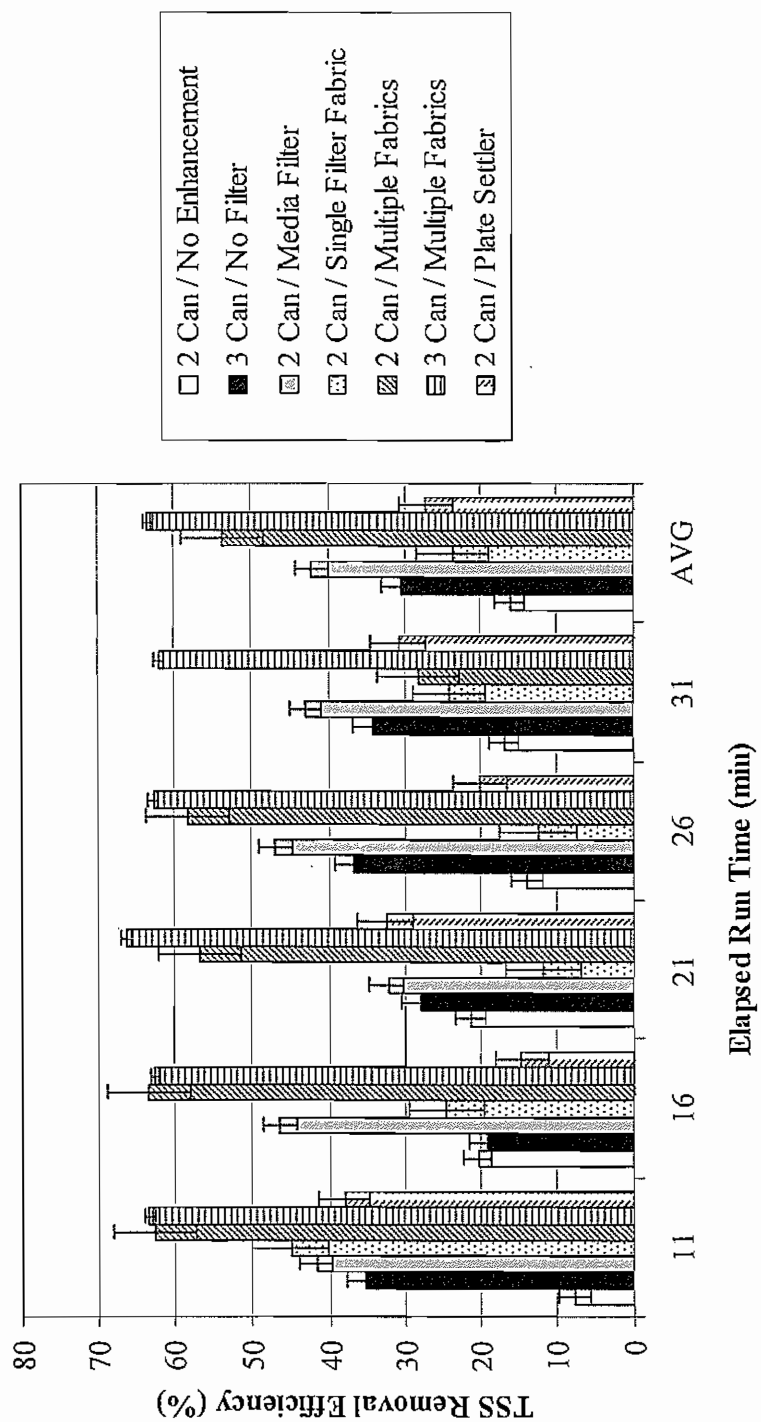


Figure 4.1 TSS removal efficiency with elapsed run time for the enhanced double can sediment trap (475 L/min, 6.8 kg/min road sand)

The multiple layers of filter fabric were tested to determine whether increased surface area of fabric would continue to retain particles and also provide for a backup when the initial layer of filter fabric became clogged and began to overflow. Multiple layers for the two cans always involved a total of five layers of fabric, where two layers were back-to-back. Multiple layers for the three cans always involved seven layers of fabric, where two layers were also back-to-back. The filter fabrics used were Propex 4516 for filters with a single layer of filter fabric and Propex 4510 for filters with multiple layers of fabric. Comparison testing of Propex 4516 revealed minimal performance difference from Propex 4510. Therefore, Propex 4510 was used for economic reasons. More information on the life and extended use of the filter fabrics can be found in Section 4.4.1.

As seen in Figure 4.2, for the elapsed run time as a whole, the TSS removal efficiency of the three can sediment trap with multiple fabrics did not experience breakthrough before the test ended, having a removal that was consistently around 60% to 70%. The removal efficiency of the double can sediment trap with multiple fabrics decreased during the overall run time from an efficiency of 63% to 28%. Yet, removal was consistently around 55% to 60% until it began to drop at roughly 25 minutes of elapsed run time. The decrease was also observed from the beginning of the testing for the single filter fabric, where the overall efficiency decreased during run time from 45% to 24%. This decrease was attributed to clogging of the pore spaces of the fabric which gradually increased head loss and eventually resulted in failure where the water flowed over the top of the filter fabric layers. Because of this, if the filter fabrics were to be installed in existing sediment cans, they would need to be routinely checked and changed to maintain maximum effectiveness. Of the other enhancements tested, the plate settler had the second lowest efficiency at 27%±10%. The high cost of construction coupled with its lack of effectiveness due to the turbulent mixing environment within the sediment trap made the plate settler uneconomical and less desirable for use. The full-scale silica sand filter had an efficiency of 42%±6% for a loading rate of 159 L/min/m^2 (4 gpm/ft^2). Typically, the head loss was roughly 12 inches over 25 minutes of time. The efficiency could potentially be increased further by reducing the filter loading rate and increasing media depth. More information on media filter testing is included in Section 4.4.4.

The can sediment trap having three cans arranged in series was more effective at TSS removal by increasing the removal efficiency of the standard double can from 16%±5% to 30%±7%. The addition of multiple fabrics into the three-can sediment trap resulted in a TSS removal efficiency of 63%±2%. This result can be compared to Table 2.4 for the removal of TSS by Caltrans (2003) for both sand trap types.

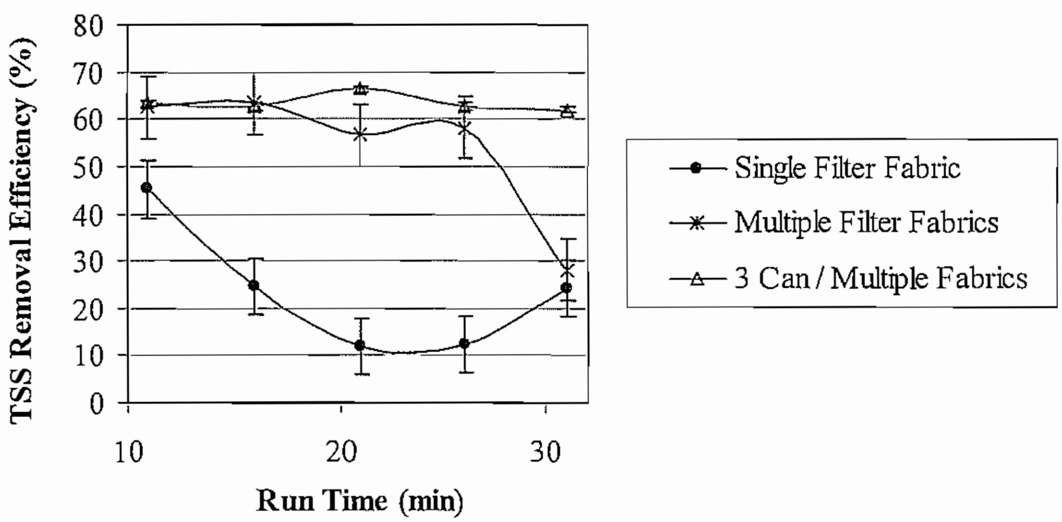


Figure 4.2 TSS removal efficiency with elapsed run time for the double can sediment trap with filter fabrics (475 L/min, 6.8 kg/min road sand)

The results obtained when testing the enhanced double can sediment trap with a flow of 475 L/min and a sediment mixture with a feed rate of 4.0 kg/min are summarized in Table 4.9. The mixture was of one part of decomposed granite and three parts of road sand mixture, which is expected to be more realistic in its representation as runoff constituents during winter months.

The lowest TSS removal efficiency for the double can sediment trap enhancements was by the single filter fabric at 28%±6%. Having multiple filter fabrics increased this to 47%±17%. The performance of the multiple fabrics was similar to the removal efficiency of the traps in series without filter fabrics having an efficiency of 46%±8%. The highest removal efficiency was by the multiple fabrics in the traps in series at 66%±10%. In comparison with Table 4.8, Table 4.9 reveals that the enhancements performed similarly with regard to the removal capabilities for road sand and the sediment mixture. Where the efficiency from Table 4.8 for road sand of the three cans in series with multiple filter fabrics was 63%±2%, and the sediment mixture in Table 4.9 is 66%±10%. The greatest difference between road sand and the sediment mixture is for the three cans in series having an efficiency of 66%±10% for road sand in Table 4.8, and 46%±8% in Table 4.9 for the sediment mixture.

Table 4.9 TSS removal efficiency with elapsed run time for the enhanced double can sediment trap (475 L/min, 4.0 kg/min mixture of decomposed granite and road sand)

Test Conditions	Elapsed Run Time (min)					Avg.	Std. Dev.
	11	*16*	*21*	*26*	*31*		
3 Can / No Filters	53%	49%	53%	36%	39%	46%	8%
2 Can / Media Filter	44%	54%	56%	46%	53%	51%	5%
2 Can / Single Filter Fabric	18%	27%	29%	32%	33%	28%	6%
2 Can / Multiple Fabrics	71%	56%	45%	27%	36%	47%	17%
3 Can / Multiple Fabrics	76%	76%	64%	57%	57%	66%	10%

4.2.4 Removal of Total Suspended Solids within the Enhanced Drop Inlet Sediment Traps

The results obtained when testing the enhanced drop inlet sediment trap with road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min are summarized in Table 4.10 and Figure 4.3. This combination of flow and sediment feed rate resulted in the highest TSS concentration that was tested. These results are compared to those obtained for the single standard drop inlet sediment trap with no enhancements. Similar to the standard sediment trap, each value analyzed is the average TSS concentrations for a thirty-minute test as a whole.

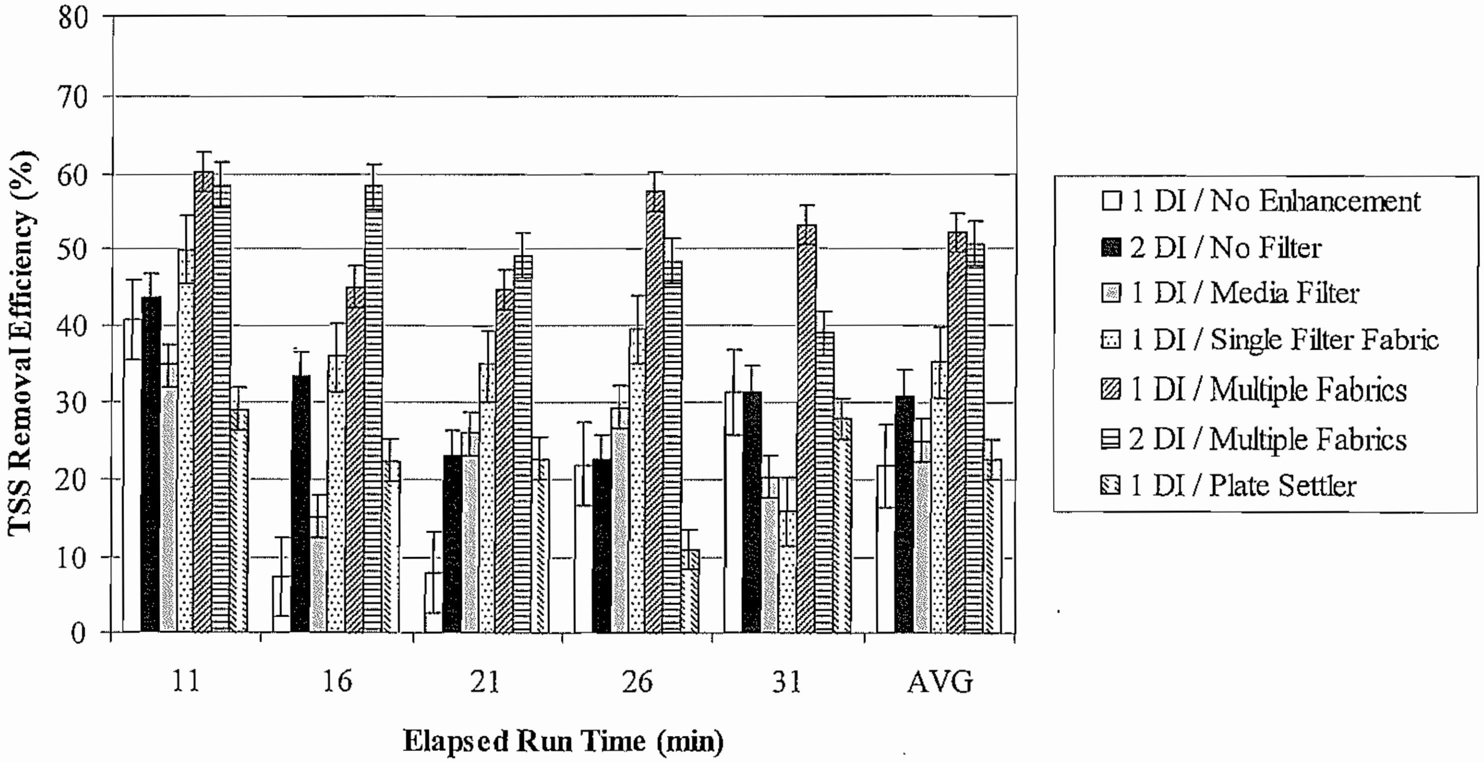
The lowest overall removal efficiency of TSS was achieved in the single standard drop inlet sediment trap at 22%±15%. The next lowest average removal efficiency of TSS was achieved with the plate settler at 23%±7%. The high cost of construction coupled with its lack of effectiveness due to the turbulent mixing environment within the sediment trap made the plate settler uneconomical and less desirable for use.

Table 4.10 TSS removal efficiency with elapsed run time for the enhanced drop inlet sediment trap (475 L/min, 6.8 kg/min road sand)

Test Conditions	Elapsed Run Time (min)					Avg.	Std. Dev.
	11	*16*	*21*	*26*	*31*		
1 DI / No Enhancements	41%	7%	8%	22%	31%	22%	15%
2 DI / No Filter	44%	33%	23%	23%	31%	31%	9%
1 DI / Media Filter	35%	15%	26%	29%	20%	25%	8%
1 DI / Single Filter Fabric	50%	36%	35%	39%	16%	35%	12%
1 DI / Multiple Fabrics	60%	45%	45%	58%	53%	52%	7%
2 DI / Multiple Fabrics	58%	58%	49%	48%	39%	51%	8%
1 DI / Plate Settler	29%	23%	23%	11%	28%	23%	7%

Multiple layers of filter fabric were tested to determine whether the increased surface area of fabric would continue to retain particles and also provide for a backup when the initial layer of filter fabric became clogged and began to overflow. Multiple fabric layers for a single drop inlet included a total of four layers of fabric arranged in series, where two layers were placed back-to-back. Multiple fabric layers for two drop inlets in series involved five layers of fabric arranged in series, where two layers were also placed back-to-back. The filter fabrics used were Propex 4516 for filters with a single layer of filter fabric and Propex 4510 for filters with multiple layers of fabric arranged in series. Comparison testing of Propex 4516 revealed minimal performance difference from Propex 4510. Therefore, Propex 4510 was used for economic reasons. More information on the life and extended use of the filter fabrics can be found in Section 4.4.1. The removal efficiency for multiple filter fabrics was 52%±7%, increasing from the single filter fabric at 35%±12%. The second highest removal efficiency was found

Figure 4.3 TSS removal efficiency with elapsed run time for the enhanced drop inlet sediment trap (475 L/min, 6.8 kg/min road sand)



while using the two drop inlet sediment traps with multiple fabrics, where the efficiency was 51%±8%.

As seen in Figure 4.4, when using road sand the removal efficiency of TSS for the filter fabrics generally decreased as elapsed run time increased. The removal efficiency of the single trap with multiple fabrics decreased until roughly 18 minutes of elapsed run time where it then increased before decreasing a second time. The overall efficiency decreased during the elapsed run time from 60% to 53%.. This was similar for the single filter fabric, where the overall efficiency for the single filter fabric decreased during the elapsed run time from 50% to 16%. This decrease was attributed to clogging of the pore spaces of the fabric which gradually increased head loss and eventually resulted in failure when the water flowed over the top of the filter fabric layers. Because of this, if the filter fabrics were to be installed in existing sediment cans, they would need to be routinely checked and changed to maintain maximum effectiveness.

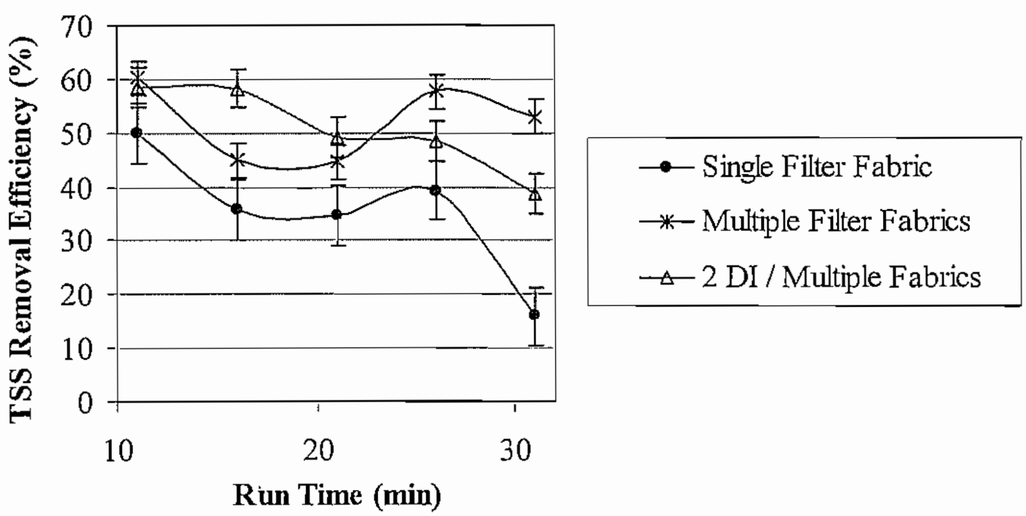


Figure 4.4 TSS removal efficiency with elapsed run time for the drop inlet sediment traps with filter fabrics (475 L/min, 6.8 kg/min road sand)

Of the other enhancements tested and summarized in Table 4.10 and Figure 4.3, the two drop inlets arranged in series with no filter fabrics were more effective at TSS removal by increasing the removal efficiency of the standard drop inlet sediment trap from 22%±15% to 31%±9%. The full-scale silica sand filter had an efficiency of 25%±8% for a loading rate of 159 L/min/m^2. Typically, the head loss was roughly 12 inches over 25 minutes of time. The efficiency could potentially be increased further by reducing the filter loading rate and increasing media depth. More information on media filter testing is included in Section 4.4.4.

The results obtained when testing the enhanced drop inlet sediment trap with a flow of 475 L/min and a sediment mixture with a feed rate of 4.0 kg/min are summarized in Table 4.11. The mixture was of one part of decomposed granite and three parts of road sand mixture, which is expected to be more realistic in its representation as runoff constituents during winter months.

The lowest removal efficiency of TSS for the enhancements of the drop inlet sediment trap was by the two drop inlets without filters at 15%±5%. The efficiency of the single filter fabric was 22%±17%. The performance of the multiple fabrics at 29%±25% did not increase in efficiency greatly from the single fabrics. The highest removal efficiency was by the multiple fabrics in the traps in series at 52%±15%. In comparison with Table 4.10, Table 4.11 reveals that the enhancements were more effective at removing the road sand than the sediment mixture. The traps in series with multiple fabrics were similar for both sediment types, having 51%±8% from Table 4.10 for the road sand and 52%±15% from Table 4.11 for the sediment mixture. The media

Table 4.11 TSS removal efficiency with elapsed run time for the enhanced drop inlet sediment trap (475 L/min, 4.0 kg/min mixture of decomposed granite and road sand)

Test Conditions	Elapsed Run Time (min)					Avg.	Std. Dev.
	11	*16*	*21*	*26*	*31*		
2 DI / No Filters	21%	17%	14%	14%	8%	15%	5%
1 DI / Media Filter	25%	21%	23%	28%	27%	25%	3%
1 DI / Single Filter Fabric	47%	31%	18%	14%	1%	22%	17%
1 DI / Multiple Fabrics	73%	17%	23%	19%	11%	29%	25%
2 DI / Multiple Fabrics	65%	62%	51%	54%	28%	52%	15%

filter also has similar values for both sediment types, where all others were less effective on the sediment mixture than road sand.

4.3 Evaluation of the Reduction of Turbidity

The performance of the sediment traps with respect to turbidity reduction was monitored. Results for the standard sediment traps with no enhancements are discussed first followed by the results for the enhanced sediment traps. The background, influent, and effluent turbidity readings over the total elapsed run time for the testing are summarized in the tables.

4.3.1 Reduction of Turbidity within the Standard Double Can Sediment Trap

The results of testing for the removal of turbidity in the standard double can sediment trap are summarized in Table 4.12. Typically, the turbidity increased gradually with elapsed run time, which was attributed to changes in the background water quality. For example, the tests using road sand at a flow of 675 L/min and a sediment feed rate of 6.8 kg/min, the average turbidity in the background water increased from 24 NTU to 47 NTU during the tests. Since the water used to perform the tests was stored in a sump, an increase in turbidity was expected since the water was recirculated back to the storage sump after passing through the sediment traps. In addition, particles that settled in the storage sump between tests were also resuspended as the water levels in the sump fluctuated during testing.

During the standard thirty-minute run time for each test, the average influent turbidity for every test was greater than the effluent turbidity. The performance of the sediment traps with respect to the reduction of turbidity is determined by comparing the influent turbidity to the effluent turbidity.

Table 4.12 Variations of turbidity with elapsed run time in the standard double can sediment traps for road sand (Sand) and decomposed granite (DG)

Sample Location	**Elapsed Run Time (min)**	**Average Turbidity (NTU) for Flow and Sediment Feed**					
		475 L/min 4.4 kg/min (Sand)	675 L/min 4.4 kg/min (Sand)	475 L/min 6.8 kg/min (Sand)	675 L/min 6.8 kg/min (Sand)	475 L/min 3.3 kg/min (DG)	675 L/min 5.6 kg/min (DG)
Background	*1*	73	24	28	24	106	63
	17	56	25	24	35	104	78
	32	64	35	40	47	131	102
	Average:	**64**	**28**	**31**	**35**	**114**	**81**
Influent	*11*	74	39	78	53	161	121
	16	77	43	79	59	172	141
	21	85	47	82	69	176	155
	26	84	47	86	73	178	139
	31	93	52	90	81	200	159
	Average:	**83**	**46**	**83**	**67**	**178**	**143**
Effluent	*10*	82	46	81	59	162	129
	15	76	41	77	57	161	118
	20	77	42	78	64	150	122
	25	80	44	81	67	163	141
	30	84	47	91	74	175	141
	Average:	**80**	**44**	**81**	**64**	**162**	**130**
Δ Turbidity		*3*	*2*	*2*	*3*	*15*	*13*

As indicated in Table 4.12, for the tests performed using road sand (RS) the changes in turbidity for all flow and sediment feed rates performed similarly at a change of roughly 2 NTU to 3 NTU. The tests with decomposed granite (DG) performed at a much higher rate, where the change in turbidity for the 475 L/min flow with a feed rate of 3.3 kg/min had the greatest turbidity reduction at 15 NTU. The 675 L/min flow rate with 5.6 kg/min of decomposed granite reduced in turbidity by 13 NTU. Overall, the results indicated that the standard double can sediment trap performed poorly with respect to the reduction of turbidity.

4.3.2 Reduction of Turbidity within the Standard Drop Inlet Sediment Trap

The results of testing for turbidity reduction in the standard drop inlet sediment trap are summarized in Table 4.13. Similar to the results for the testing of the double can sediment trap, the turbidity typically increased gradually with elapsed run time, which was attributed to changes in the background water quality.

During the standard thirty-minute run time for each test, the average influent turbidity for every test was greater than the effluent turbidity. The performance of the sediment traps with respect to turbidity reduction is determined by comparing the influent turbidity to the effluent turbidity. As indicated in Table 4.13, for the tests performed using road sand (RS) the changes in turbidity for all flow and sediment feed rates performed similarly at a change of roughly 3 NTU to 8 NTU. The greatest reduction in turbidity was 8 NTU, which occurred when the flow was 675 L/min and the sediment feed rate was 6.8 kg/min. The tests with decomposed granite (DG) performed similarly, where the change in turbidity for the 475 L/min flow with a feed rate of 3.3 kg/min had the greatest turbidity reduction at 18 NTU. The 675 L/min flow rate with 5.6 kg/min of decomposed granite reduced in turbidity by 17 NTU. Overall, the results indicated that the standard drop inlet sediment trap performed poorly with respect to the reduction of turbidity.

Table 4.13 Variation of turbidity with elapsed run time in the standard drop inlet sediment traps for road sand (Sand) and decomposed granite (DG)

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed					
		475 L/min 4.4 kg/min (Sand)	675 L/min 4.4 kg/min (Sand)	475 L/min 6.8 kg/min (Sand)	675 L/min 6.8 kg/min (Sand)	475 L/min 3.3 kg/min (DG)	675 L/min 5.6 kg/min (DG)
Background	***1***	55	22	13	47	110	95
	17	58	42	16	49	78	122
	32	64	48	24	54	101	147
	Average:	***59***	***37***	***17***	***50***	***97***	***121***
Influent	***11***	75	59	47	70	151	174
	16	71	65	42	70	153	173
	21	81	60	46	77	165	195
	26	74	62	51	74	166	201
	31	82	63	50	78	168	210
	Average:	***76***	***62***	***47***	***74***	***161***	***191***
Effluent	***10***	68	53	35	59	133	149
	15	68	56	41	64	135	165
	20	74	57	44	67	139	179
	25	77	59	48	70	151	185
	30	75	61	52	70	155	192
	Average:	***72***	***57***	***44***	***66***	***143***	***174***
Δ Turbidity		***4***	***5***	***3***	***8***	***18***	***17***

4.3.3 Reduction of Turbidity within the Enhanced Double Can Sediment Trap

As described in Chapter 3, Section 7, various enhancements were made to the standard double can sediment trap in an effort to improve the reduction of turbidity. The results obtained when testing the enhanced double can sediment trap with road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min are summarized in Table 4.14. This combination of flow and sediment feed rate resulted in the highest influent turbidity that was tested. These results are compared to those obtained for the standard (no enhancements) double can sediment trap.

During the typical thirty-minute run time for each test, the average influent turbidity was greater than the effluent turbidity, as seen in Table 4.14. When comparing the performance of the standard trap to the various enhancements, the results indicated that the enhanced traps were more effective at reducing turbidity than the standard traps. The highest reduction in turbidity was observed for the can sediment trap with three cans arranged in series with multiple filter fabrics. The influent turbidity of this enhancement was 74 NTU, and the effluent turbidity was reduced to 34 NTU, making the change in turbidity 40 NTU. The media filter performed second best, having a change in turbidity of 36 NTU. The next best performing enhancement was the double can sediment trap with no filter fabrics, which was similar in turbidity reduction to the three cans in series with no filter fabrics. The change in turbidity for both enhancements was 18 NTU. For the various enhancements that were tested, the least effective enhancement was the plate settler with a reduction of only 5 NTU. The high cost of construction coupled with its lack of effectiveness due to the turbulent mixing environment within the sediment trap made the plate settler uneconomical and less desirable for use.

Table 4.14 Reduction of turbidity within the enhanced double can sediment trap for tests with road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed Rate						
		2 Can / Standard Trap	3 Can / No Filter	2 Can / Media Filter	2 Can / Single Fabric	2 Can / Multiple Fabrics	3 Can / Multiple Fabrics	2 Can / Plate Settler
Background	*1*	28	42	91	28	19	33	16
	17	24	45	84	31	18	30	17
	32	40	52	89	44	24	34	31
	Average:	**31**	**46**	**88**	**34**	**20**	**32**	**21**
Influent	*11*	78	77	132	60	41	68	56
	16	79	77	132	61	49	72	57
	21	82	75	130	67	57	80	60
	26	86	83	143	70	44	76	69
	31	90	85	138	72	46	76	72
	Average:	**83**	**79**	**135**	**66**	**47**	**74**	**63**
Effluent	*10*	81	58	107	42	20	34	50
	15	77	61	99	49	25	27	53
	20	78	61	98	57	29	34	60
	25	81	63	99	63	32	36	61
	30	91	63	93	64	39	40	68
	Average:	**81**	**61**	**99**	**55**	**29**	34	**58**
Δ Turbidity		*2*	*18*	*36*	*11*	*18*	*40*	*5*

The results obtained when testing the enhanced double can sediment trap with a flow of 475 L/min and a sediment mixture with a feed rate of 4.0 kg/min are summarized in Table 4.15. The mixture was of one part decomposed granite and three parts road sand mixture, which is expected to be more realistic in its representation as runoff constituents during winter months.

During the typical thirty-minute run time for each test, the average influent turbidity was greater than the effluent turbidity, as seen in Table 4.15. The results indicated that the enhancements were effective at reducing turbidity. The highest reduction was observed with the can sediment trap with three cans arranged in series with multiple filter fabrics. The influent turbidity of this enhancement was 94 NTU, and the effluent turbidity was reduced to 51 NTU, making the change in turbidity 43 NTU. The second highest reduction in turbidity was observed for the media filter, with a change in turbidity of 35 NTU. The next best performing enhancement was the double can sediment trap with multiple filter fabrics, having a change in turbidity of 20 NTU.

Table 4.15 Turbidity removal efficiency with elapsed run time for the enhanced double can sediment trap (475 L/min, 4.0 kg/min decomposed granite and road sand sediment mixture)

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed Rate				
		3 Can / No Filter	2 Can / Media Filter	2 Can / Single Fabric	2 Can / Multiple Fabrics	3 Can / Multiple Fabrics
Background	*1*	61	17	118	36	37
	17	65	23	140	37	35
	32	72	30	166	48	41
	Average:	**66**	**23**	**141**	**40**	**38**
Influent	*11*	131	73	182	68	95
	16	133	85	208	73	102
	21	94	74	216	74	86
	26	123	74	214	77	96
	31	116	80	238	85	92
	Average:	**119**	77	**212**	**75**	**94**
Effluent	*10*	100	47	171	41	44
	15	99	42	176	46	50
	20	98	42	194	52	48
	25	96	39	216	63	55
	30	106	42	218	72	56
	Average:	**100**	**42**	**195**	**55**	**51**
Δ Turbidity		*19*	*35*	*17*	*20*	*43*

For the various enhancements that were tested, the least effective enhancement was the single filter fabric with a reduction of only 17 NTU.

4.3.4 Removal of Turbidity within the Enhanced Drop Inlet Sediment Trap

As described in Chapter 3, Section 7, various enhancements were made to the standard drop inlet sediment trap in an effort to improve the reduction of turbidity. The results obtained when testing the enhanced drop inlet sediment trap with road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min are summarized in Table 4.16. This combination of flow and sediment feed rate resulted in the highest influent turbidity that was tested. These results are compared to those obtained for the standard (no enhancements) drop inlet sediment trap.

During the typical thirty-minute run time for each test, the average influent turbidity was greater than the effluent turbidity, as seen in Table 4.16. When comparing the performance of the standard trap to the various enhancements, the results indicated that the enhancements were more effective at reducing turbidity than the standard traps. The highest reduction in turbidity was observed with the addition of the media filter. The influent turbidity of this enhancement was 140 NTU, and the effluent turbidity was reduced to 113 NTU, making the change in turbidity 27 NTU. The two drop inlets with multiple filter fabrics performed second best, having a change in turbidity of 16 NTU. For the various enhancements that were tested, the least effective enhancement was the plate settler with a reduction of only 1 NTU. The high cost of construction coupled with its lack of effectiveness due to the turbulent mixing environment within the sediment trap made the plate settler uneconomical and less desirable for use.

The results obtained when testing the enhanced double can sediment trap with a flow of 475 L/min and a sediment mixture with a feed rate of 4.0 kg/min are summarized in Table 4.17. The mixture was of one part decomposed granite and three parts road sand mixture, which is expected to be more realistic in its representation as runoff constituents during winter months.

Table 4.16 Turbidity removal efficiency with elapsed run time for the enhanced drop inlet sediment trap (475 L/min, 6.8 kg/min road sand)

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed Rate						
		1 DI / Standard Trap	2 DI / No Filter	1 DI / Media Filter	1 DI / Single Fabric	1 DI / Multiple Fabrics	2 DI / Multiple Fabrics	1 DI / Plate Settler
Background	*1*	13	53	103	49	46	34	29
	17	16	40	102	49	33	27	30
	32	24	51	106	52	38	36	39
	Average:	**17**	**48**	**104**	**50**	**39**	**33**	**33**
Influent	*11*	47	93	148	75	56	65	78
	16	42	68	126	68	56	63	69
	21	46	71	145	67	62	62	74
	26	51	73	141	66	64	66	72
	31	50	79	140	72	66	63	73
	Average:	**47**	**77**	**140**	**69**	**61**	**64**	**73**
Effluent	*10*	35	74	116	54	38	45	71
	15	41	71	109	63	40	43	71
	20	44	61	113	60	46	47	73
	25	48	62	114	61	49	52	74
	30	52	61	113	61	63	53	71
	Average:	**44**	**66**	**113**	**60**	**47**	**48**	**72**
Δ Turbidity		***3***	***11***	***27***	***9***	***14***	***16***	***1***

During the typical thirty-minute run time for each test, the average influent turbidity was greater than the effluent turbidity, as seen in Table 4.17. The results indicated that the enhancements were effective at reducing turbidity. The highest reduction was observed with the addition of the media filter. The influent turbidity of this enhancement was 87 NTU, and the effluent turbidity was reduced to 59 NTU, making the change in turbidity 28 NTU. The second highest reduction in turbidity was observed for the can sediment trap with three cans arranged in series with multiple filter

Table 4.17 Turbidity removal efficiency with elapsed run time for the enhanced drop inlet sediment trap (475 L/min, 4.0 kg/min decomposed granite and road sand sediment mixture)

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed Rate				
		2 DI / No Filter	1 DI / Media Filter	1 DI / Single Fabric	1 DI / Multiple Fabrics	2 DI / Multiple Fabrics
Background	*1*	41	44	153	60	33
	17	34	48	152	43	29
	32	45	52	180	59	37
	Average:	**40**	**48**	**162**	**54**	**33**
Influent	*11*	72	81	197	78	70
	16	67	79	207	80	73
	21	65	97	229	93	83
	26	67	95	246	91	84
	31	76	80	252	89	62
	Average:	**69**	**87**	**226**	**86**	**74**
Effluent	*10*	67	58	198	55	46
	15	66	57	187	85	47
	20	65	61	198	92	55
	25	67	60	214	83	52
	30	69	59	222	88	61
	Average:	**67**	**59**	**204**	**81**	**52**
Δ Turbidity		*3*	*28*	*22*	*5*	*22*

fabrics, which was similar to the trap with the single filter fabric. The change in turbidity for these was 22 NTU. For the various enhancements that were tested, the least effective enhancement were the multiple filter fabrics with a reduction of only 5 NTU.

3.5 Particle Count Trends

A particle counter was used to categorize trends in the sizes of the particles in the effluent from the sediment traps. Removal efficiencies were not determined since a particle counter was not available to monitor the influent flow to the sediment traps. The particle count data provides the number of particles per milliliter for various ranges of bin sizes over an elapsed run time for each test. The bin size ranges were >2-3 microns (μm), >3-5 μm, >5-7 μm, >7-10 μm, >10-15 μm and greater than 15 μm. The number of particles in each size range was recorded. Particle monitoring began after ten minutes of elapsed run time since that was the typical time required for the sediment traps to fill with water and begin having an effluent flow. The particle count data were collected for tests in both the standard sediment traps and the enhanced sediment traps. Tests using road sand were performed at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min. Tests using the mixed sediment (i.e., three parts road sand and one part decomposed granite) were performed at a flow of 475 L/min and a sediment feed rate of 4.0 kg/min.

4.3.5 Particle Count Trends for the Double Can Sediment Trap

The average of cumulative particle counts for tests on the standard and enhanced double can sediment traps are summarized in Figure 4.5 and Table 4.18. The data for the averages and standard deviations are given for each bin size over the elapsed run time of

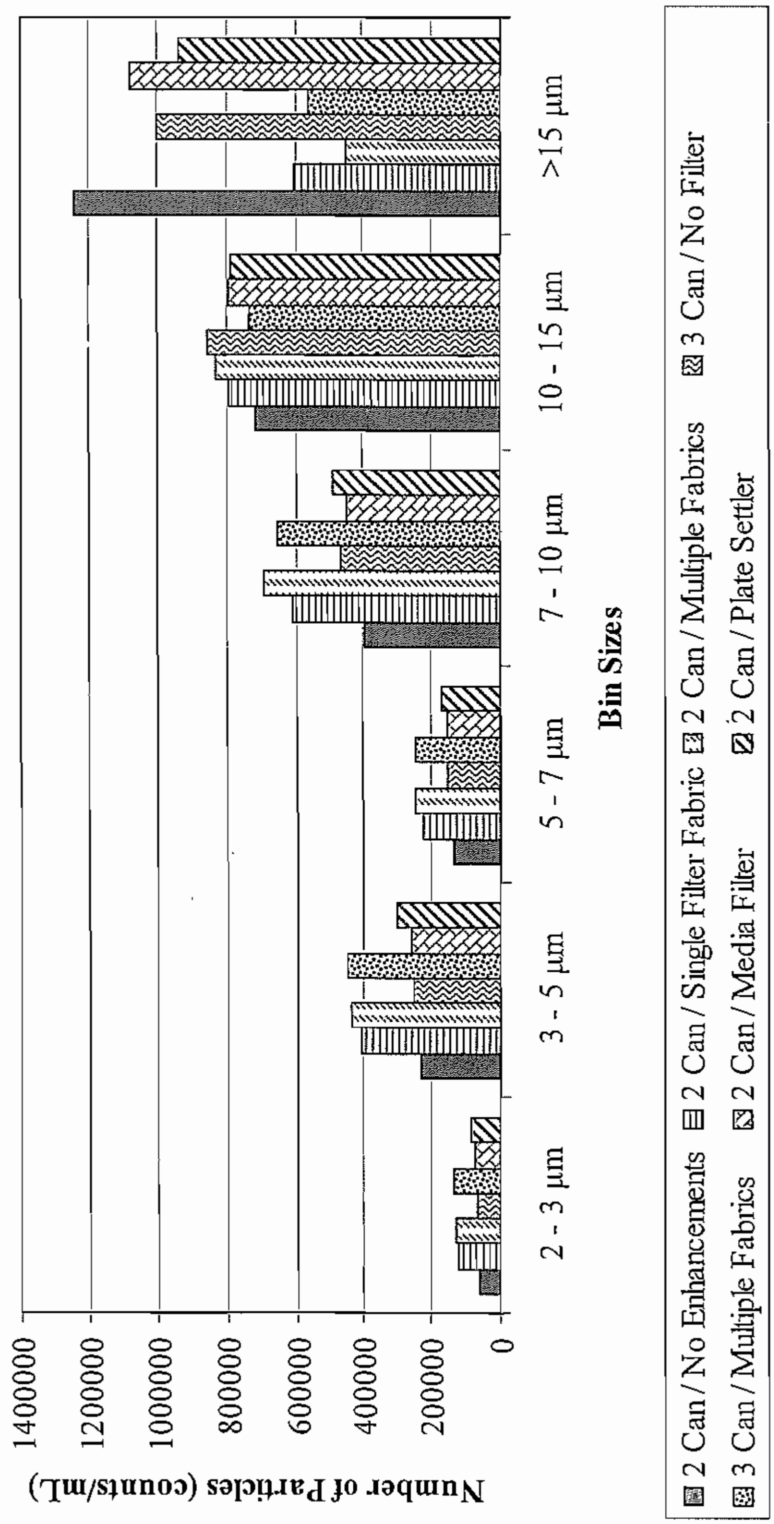


Figure 4.5 Average of cumulative particle counts for the double can sediment trap (475 L/min, 6.8 kg/min road sand)

Table 4.18 Average of cumulative particle counts for the double can sediment trap (475 L/min, 6.8 kg/min road sand)

Test Conditions	Average of Cummulative Particle Counts (1000 counts/mL) per Bin Size					
	>2 - 3 μm	*>3 - 5 μm*	*>5 - 7 μm*	*>7 - 10 μm*	*>10 - 15 μm*	*>15 μm*
2 Can / No Enhancements	**60**	**228**	**132**	**394**	**721**	**1,244**
Std. Dev.	15	53	30	88	150	219
2 Can / Single Filter Fabric	**119**	**407**	**224**	**607**	**795**	**606**
Std. Dev.	40	114	56	110	45	347
2 Can / Multiple Fabrics	**125**	**436**	**248**	**693**	**835**	**448**
Std. Dev.	41	127	68	156	68	221
3 Can / No Filter	**65**	**254**	**150**	**466**	**859**	**1,000**
Std. Dev.	3	10	7	24	47	95
3 Can / Multiple Fabrics	**132**	**446**	**247**	**652**	**734**	**560**
Std. Dev.	42	102	40	42	209	230
2 Can / Media Filter	**71**	**260**	**151**	**448**	**795**	**1,083**
Std. Dev.	11	40	23	69	84	274
2 Can / Plate Settler	**83**	**299**	**170**	**490**	**792**	**939**
Std. Dev.	16	49	26	64	58	90

10 to 30 minutes. The greatest variation of cumulative particle counts occurred in the bin size for particles >15 μm, as seen in Figure 4.5. The main function of the traps and enhancements was for discrete particle settling. When referring to Table 2.1, particles near 15 μm in size are classified as fine silts. Therefore, particles smaller than 15 μm would not be expected to settle readily in the sediment traps. As a result, the bin size for particles >15 μm is the main focus of the particle count data. It is noted that particles in the smallest five bin sizes include finer silts and clays which undoubtedly have very significant impacts on water quality. Therefore, further research needs to be done to enhance the removal of the smaller particle sizes.

In Table 4.18, the tests in the standard double can sediment trap with no enhancements had the highest cumulative number of particles >15 μm at approximately 1,244,000 counts/mL. The next highest cumulative particle count of approximately 1,083,000 counts/mL was in the effluent from the media filter. The lowest particle counts in the larger than 15 μm range was the multiple filter fabrics at about 448,000 counts/mL. Thus, the number of particles larger than 15 μm was reduced by more than 60% when multiple filter fabrics were used. Similar reductions were observed when looking at the TSS data.

In Figure 4.6, the average of cumulative particle counts in the >15 μm bin size for the typical tests in the double can sediment trap using road sand and the mixed sediment are compared. The results indicate that the cumulative particle counts in the standard double can sediment trap were over 1.2 million counts/mL for tests using road sand and over 1.4 million counts/mL for tests using the mixed sediment. The decomposed granite markedly increased the number of particles. This suggests that controlling the source of decomposed granite through watershed protection and erosion control measures is important. The sediment traps using multiple filter fabrics performed best for both the road sand and the sediment mixture, having between 425,000 and 600,000 counts/mL, respectively. The media filter was more effective at removing the mixed sediment particles than the road sand particles. This was potentially due to the greater number of particles in the effluent causing a cake to form on top of the filter media, resulting in an improved particle removal by straining. For tests using a single layer of filter fabric, the results indicated that the road sand was much more effectively removed

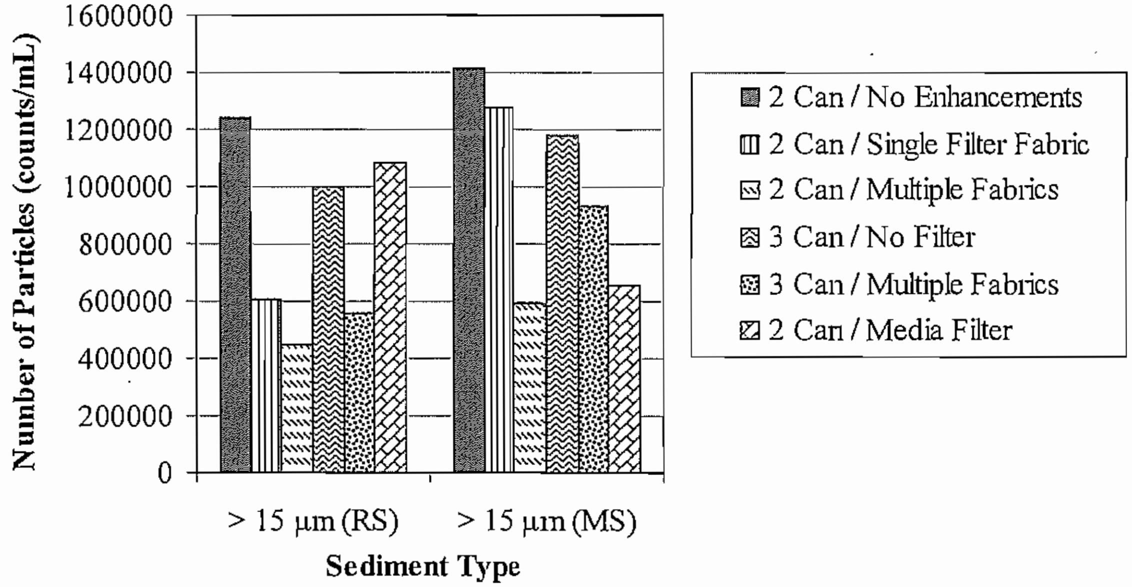


Figure 4.6 Comparison of average cumulative particle counts >15 μm for typical tests using road sand and mixed sediment in the double can sediment trap (475 L/min, 6.8 kg/min road sand (RS) and 475 L/min, 4.0 kg/min mixed sediment (MS))

than the sediment mixture. The particles may potentially be clogging the filter fabric at a higher rate, causing the reduced performance.

Incremental trends in particle counts >15 μm over the elapsed run time from ten minutes to thirty minutes are compared in Figure 4.7. Overall, the results indicated that the filter fabrics effectively removed road sand particles >15 μm throughout the duration of the elapsed run time. The standard double can sediment trap with no enhancements consistently had the highest particle count at about 8,000 counts/mL. After about 15 minutes of elapsed run time, the triple can with multiple filter fabrics removed the greatest number of particles. Its particle count started out high, but dropped greatly over the first fifteen minutes of the test as the filter fabric ripened. A similar trend was observed for the media filter. Ripening was expected for all of the filter fabrics but was not observed prominently in every case, meaning that either ripening did not occur or occurred before ten minutes of elapsed run time or at a smaller scale. Spike increases in particles were observed in the data and may be attributed to periodic flushing of particles trapped in the filter fabrics or to flushing of settled particles within the traps. Flushing of particles from the filter fabrics may have been the result of a high head gradient across two sides of the filter fabrics, which increase as a layer of fabric became clogged over time.

Overall, the filter fabrics achieved higher particle removals than any of the other enhancements and increasing the number of filter fabrics further improved particle removal in general. The multiple filter fabrics in the double can sediment trap consistently had particle counts in the range of 2,000 to 3,000 counts/mL which was the second lowest particle counts during the run time. The single filter fabric had the third smallest trend over the elapsed run time. After particle breakthrough, the media filter performed similarly to the plate settler and the 3 can with no filter fabrics; each of these was in the range of 6,000 to 7,000 counts/mL.

Incremental trends in particle counts >15 μm over the elapsed run time from ten minutes to thirty minutes are compared in Figure 4.8 for the sediment mixture. The single filter fabric consistently had the highest particle count at about 8,000 to 9,000 counts/mL. Until about 20 minutes of elapsed run time, the multiple filter fabrics removed the greatest number of particles. The multiple filter fabrics and the media filter were similar thereafter. The increase in the media filter performance was expected due to ripening. All of the fabrics were expected to ripen, yet this was not observed prominently in every case, meaning that either ripening did not occur or occurred before ten minutes of elapsed run time or at a smaller scale. Spike increases in particles occurred in the data

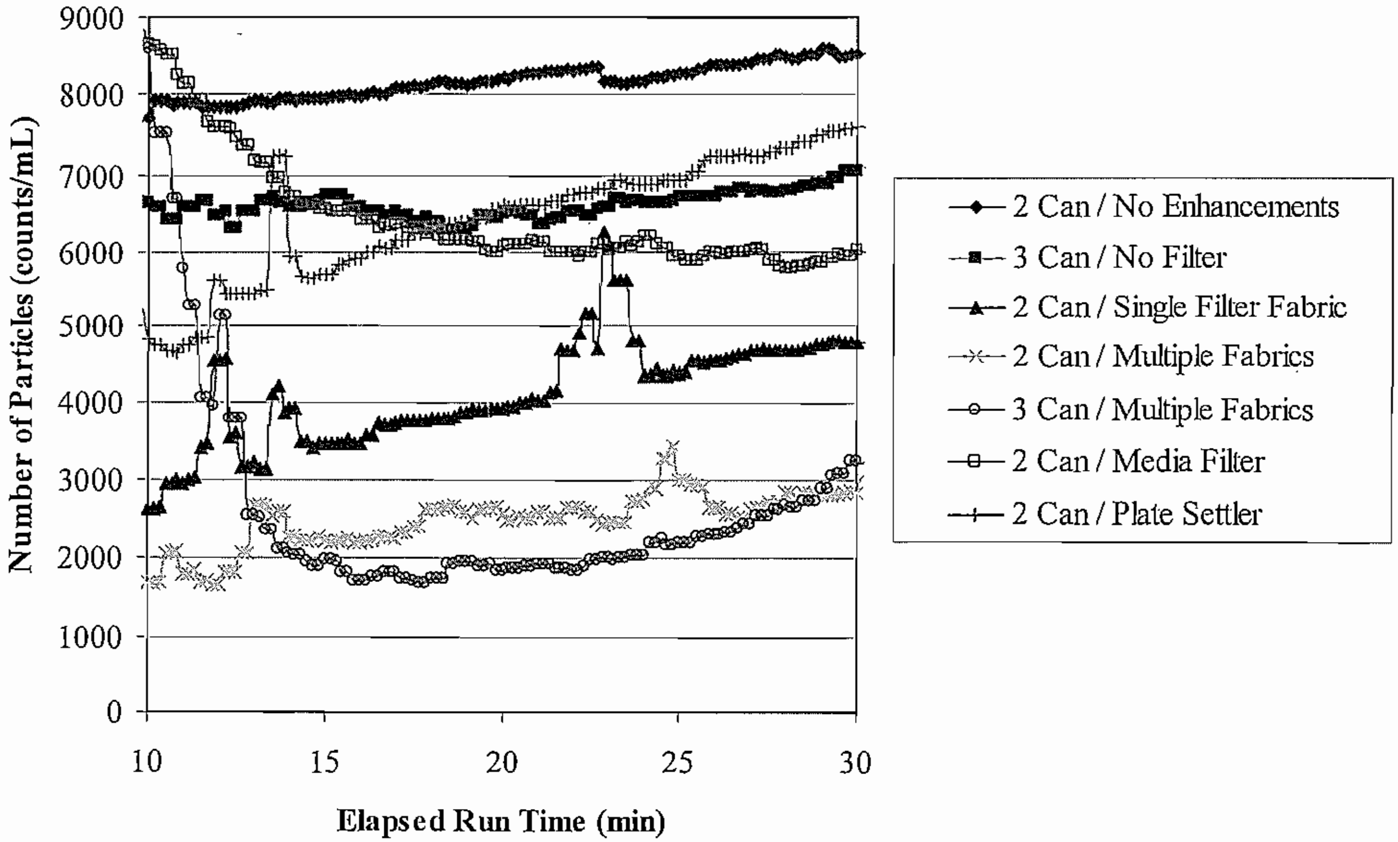


Figure 4.7 Incremental particle counts >15 μm for the standard and enhanced double can sediment traps (475 L/min, 6.8 kg/min road sand)

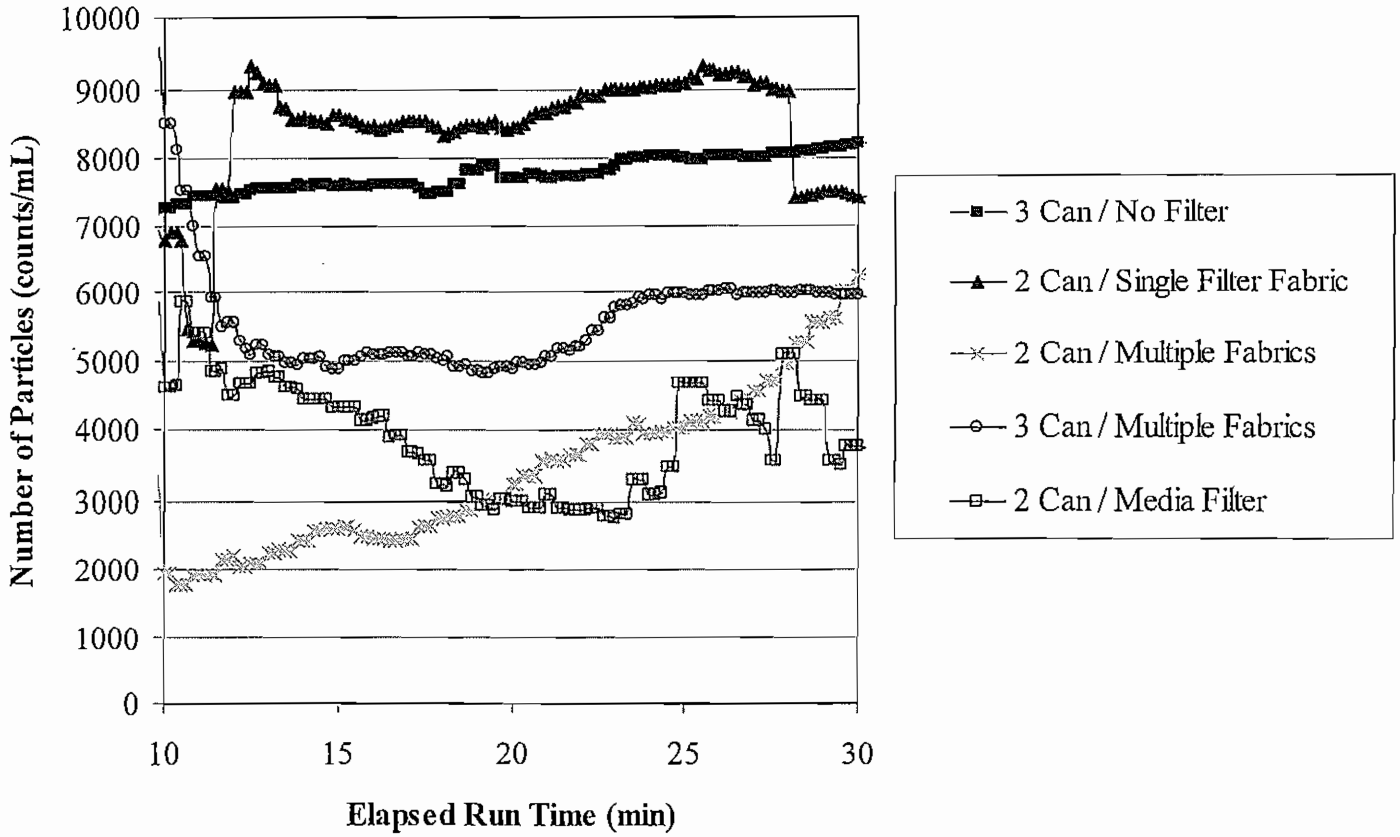


Figure 4.8 Incremental particle counts >15 μm for the standard and enhanced double can sediment traps (475 L/min, 6.8 kg/min mixed sediment)

and may be attributed to periodic flushing of particles trapped in the filter fabrics or to flushing of settled particles within the traps. Flushing of particles from the filter fabrics may have been the result of a high head gradient across both sides of the filter fabrics, which increased as a layer of fabric became clogged over time.

Overall, the filter fabrics achieved high particle removals and increasing the number of filter fabrics generally further improved particle removal. The media filter performed well when tested with the sediment mixture, which was potentially due to the caking of the sediment.

4.3.6 Particle Count Trends for the Drop Inlet Sediment Trap

The average of cumulative particle counts for tests on the standard and enhanced drop inlet sediment traps are summarized in Figure 4.9 and Table 4.19. The data for the averages and standard deviations are given for each bin size over the elapsed run time of 10 to 30 minutes. The greatest variation of cumulative particle counts occurred in the bin size for particles >15 μm, as seen in Figure 4.9. The main function of the traps and enhancements was for discrete particle settling. When referring to Table 2.1, particles at around 15 μm are classified as fine silts. Therefore, particles smaller than 15 μm would not be expected to settle readily in the sediment traps. As a result, the bin size for particles >15 μm is the main focus of the particle count data. It is noted that particles in the smallest five bin sizes include finer silts and clays which undoubtedly have very significant impacts on water quality. Therefore, further research needs to be done to enhance the removal of the smaller particle sizes.

In Table 4.19, the tests in the standard double can sediment trap with no enhancements had the highest cumulative number of particles >15 μm at approximately 1,426,000 counts/mL. The next highest cumulative particle count of approximately 1,304,000 counts/mL was in the effluent from the media filter. The lowest particle counts in the larger than 15 μm range was the multiple filter fabrics and the traps in series with multiple fabrics at about 508,000 counts/mL. Thus, the number of particles larger than 15 μm was reduced by more than 60% when multiple filter fabrics were used. Similar reductions were observed when looking at the TSS data.

In Figure 4.10, the average of cumulative particle counts in the >15 μm bin size for the typical tests in the drop inlet sediment trap using road sand and the mixed sediment are compared. The results indicate that the cumulative particle counts in the standard drop inlet sediment trap were over 1.4 million counts/mL for tests using road sand and over 1.6 million counts/mL for tests using the mixed sediment. The decomposed granite significantly increased the number of particles. This suggests that controlling the source of decomposed granite through watershed protection and erosion control measures is important. The sediment traps using multiple filter fabrics performed best for both the road sand and the sediment mixture, having between 400,000 and 600,000 counts/mL, respectively. The media filter was more effective at removing the mixed sediment particles than the road sand particles. This was potentially due to the greater number of particles in the effluent causing a cake to form on top of the filter media, resulting in an improved particle removal by straining. For tests using a single layer of filter fabric, the results indicated that the road sand was much more effectively removed than the sediment mixture. The mixed sediment particles may potentially

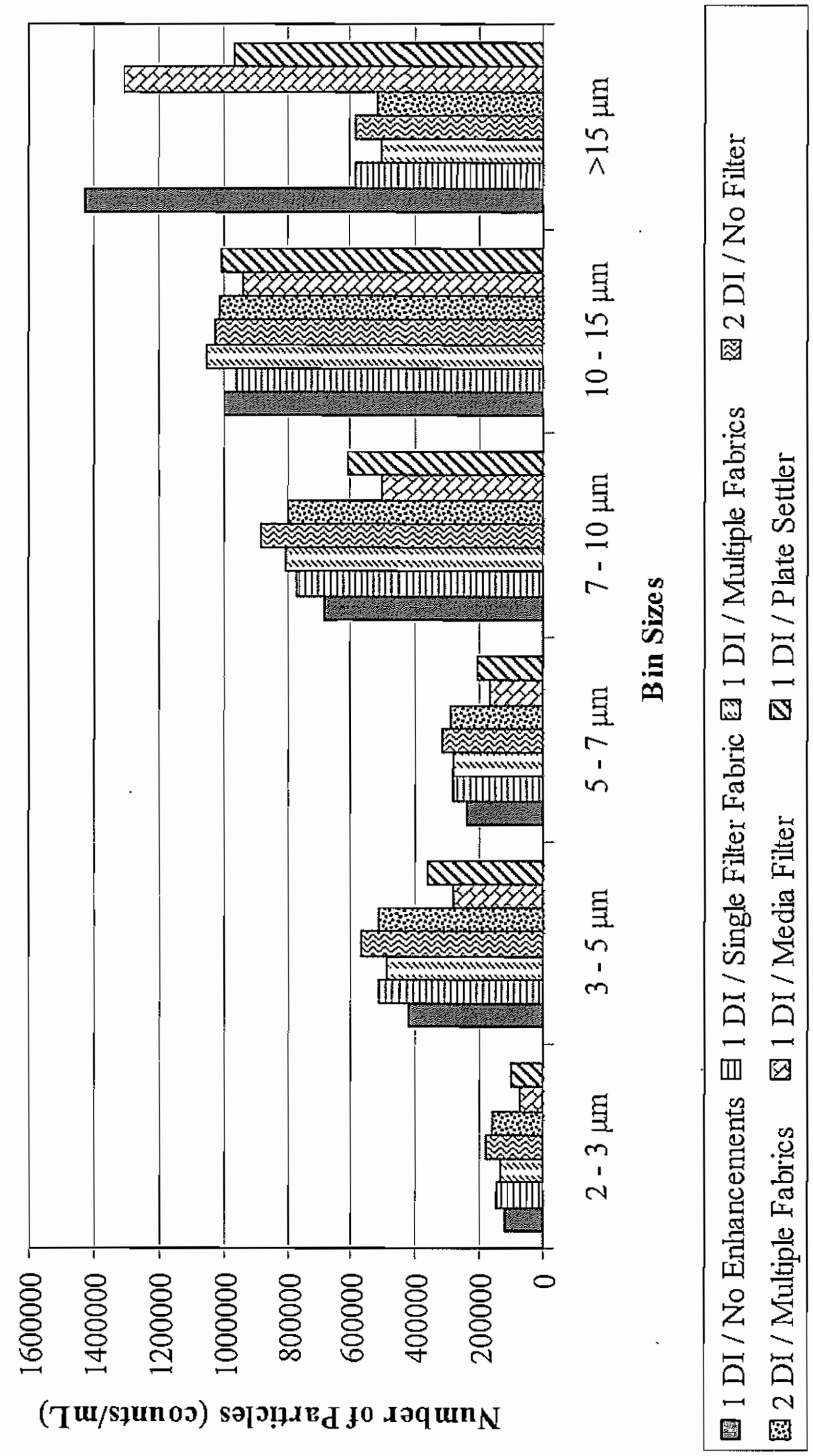


Figure 4.9 Average of cumulative particle counts for the drop inlet sediment trap (475 L/min, 6.8 kg/min road sand)

Table 4.19 Average of cumulative particle counts for the drop inlet sediment trap (475 L/min, 6.8 kg/min road sand)

Test Conditions	Average of Cummulative Particle Counts (1000 counts/mL) per Bin Size					
	>2 - 3 μm	*>3 - 5 μm*	*>5 - 7 μm*	*>7 - 10 μm*	*>10 - 15 μm*	*>15 μm*
1 DI / No Enhancements	**119**	**420**	**239**	**684**	**999**	**1,426**
Std. Dev.	30	100	57	163	158	214
1 DI / Single Filter Fabric	**147**	**509**	**283**	**768**	**958**	**584**
Std. Dev.	35	111	57	123	16	210
1 DI / Multiple Fabrics	**136**	**484**	**280**	**805**	**1,053**	**495**
Std. Dev.	43	148	85	222	159	147
2 DI / No Filter	**181**	**566**	**316**	**881**	**1,023**	**585**
Std. Dev.	9	49	29	82	101	10
2 DI / Multiple Fabrics	**163**	**512**	**285**	**794**	**1,012**	**508**
Std. Dev.	7	57	37	127	246	117
1 DI / Media Filter	**75**	**281**	**165**	**496**	**936**	**1,304**
Std. Dev.	8	31	19	59	110	111
1 DI / Plate Settler	**101**	**365**	**209**	**607**	**1,003**	**967**
Std. Dev.	5	14	7	23	71	163

be clogging the filter fabric at a quicker rate, causing the reduced performance.

Incremental trends in particle counts >15 μm over the elapsed run time from ten minutes to thirty minutes are compared in Figure 4.11. Overall, the results indicated that the filter fabrics effectively removed road sand particles >15 μm throughout the duration of the elapsed run time. The standard drop inlet sediment trap with no enhancements consistently had the highest particle count at about 8,000 to 10,000 counts/mL. After about 15 minutes of elapsed run time, the double drop inlet with multiple filter fabrics removed the greatest number of particles. Its particle count started out high, but dropped greatly over the first fifteen minutes of the test as the filter ripened. A similar trend

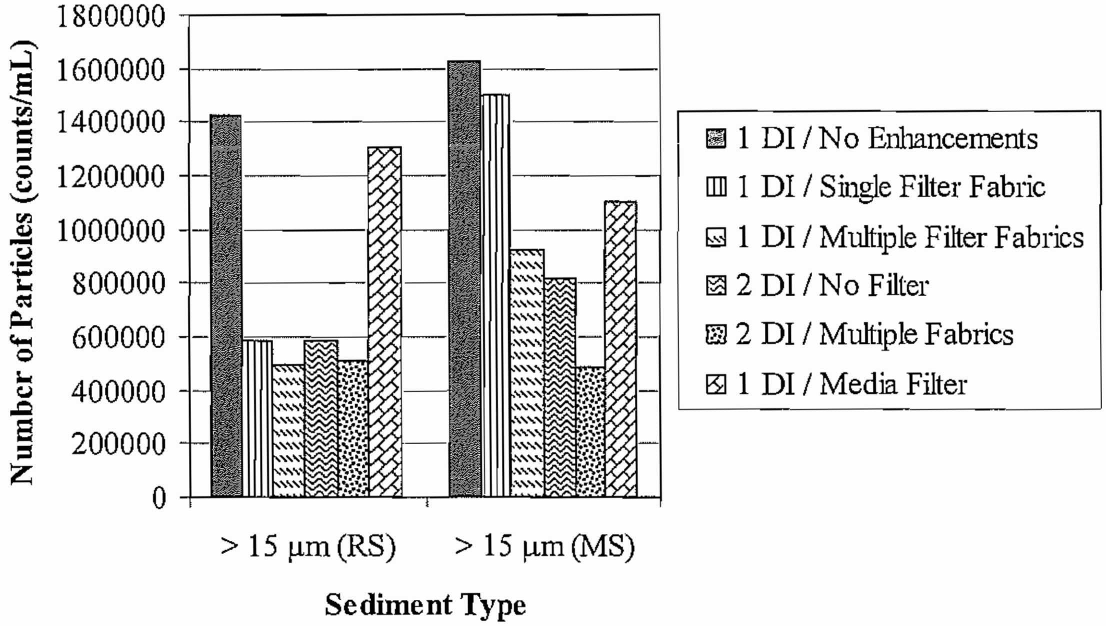


Figure 4.10 Comparison of average cumulative particle counts >15 µm for typical tests using road sand and mixed sediment in the drop inlet sediment trap (475 L/min, 6.8 kg/min road sand (RS) and 475 L/min, 4.0 kg/min mixed sediment (MS))

was observed for the media filter. Ripening was expected for all of the filter fabrics but was not observed prominently in every case, meaning that either ripening did not occur or occurred before ten minutes of elapsed run time or at a smaller scale. Spikes which occurred in the data and may be attributed to periodic flushing of particles trapped in the filter fabrics or to flushing of settled particles within the traps. Flushing of particles from the filter fabrics may have been the result of a high head gradient across two sides of the filter fabrics, which increases as a layer of fabric becomes clogged over time.

Overall, the filter fabrics achieved equal to or higher particle removals than any of the other enhancements and increasing the number of filter fabrics further improved particle removal in general. The multiple filter fabrics in the single drop inlet sediment trap consistently had particle counts in the range of 2,000 to 4,000 counts/mL. After ripening, the media filter performed in a range of 7,000 to 8,000 counts/mL.

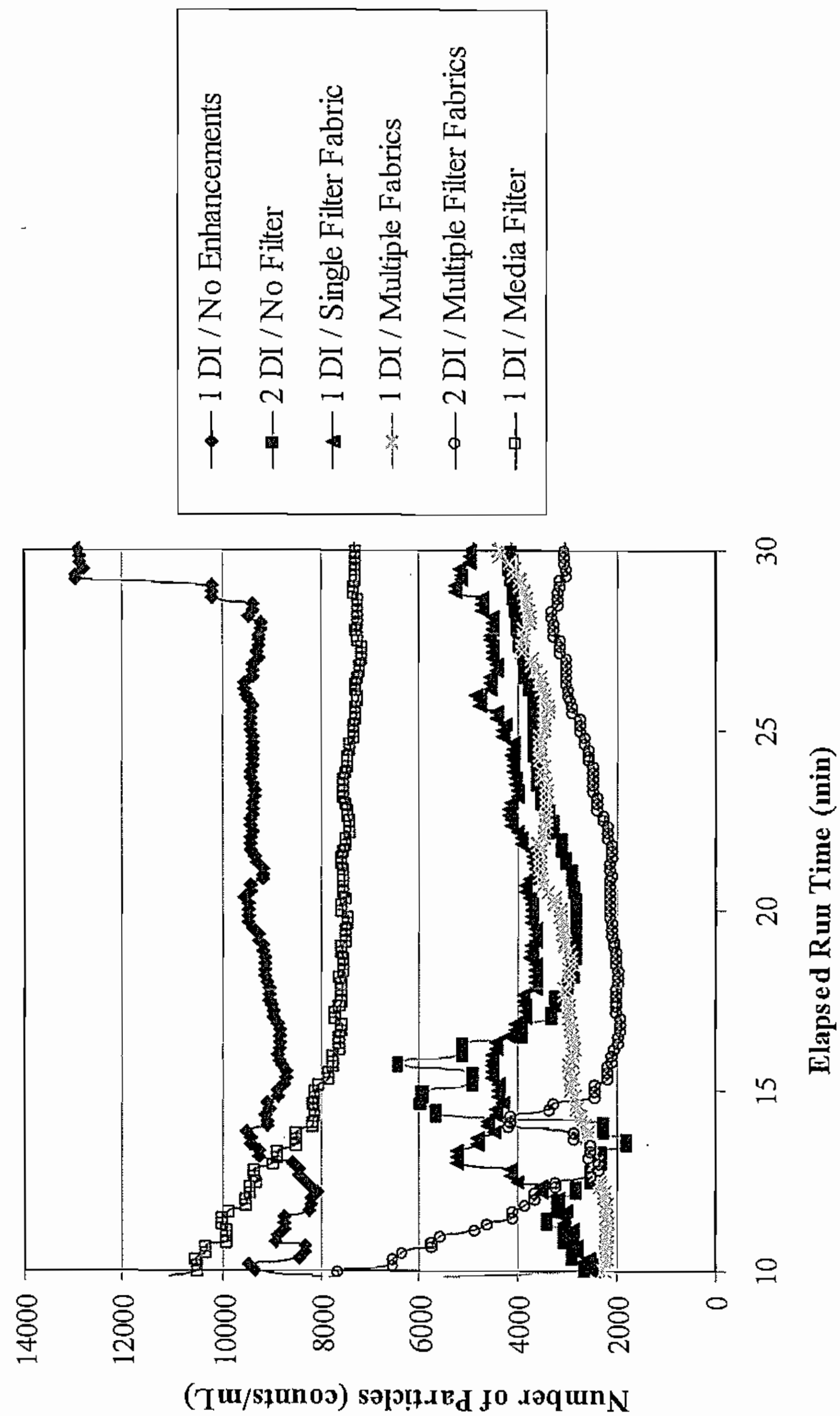


Figure 4.11 Incremental particle counts >15 µm for the standard and enhanced drop inlet sediment traps (475 L/min, 6.8 kg/min road sand)

Incremental trends in particle counts >15 μm over the elapsed run time from ten minutes to thirty minutes are compared in Figure 4.12 for the sediment mixture. The single filter fabric consistently had the highest particle count at about 9,000 to above 10,000 counts/mL. The multiple filter fabrics in the traps in series performed consistently the best over the thirty minutes of elapsed run time. The media filter exhibited a consistent decrease in particle counts over time as it ripened. All of the fabrics were also expected to ripen, yet this was not observed noticeable in every case, meaning that either ripening did not occur or occurred before ten minutes of elapsed run time or at a smaller scale. Spikes which occurred in the data and may be attributed to periodic flushing of particles trapped in the filter fabrics or to flushing of settled particles within the traps. Flushing of particles from the filter fabrics may have been the result of a high head gradient across two sides of the filter fabrics, which increases as a layer of fabric becomes clogged over time.

Overall, the filter fabrics achieved high particle removals and increasing the number of filter fabrics further improved particle removal in general. The media filter performed well when tested with the sediment mixture, which was potentially due to the caking of the sediment.

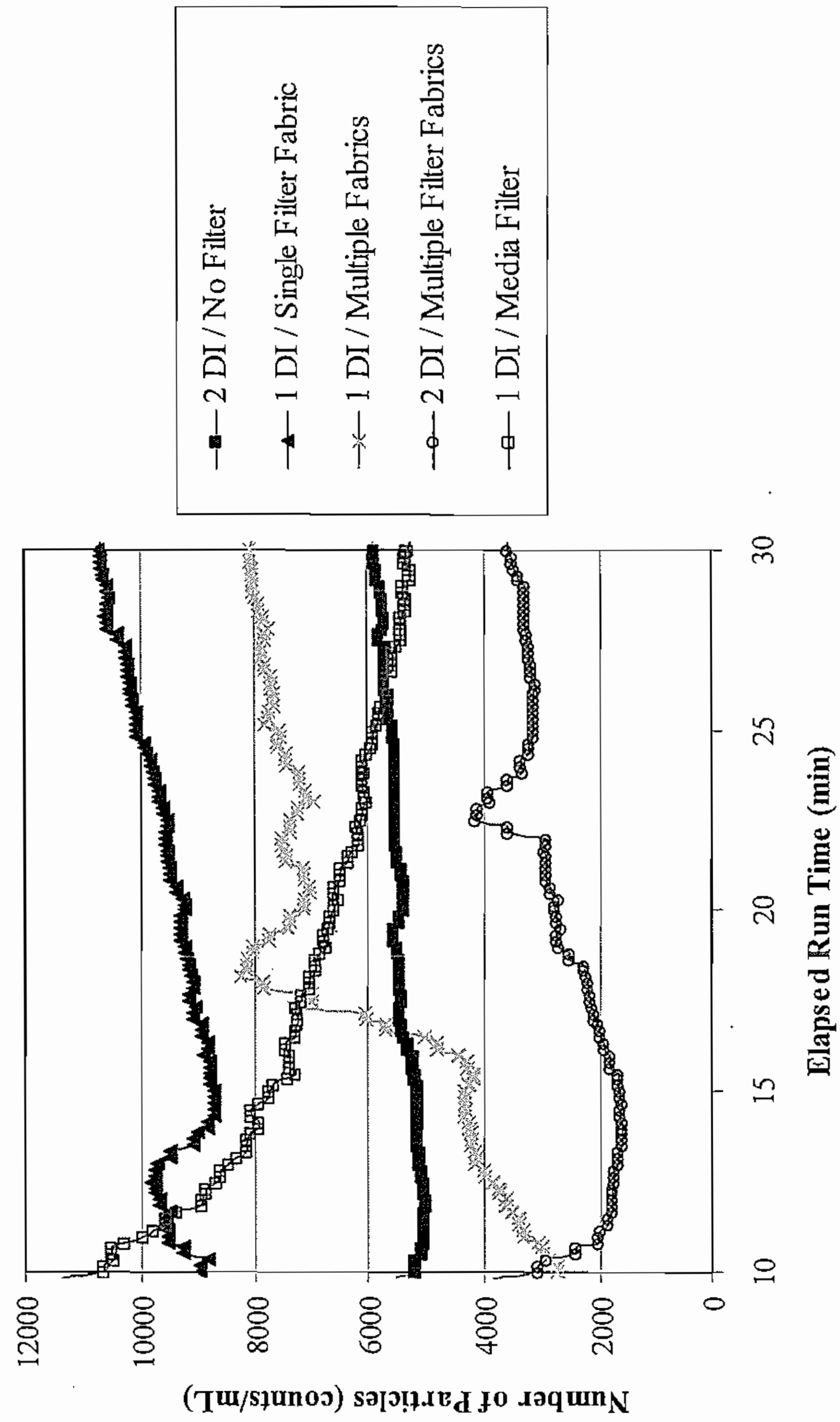


Figure 4.12 Incremental particle counts >15 µm for the standard and enhanced drop inlet sediment traps (475 L/min, 6.8 kg/min mixed sediment)

4.4 Additional Testing

As described in Chapter 3, Section 7, various enhancements were made to both the standard double can and the standard drop inlet sediment traps in an effort to improve the removal of particles. Additional testing was completed to evaluate the performance of the filter fabric enhancements under conditions of extended use. The sediment traps were also tested when filled with sediment to evaluate how poor maintenance practices might influence particle removal. The performance of the filter media columns was also compared to the performance of the large-scale filter box.

4.4.1 Removal of Total Suspended Solids and Turbidity within the Sediment Traps with Extended Filter Fabric Use

Tests using a single layer of filter fabric were repeated three times in a row using the same piece of filter fabric without cleaning between tests. The performance of clogged filter fabrics over time could provide valuable information about the particle removal efficiency and the projected life expectancy of the filter fabrics. Though the fabrics did not always have sufficient time to dry completely, the water was allowed to completely drain from the trap before the following test in order to simulate infrequent, isolated storm event activity.

The results obtained when testing the enhanced double can and drop inlet sediment traps with road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min are summarized in Table 4.20. The TSS percent removal represents the average of the TSS removal for a typical thirty-minute test, and allows the overall efficiencies to be compared.

The results revealed a decrease in the efficiency of TSS removal from the initial use of the filter fabrics to the other trials for the double can sediment trap. The average TSS removal efficiency declined from 47%±17% during the first trial to 30%±12% for the second trial and was 33%±8% for the third trial. Similar results were obtained for tests performed in the drop inlet sediment trap. The average TSS removal efficiency declined from 29%±25% during the first trial to 16%±5% for the second trial and was 19%±10% for the third trail. For both the double can and the drop inlet sediment traps the slight increase in efficiency observed for the third trial may be the result of filter ripening and the gradual accumulation of finer particles on the filter fabrics.

The variations in turbidity during a typical thirty-minute test are summarized in Table 4.21. The changes between the influent and effluent turbidities are given at the bottom of the table. The results indicated that the filter fabrics were less effective at reducing turbidity during successive tests. For the tests in the double can sediment trap using road sand, the reduction in turbidity declined gradually from 20 NTU during the first trial, 15 NTU during the second trial, and 11 NTU during the third trial.

Table 4.20 Variation of TSS removal efficiency with elapsed run time during extended filter fabric use (475 L/min, 6.8 kg/min road sand)

	Elapsed Run Time (min)						Std.
Test Conditions	*11*	*16*	*21*	*26*	*31*	**Avg.**	**Dev.**
Double Can (Trial 1)	71%	56%	45%	27%	36%	47%	17%
Double Can (Trial 2)	48%	27%	26%	32%	16%	30%	12%
Double Can (Trial 3)	39%	42%	24%	24%	33%	33%	8%
Drop Inlet (Trial 1)	73%	17%	23%	19%	11%	29%	25%
Drop Inlet (Trial 2)	19%	9%	13%	15%	23%	16%	5%
Drop Inlet (Trial 3)	27%	24%	27%	14%	4%	19%	10%

Table 4.21 Variation of turbidity with elapsed run time for the sediment traps during continual filter fabric utilization (475 L/min, 6.8 kg/min road sand)

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed Rate					
		Double Can (Trial 1)	Double Can (Trial 2)	Double Can (Trial 3)	Drop Inlet (Trial 1)	Drop Inlet (Trial 2)	Drop Inlet (Trial 3)
Background	*1*	36	33	36	60	75	64
	17	37	29	35	43	67	48
	32	48	40	43	59	80	62
	Average:	**40**	**34**	**38**	**54**	74	**58**
Influent	*11*	68	68	69	78	102	74
	16	73	74	72	80	110	89
	21	74	78	75	93	107	104
	26	77	76	68	91	113	89
	31	85	84	83	89	113	97
	Average:	**75**	**76**	**74**	**86**	**109**	**91**
Effluent	*10*	41	46	59	55	95	72
	15	46	55	57	85	100	81
	20	52	62	61	92	102	89
	25	63	68	66	83	106	91
	30	72	73	72	88	108	94
	Average:	**55**	**61**	**63**	**81**	**102**	**85**
Δ Turbidity		*20*	*15*	*11*	*5*	*7*	*6*

The drop inlet sediment trap was less effective at reducing turbidity than the double can sediment trap. The reduction in turbidity for tests on the drop inlet was essentially the same for each trial run, 5 NTU for the first trial, 7 NTU for the second trial, and 6 NTU for the third trial.

In general, the results for both TSS and turbidity demonstrated that the performance of the filter fabrics decreased in efficiency during subsequent uses. As a result, it is recommended that the filter fabrics be routinely replaced in order to maintain effective particle removal.

4.4.2 Comparison of Propex 4510 and 4516 Filter Fabrics

Additional tests were conducted in order to compare the performances of the Propex 4510 and the Propex 4516 filter fabrics. Information on the properties of the fabrics was summarized in Section 3.7.1. Propex 4510 is thinner than Propex 4516. Due to its thickness and weight, Propex 4516 had a higher cost and was slightly more difficult to work with. The objective of testing the two filter fabrics in the enhanced double can and drop inlet sediment traps was to determine which fabric was most effective and economical based on particle removal efficiency and cost, respectively. The tests were performed for the sediment traps arranged in series using multiple fabrics. The tests were conducted using the mixed sediment (one part decomposed granite with three parts of road sand) at a flow of 475 L/min and a sediment feed rate of 4.0 kg/min. The fabrics have the same apparent opening size (AOS) of 0.15 mm, which would theoretically trap 40% or less of the particles based on the sieve analyses in Section 3.5.

The results for the double can sediment trap summarized in Table 4.22 indicated that the average removal efficiencies of TSS were 40%±7% and 68%±12% for the Propex 4516 and Propex 4510 products, respectively. The average removal efficiency of TSS for the drop inlet sediment trap were 45%±23% and 53%±13% for Propex 4516 and Propex 4510 fabrics, respectively.

Table 4.22 Variation of TSS removal efficiency with elapsed run time for different filter fabrics (475 L/min, 6.8 kg/min road sand)

Test Conditions	Elapsed Run Time (min)					Avg.	Std. Dev.
	11	*16*	*21*	*26*	*31*		
Double Can (Propex 4516)	70%	64%	56%	54%	56%	60%	7%
Double Can (Propex 4510)	79%	80%	68%	56%	55%	68%	12%
Drop Inlet (Propex 4516)	61%	56%	56%	47%	5%	45%	23%
Drop Inlet (Propex 4510)	64%	65%	48%	53%	33%	53%	13%

The variations in turbidity during a typical thirty-minute test are summarized in Table 4.23. The changes between the influent and effluent turbidities are given at the bottom of the table. The results indicated that the filter fabrics were similar in performance at reducing turbidity during comparative testing. For the tests in the double can sediment trap using road sand, the reduction in turbidity for Propex 4516 was 37 NTU, while the reduction in turbidity for Propex 4510 was 47 NTU. The drop inlet sediment trap was less effective at reducing turbidity than the double can sediment trap. The reduction in turbidity for tests on the drop inlet was 14 NTU for the Propex 4516 and 26 NTU for Propex 4510.

In general, the results for both TSS and turbidity demonstrated that the performance of the filter fabrics were similar during testing, with Propex 4510 at a greater performance. Therefore, it is recommended that Propex 4510 be used since it is equally effective at particle removal at less cost.

Table 4.23 Variation of turbidity with elapsed run time for different filter fabrics (475 L/min, 6.8 kg/min road sand)

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed Rate			
		Double Can Propex 4516	Double Can Propex 4510	Drop Inlet Propex 4516	Drop Inlet Propex 4510
Background	*1*	53	30	41	29
	17	49	28	35	26
	32	53	34	40	35
	Average:	**52**	**31**	**39**	**30**
Influent	*11*	96	95	69	70
	16	107	100	74	72
	21	93	82	88	81
	26	111	89	72	90
	31	109	83	69	59
	Average:	**103**	**90**	**75**	**74**
Effluent	*10*	61	35	57	41
	15	65	43	59	41
	20	63	40	54	55
	25	70	48	54	51
	30	73	47	77	53
	Average:	**66**	**43**	**60**	**48**
Δ Turbidity		*37*	*47*	*14*	*26*

4.4.3 Removal of Total Suspended Solids and Turbidity within the Sediment Traps with Full Traps

Tests on the standard drop inlet and double can sediment traps were run with the traps filled with road sand sediment up to the 4 inches below the trap effluents. Both cans in the double can sediment traps were filled. The objective of these tests was to simulate the performance of the sediment traps when they are not properly maintained.

The results obtained when testing the double can and drop inlet sediment traps with road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min are summarized in Table 4.24. The TSS concentrations represent the average of the TSS concentrations for a typical thirty-minute test, allows the overall efficiencies to be compared.

The results indicated a decrease in efficiency of TSS removal in the double can sediment trap when the trap was filled. The average TSS removal efficiency was 16%±5% for the empty trap, and 3%±6% when the trap was filled. The results indicated an increase in efficiency of TSS removal in the drop inlet sediment trap when the trap was filled. The average TSS removal efficiency was 22%±15% for the empty trap, and 34%±2% when the trap was filled due to less distance for particles to travel to settle on the trap floor.

The variations in turbidity during a typical thirty-minute test are summarized in Table 4.25. The changes between the influent and effluent turbidities are given at the bottom of the table. The results indicated that the standard traps were similar in performance at reducing turbidity to the traps that were filled. For the tests in the double can sediment trap using road sand, the reduction in turbidity for the full trap was 4 NTU, and was 2 NTU for the standard trap. For the tests in the drop inlet sediment trap using road sand, the reduction in turbidity for the full trap was 9 NTU, and was 3 NTU for the standard trap.

Table 4.24 TSS removal efficiency with elapsed run time in filled sediment traps (475 L/min, 6.8 kg/min road sand)

Test Conditions	Elapsed Run Time (min)					Avg.	Std. Dev.
	11	*16*	*21*	*26*	*31*		
Standard Double Can	8%	20%	21%	14%	17%	16%	5%
Filled Double Can	2%	-4%	6%	12%	1%	3%	6%
Standard Drop Inlet	41%	7%	8%	22%	31%	22%	15%
Filled Drop Inlet	36%	33%	33%	36%	31%	34%	2%

Table 4.25 Turbidity quantities with elapsed run time for the sediment traps while filled with sediment (475 L/min, 6.8 kg/min road sand)

Sample Location	Elapsed Run Time (min)	Average Turbidity (NTU) for Flow and Sediment Feed Rate			
		Standard Double Can	Filled Double Can	Standard Drop Inlet	Filled Drop Inlet
Background	*1*	28	95	13	46
	17	24	99	16	41
	32	40	115	24	51
	Average:	**31**	**103**	**17**	**46**
Influent	*11*	78	131	47	71
	16	79	133	42	74
	21	82	137	46	81
	26	86	141	51	88
	31	90	146	50	87
	Average:	**83**	**138**	**47**	**80**
Effluent	*10*	81	130	35	64
	15	77	124	41	66
	20	78	134	44	70
	25	81	137	48	76
	30	91	142	52	79
	Average:	**81**	**134**	**44**	**71**
Δ Turbidity		*2*	*4*	*3*	*9*

In general, the changes in turbidity were essentially negligible, which indicated that almost no reduction was achieved. The reduction in TSS varied, yet it is recommended that the traps be properly maintained to allow storage for settled sediment.

4.4.4 Removal of Turbidity with Media Filtration

Initial media filtration was performed to reveal if there was a potential for efficient particle removal. As described in Section 3.7.2, a scaled mixed media filter was used at a loading rate of 48 L/min/m^2. This was followed by four filter columns at two loading rates and two filter media depths, which was concluded with the utilization of a full-scale media filter with a loading rate of 159 L/min/m^2. Each filter setup was fed effluent water from the double can sediment trap effluent during the thirty-minute test of road sand at a flow of 475 L/min and a sediment feed rate of 6.8 kg/min.

The turbidity of the influent and effluent of each was compared, which is shown in Table 4.26. The background, influent, and effluent turbidity readings were taken over total elapsed run time. The changes between the influent and effluent values of turbidity are given at the bottom of the table. Analysis of the initial testing shows a significant drop in average turbidity from the influent at 40 NTU to the filter effluent at 11 NTU, a change of 29 NTU. This was increased greatly for the column testing, where the change in turbidity was the greatest for the lowest loading (80 L/min/m^2) and the deepest filter media depth of 16 inches (40 cm) at 110 NTU. The change in turbidity was least for the highest loading (160 L/min/m^2) and the shallow filter media depth of 8 inches (20 cm) at 98 NTU. The filter columns performed extremely well. This was not the case for the full-scale media filter having a change in average turbidity of 27 NTU at a loading rate of

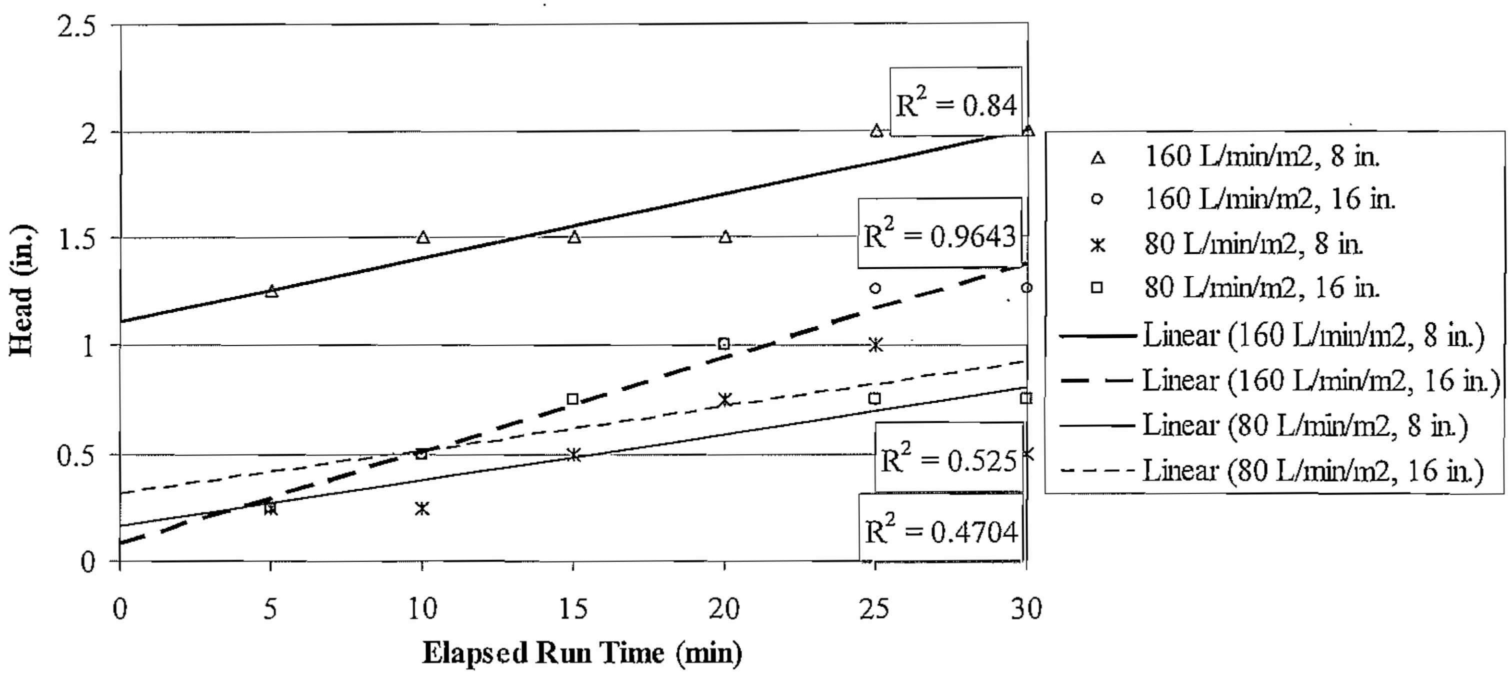
160 L/min/m^2 and 8 inches of filter media. Some potential reasons for this were scouring as a result of the influent water and localization of influent water. A proper full-scale filter design would include some type of influent distribution system and/or baffle to limit localized scouring and provide uniform distribution over the surface of the filter.

Upon analysis of data in Table 4.26 for the effluent turbidities, breakthrough of the media filters did not appear to be occurring over the thirty-minute testing times. Problems did occur, where significant storage of the head buildup above the filter media was necessary. Figure 4.13 reveals the head increase over elapsed run time for water of similar quality. The data for the loading rate of 160 L/min/m^2 and 8 inches of filter media had the greatest head following the thirty minutes of elapsed run time at about 2 inches (5 cm). The lowest was the 80 L/min/m^2 with 8 inches of filter media at about 0.75 inches (2 cm). The head may potentially increase with the addition of decomposed granite.

Table 4.26 Turbidity quantities with elapsed run time for the media filters (475 L/min, 6.8 kg/min road sand)

Sample Type	Elapsed Run Time (min)	Average Values for Flow and Sediment Feed Rate					
				Column Testing			
		Initial Testing	Full Scale Testing	160 L/min/m² 8 inch	80 L/min/m² 8 inch	160 L/min/m² 16 inch	80 L/min/m² 16 inch
Background	*1*	23	103	19	19	19	19
	17	17	102	18	18	18	18
	32	28	106	24	24	24	24
	Average:	**23**	**104**	**20**	**20**	**20**	**20**
Influent	*10*	35	148	20	20	20	20
	15	31	126	25	25	25	25
	20	39	145	29	29	29	29
	25	44	141	32	32	32	32
	30	49	140	39	39	39	39
	Average:	**40**	**140**	**124**	**124**	**124**	**124**
Filter Effluent	*10*	10	116	47	37	25	24
	15	8	109	22	31	16	19
	20	10	113	22	16	10	9
	25	12	114	20	14	12	8
	30	13	113	19	15	12	9
	Average:	**11**	**113**	**26**	**22**	**15**	**14**
Δ Turbidity		***29***	***27***	***98***	***102***	***109***	***110***

Figure 4.13 Variation of head over elapsed run time during filter column analysis (475 L/min, 6.8 kg/min road sand)



Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this research, various improvements should be implemented in order to improve performances of the drop inlet and double can sediment traps. The installation of vertically-oriented layers of filter fabrics is recommended for both types of traps since testing demonstrated their ability to greatly enhance the removal of TSS and reduce turbidity. The use of multiple layers of filter fabrics were most effective at particle removal, resulting in more than 50% removal of TSS for tests using both road sand and the mixed sediment in both the double can and drop inlet sediment traps. Comparison of TSS to particle counts showed similar results in particle removal. For tests using road sand, the use of multiple layers of filter fabrics reduced the effluent turbidity by 40 NTU from the double can sediment trap and by 16 NTU from the drop inlet sediment trap. Considering the two different filter fabrics that were evaluated (Propex 4510 and Propex 4516), the use of Propex 4510 is recommended since it is more economical and has greater workability than Propex 4516. When simulating the extended use of filter fabrics over several consecutive storm events, the performance of the fabrics decreased. The removal of TSS in the double can sediment trap dropped to approximately 30% for tests using road sand after three consecutive tests using the same fabric layers. As a result, it is recommended that the filter fabrics be replaced routinely in order to maximize their performance. The arrangement of sediment traps in series contributed to greater particle removals. For tests using road sand, the TSS removal was increased to around 30% for both types of sediment traps compared to 16% to 22% for the standard sediment traps. The media filters performed very well in the small-scale column testing, reducing the turbidity by 98 NTU for the largest loading and shallowest media depth, and up to 110 NTU for the smallest loading and deepest media depth. For the full-scale media filter, the efficiency of TSS removal was increased to over 40% for the double can sediment trap, but only to about 25% for the drop inlet. The media filter also effectively reduced turbidity, with a reduction of 36 NTU for the double can, and 27 NTU for the drop inlet. The media filter provided another opportunity to slow the water and allow for additional particle settling. Caking on the surface of the filter media occurred, increasing the water level above the filter media by approximately 25 cm during a typical test. In practice, the cake layer could periodically be scraped off, but should be routinely monitored.

Even though the performance of plate settlers was evaluated, they are not recommended for use in the sediment traps since they are costly, difficult to place in the traps, and were not very effective. Also, if the level of sediment within the traps was allowed to fill to the bottom of the settlers, then the system would fail.

When the traps were filled with sediment, the changes in turbidity were essentially negligible. The removal efficiency of TSS went from around 16% down to 3% for the double can, and 22% up to 34% for the drop inlet. It is recommended that the traps be properly maintained to provide sufficient storage for settled sediment.

Preliminary cost estimates for incorporating some of the recommended enhancements (single filter fabric, multiple filter fabrics, and the media filter) are summarized in Table 5.1, Table 5.2, and Table 5.3, respectively.

Table 5.1 Cost estimate for a single filter fabric frame

Description	Cost
Frame Material	$125
Filter Fabric	$10
Fabrication	$150
Total Cost Per Frame	*$285*

Table 5.2 Cost estimate for a multiple filter fabric frame

Description	Cost
Frame Material	$300
Filter Fabric	$25
Fabrication	$200
Total Cost Per Frame	*$525*

Table 5.3 Cost estimate for a ~~multiple~~ media filter ~~fabric frame~~

Description	Cost
Precast Concrete Filter Box (192 ft^3)	$2,600
Underdrain	$50
Influent Distribution	$50
Washed Silica Sand	$100
Fabrication	$500
Total Cost Per Filter	*$3,300*

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