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Catchbasins and Inserts for the Control of Gross Solids and Conventional Stormwater Pollutants

Robert Pitt
Dept. of Civil and Environmental Engineering
University of Alabama
Tuscaloosa, AL 35487

Richard Field
U.S. EPA
Edison, NJ

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Corresponding Author: Robert Pitt

Organization/Company: University of Alabama

Address: Dept of Civil and Environmental Engineering, Box 87205, Tuscaloosa, AL 35487

Abstract

This presentation summarizes the results from past and recent studies of catchbasin inlet devices, and recommend important features to optimize their performance. Case studies are also presented, summarizing two EPA-funded projects that examined catchbasins and insert performance. While many types of inlet devices may capture some stormwater debris, care must be taken in their design. Catchbasins with sumps may remove up to about 30% of suspended loads that enter the intet, but much of this material is relatively coarse and in many cases would not have moved to the outfall. The sumps do minimize sediment accumulation in the sewerage and reduce maintenance. These should probably be considered as grit traps, more than pollutant trapping devices. Some devices can also trap floatables. However, if not frequently maintained, clogging and ponding may occur. In addition, if water is forced through the trapped debris (especially leaves), degradation of the organic material may occur, actually causing the production of some pollutants. Some new inlet devices have been recently designed and are undergoing testing that promise more effective control of stormwater pollutants, along with better retention of bed load material and floatables.

Background

Storm drainage system inlet structures can be separated into three general categories. The first category is a simple inlet that is comprised of a grating at the curb and a box, with the discharge located at the bottom of the box which connects directly to the main storm drainage or combined sewerage. This inlet simply directs the runoff to the drainage system and contains no attributes that would improve water quality. However, large debris (several cm in size) may accumulate (if present in the stormwater, which is unlikely). The second type of inlet is similar to the simple inlet, but it contains a sump that typically extends 0.5 to 1 m below the bottom of the outlet. This is termed a catchbasin in the U.S., or a gully pot in the U.K., and has been shown to trap appreciable portions of the course sediment. The third category is also similar to the simple inlet, but contains some type of screening to trap debris. These include small cast iron perforated buckets placed under the street grating, as used in Germany, large perforated and lipped stainless steel plates placed under the street grating, as used in Austin, Texas, and a number of proprietary devices incorporating filter fabric or other types of screening placed to intercept the stormwater flow.

Over the past 85 years, there has been extensive use of catchbasins for coarse material removal from stormwater runoff (Lager, et al. 1977), mainly to reduce sedimentation problems in the storm drainage system. Catchbasins have also been utilized in Europe for over a century. The purpose of catchbasins historically has been to prevent the clogging of sewer lines with sediment and organic debris, and to prevent odors from escaping from the sewers by creating a water seal. Over the years, many different styles of catchbasins have been used, and many different enhancement devices have been added to increase their effectiveness. According to Lager, *et al*. (1977), catchbasins were considered marginal in performance as early as the turn of the century. They felt that the use of catchbasins may be more of a tradition for most municipalities rather than a practice based on performance. Sartor and Boyd (1972) suggested that all catchbasins should be filled in, citing their ineffectiveness at removal of pollutants and the threat of slug pollution of the scoured material. Grottker (1990) was more positive. He reports of an inlet design in Germany that is modified with sumps and a primary filter to screen out the larger debris. He recommended the modified device as a cost-saving device that improves water quality.

Catchbasin performance has been investigated for some time in the U.S. Sartor and Boyd (1972) conducted controlled field tests of a catchbasin in San Francisco, using simulated sediment in fire hydrant water flows. They sampled water flowing into and out of a catchbasin for sediment and basic pollutant analyses. Lager, *et al*. (1977) was the first EPA funded research effort that included a theoretical laboratory investigation to evaluate sedimentation in catchbasins and to develop effective designs. They also conducted extensive laboratory tests using simulated runoff.

The mobility of catchbasin sediments was investigated by Pitt (1979). Long-duration tests were conducted using an "idealized" catchbasin (based on Lager, *et al*.'s 1977 design), retro-fitted in San Jose, CA. The research focused on re-suspension of sediment from a full catchbasin over an extended time period. It was concluded that the amount of catchbasin and sewerage sediment was very large in comparison with storm runoff yields, but was not very mobile. Cleaning catchbasins would enable them to continue to trap sediment, instead of reaching a steady-state loading and allowing subsequent stormwater flows to pass through untreated.

Bellevue Catchbasin Monitoring Study

Catchbasins, simple inlets, man-holes, and sewerage sediment accumulations were monitored at more than 200 locations in Bellevue, Washington, in two mixed residential and commercial study areas as part of the Bellevue research conducted for the Nationwide Urban Runoff Program (Pitt 1985). These locations were studied over three years to monitor accumulation of sediment and sediment quality. The sediment in the catchbasins and the sewerage was found to be the largest particles that were washed from the streets. The sewerage and catchbasin sediments had a much smaller median particle size than the street dirt and were therefore more potentially polluting than the particulates that can be removed by street cleaning. Cleaning catchbasins twice a year was found to allow the catchbasins to capture particulates most effectively. This cleaning schedule was found to reduce the total residue and lead urban runoff yields by between 10 and 25 percent, and COD, total Kjeldahl nitrogen, total phosphorus, and zinc by between 5 and 10 percent (Pitt and Shawley 1982).

The Bellevue, WA, NURP project was conducted to characterize Pacific Northwest stormwater quality, and to evaluate the effectiveness of street cleaning and catchbasin cleaning. In addition, a small sub-study was conducted by the USGS to investigate the effectiveness of a small dry detention pond. There were two study areas examined: Lake Hills and Surrey Downs, both similar medium density residential areas. Each study area was examined with four separate experimental conditions: no controls, street cleaning alone, catchbasin cleaning alone, and both street cleaning and catchbasin cleaning together. This research was therefore conducted in a replicated complete block design, allowing runoff quality comparisons between periods having these different public works practices. When evaluating the effectiveness of these practices, one must therefore compare the results from the separate data categories. These eight data categories are as follows:

1. Bellevue, Lake Hills, Active CB, No SC (catchbasins were accumulating material, but no street cleaning operations were being conducted during this project period).

2. Bellevue, Lake Hills, Active CB, SC (catchbasins were accumulating material, and street cleaning operations were being conducted during this project period).

3. Bellevue, Lake Hills, Full CB, No SC (catchbasins were full and not accumulating material, and no street cleaning operations were being conducted during this project period).

4. Bellevue, Lake Hills, Full CB, SC (catchbasins were full and not accumulating material, street cleaning operations were being conducted during this project period).

5. Bellevue, Surrey Downs, Active CB, No SC (catchbasins were accumulating material, but no street cleaning operations were being conducted during this project period).

6. Bellevue, Surrey Downs, Active CB, SC (catchbasins were accumulating material, and street cleaning operations were being conducted during this project period).

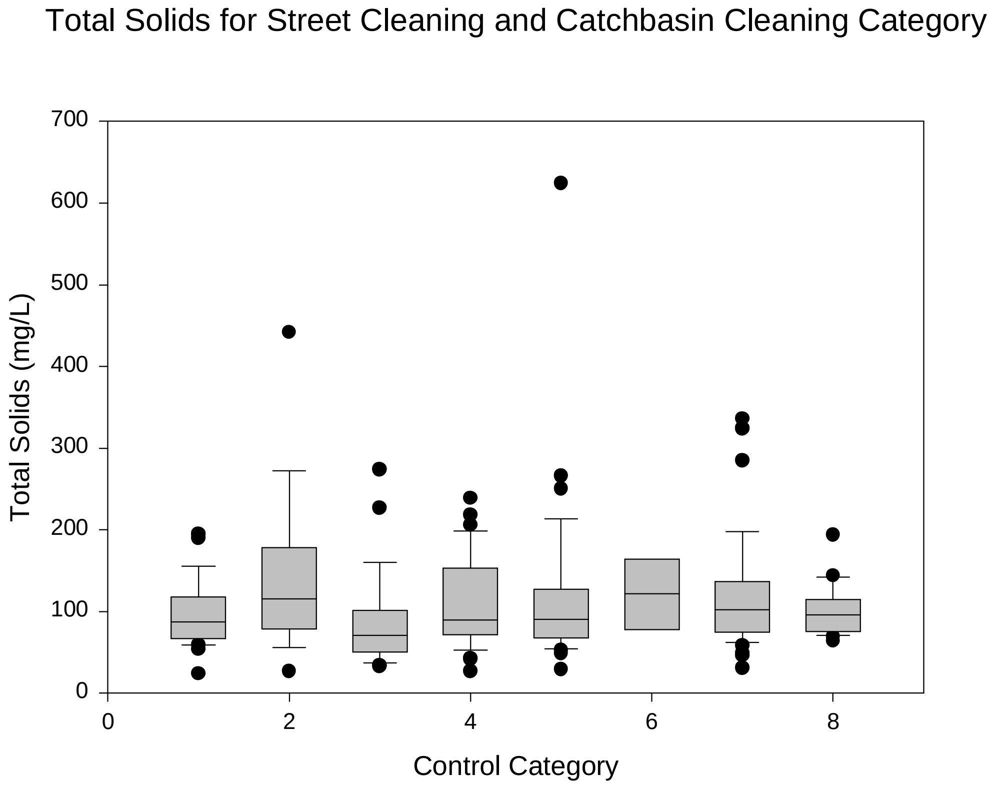
7. Bellevue, Surrey Downs, Full CB, No SC (catchbasins were full and not accumulating material, and no street cleaning operations were being conducted during this project period).

8. Bellevue, Surrey Downs, Full CB, SC (catchbasins were full and not accumulating material, street cleaning operations were being conducted during this project period).

The use of the two study areas was necessary because different time periods were obviously used for each of these project phases. The two separate areas were therefore needed to account for variations in rainfall, and other seasonal factors, that may have affected the results and confused the effects of the public works activities.

A note should be made concerning the catchbasin "cleaning" study phases. Obviously, catchbasins were present during the complete study period. They were cleaned and surveyed at the beginning of the project. The accumulation of material was then monitored through periodic measurements. The project periods were therefore categorized as "active" or "full." The active periods were when accumulation was taking place in the catchbasins, while the full periods were when the catchbasins were at an equilibrium, with no additional accumulation of material.

The first simple step is the preparation of grouped box and whisker plots to see how the observations in each of these 8 data groupings compare:



Total Solids for Street Cleaning and Catchbasin Cleaning Category

Note: The control categories in the above plot are:

Control Category	Bellevue Test Site	Street Cleaning?	Catchbasin Cleaning?
1	Lake Hills	N	Y
2	Lake Hills	Y	Y
3	Lake Hills	N	N
4	Lake Hills	Y	N
5	Surrey Downs	N	Y
6	Surrey Downs	Y	Y
7	Surrey Downs	N	N

8	Surrey Downs	Y	N

The following are simple Student *t* test results to measure the significance of the difference between selected data groups for outfall total solids concentrations. There would have to be a 50 to 75% difference between the sample means of the two categories to identify a significant difference, with 10 to 15 storms representing each of the two categories for each test site, using a power of 80%, and assuming a typical COV of about 0.75. P values smaller than 0.05 are usually considered as being significantly different (at the 95% confidence level), while larger P values indicate that not enough data are available to distinguish the data groups at the measured differences.

Student's *t*-test results:

2 vs. 6: both street and catchbasin cleaning in both areas, LH vs. SD
P value: 0.71 (not enough data to detect a difference)

3 vs. 7: nothing in both areas, LH vs. SD
P value: 0.031 (significantly different)

2 vs. 3 LH both street and catchbasin cleaning vs. nothing
P value: 0.037 (significantly different)

6 vs. 7 SD both street and catchbasin cleaning vs. nothing
P value: 0.99 (not enough data to detect a difference)

When both street and catchbasin cleaning was being conducted in both areas, the outfall total solids concentrations appeared to be the same (as expected). However, when no controls were in use in either area, the outfall total solids concentrations were significantly different (Lake Hills had lower total solids concentrations compared to Surrey Downs), which was not expected. When both street and catchbasin cleaning was conducted in Lake Hills, the outfall total solids concentrations were significantly larger than when no cleaning was being conducted, which also was not expected. In Surrey Downs, no differences were detected when cleaning was conducted compared to no cleaning.

These results are counter-intuitive. The hypothesis was that the two watersheds would behave in a similar manner when similar activities were being conducted in each, and that the cleaning would reduce the outfall total solids discharges. Over the years, a number of reasons have been given for the observed odd behavior. Older street cleaning equipment was not very efficient in removing the particles that are washed off, and in fact, have been found to actually remove the larger particles that actually armour the finer materials, potentially increasing the solids discharges. However, the catchbasins are removing particles that have washed off the watershed area and have been transported to the drainage system, but this material likely would not have been transported all the way to the outfall. Ashley, *et al.* (1999, 2000, 2002) has extensively researched the transport of solids in combined sewerage. Unfortunately, similar information is currently lacking for separate storm drains. The initial objective for the use of catchbasin sumps was to reduce the accumulation of coarse debris in the sewerage. These Bellevue tests seem to indicate the substantial benefit of the removal of this material that may otherwise cause potential flow obstruction problems in the drainage system. However, it is quite likely that this large material would rarely flow completely to the outfalls, at least under the relatively mild Bellevue conditions and during the time frame of this study. The New Jersey tests described later presents more detailed removal data at the inlet, showing how much of the inlet pollutants are actually trapped at the inlets.

Accumulation of Sediment in Bellevue Inlet Structures

An important part of the Bellevue NURP project was the measurement of the sediment accumulating in the inlet structures. The storm drainage system inlets were cleaned and surveyed at the beginning of the project. The 207 inlet structures were then surveyed nine times over two years to determine the depth of accumulating material (from December 1979 through January 1981). The first year rate of accumulation was relatively steady (based on 3 observation periods), while the sediment loading remained almost constant during the second year. During the second year, there was about twice as much contaminated sediments in the storm drainage system at any one time as there was on the streets. The flushing of the sewerage sediments out of the drainage systems was not found to be significant during the project period. There was a period of heavy rains in October of 1981 (about 100 mm of rain during a week, very large for Bellevue) during the second year when the accumulated material did not decrease, based on observations made before and after the rain (August 1981 and January 1982). The lack of sediment movement from catchbasin sumps was also observed during earlier tests conducted in San Jose by Pitt (1979). During that study, an idealized catchbasin and sump were constructed based on Lager, *et al.* (1974) and was filled with clean material having the same particle sizes as typical sump material, along with fluorencent tracer beads. During a year, freezing core samples were obtained and the sediment layers were studied to determine any flushing and new accumulations of material. The sediment material was found to be very stable, except for a very thin surface layer.

The first year accumulation rates (L/month per inlet) ranged from 1.4 in Lake Hills to 4.8 in Surrey Downs, as shown on Table 1. The catchbasins and inlets had sumps (the catchbasin sumps were somewhat larger), while the manholes were much larger, with more volume available for accumulation sediment. The stable volume that occurred during the second year were about 60% of the total storage volumes of the catchbasins and inlets (sump volume below the outlet pipe). If the sumps were very shallow, the maximum sediment depth was only about 12 mm, while the deeper sumps had about 150 mm of accumulated sediment. Individual inlet structures had widely varying depths, but the depth below the outlet appeared to the most significant factor affecting the maximum sump volume available. This "scour" depth generally was about 300 mm. If the sumps were deeper, they generally were able to hold more sediment before their equilibrium depth was reached and would therefore would require less frequent maintenance. About 100 L/ha/yr accumulated in Surrey Downs, while only about 2/3 of this value accumulated in Lake Hills. Nine of the most heavily loaded catchbasins in the first summer inventory in Surrey Downs were located very near two streets that did not have curbs and had extensive nearby sediment sources (eroding hillsides). These few catchbasins (about 10% of the total catchbasins) accounted for more than half of the total Surrey Downs sediment observed during that survey. They also represented about 70% of the observed increased loadings between the first winter and summer inventories.

Table 1. Accumulation Rate of Sediment in Inlet Structures in Bellevue, WA (Pitt 1985)

	Number of structures		**Sediment accumulation (L/month)**		**Approx. months to stable volume**	**Stable volume (L)**	
Surey Downs (38.0 ha)	total	per ha	per ha	per unit		per ha	per unit
Catchbasins	43	1.1	5.3	4.8	13	68	62
Inlets	27	0.7	2.0	2.8	20	40	57
Manholes	6	0.2	0.8	4.0	19	15	76
Average	76 total	2.0 total	8.1	4.2	15	123 total	62
Lake Hills (40.7 ha)							
Catchbasins	71	1.7	2.4	1.4	18	43	25
Inlets	45	1.1	1.5	1.4	14	22	20
Manholes	15	0.4	1.6	4.0	23	36	90
Average	131 total	3.2 total	5.5	1.7	18	101 total	31

Besides inlet sediment surveys, pipe surveys were also conducted during the study. Very few storm drain pipes in either test area had slopes less than one percent, the assumed critical slope for sediment accumulation. In Lake Hills, the average slope of the 118 pipes surveyed was about 4 percent. Only 7 percent of the Lake Hills pipes had slopes less than 1 percent. The 75 pipes surveyed in Surrey Downs had an average slope of 5 percent, and 12 percent had slopes less than 1 percent. A pipe sediment survey was conducted in October of 1980. Very little sediments were found in the storm drains in either study area. The pipes that had significant sediment were either sloped less than 1-1/2 percent or located close to a source of sediment. The characteristics of the pipe sediments were similar to the characteristics of the sediment from closeby inlets and catchbasins, indicating a common source, and the eventual movement of the inlet sediments. The volume of sediment found in the Lake Hills pipes was about 1-1/2 m^3, or about 0.04 m^3 per ha, or about 40% of the total sediment in the inlet structures (about 0.1 m^3 per ha stable volume). This was equilivent to about 70 kg of sediment/ha. In Surrey Downs, much more sediment was found in the storm drainage: more than 20 m^3 of sediment was found in the pipes, or about 0.5 m^3/ha or 1,000 kg/ha. Most of this sediment was located in silted-up pipes along 108th St. and Westwood Homes Rd. which were not swept and were close to major sediment sources.

The chemical quality of the captured sediment was also monitored. Tables 2 and 3 show the sediment quality for Surrey Downs inlet structures sampled between January 13 and June 17, 1981. The sediment quality shown on this table is very similar to the street dirt chemical quality that was simultaneiously sampled and analyzed. It is interesting to note that the COD values increase with increasing particle sizes, likely corresponding to increasing amounts of organic material in the larger material. The nutrients are generally constant with size, while the metal concentrations are much higher for the smaller particles, as expected for street dirt. As indicated on the table, the lead values were likely much higher when these samples were taken compared to current conditions. Current outfall lead concentrations are now about 1/10 of the values they were in the early 1980s.

Table 2. Chemical Quality of Bellevue, WA, Inlet Structure Sediment (mg constituent/kg total solids) (Pitt 1985)

Particle Size (µm)	COD	TKN	TP	Pb*	Zn
<63	160,000	2,900	880	1,200	400
61-125	130,000	2,100	690	870	320
125-250	92,000	1,500	630	620	200
250-500	100,000	1,600	610	560	200
500-1,000	140,000	1,600	550	540	200
1,000-2,000	250,000	2,600	930	540	230
2,000-6,350	270,000	2,500	1,100	480	190
>6,350	240,000	2,100	760	290	150

* these lead values are much higher than would be found for current samples due to the decreased use of leaded gasoline since 1981.

Table 3. Annual Calculated Accumulation of Pollutants in Bellevue, WA, Inlet Structures (Pitt 1985)

	Total solids						
	L/ha/yr	kg/ha/yr	COD kg/ha/yr	TKN kg/ha/yr	TP kg/ha/yr	Pb kg/ha/yr	Zn kg/ha/yr
Surrey Downs	96	147	37	0.17	0.25	0.49	0.10
Lake Hills	66	100	7.5	0.07	0.07	0.07	0.02

Catchbasin Sediment and Supernatnant Quality and Potential Water Quality Degradation

Catchbasins have been found to be effective in accumulating pollutants associated with coarser runoff solids. Large accumulations in total and suspended solids (up to 45% reduction for low gutter flows) were indicated by a number of studies (such as Pitt 1979, Aronson, *et al.* 1983, and Pitt 1985). Pitt (1985) found that catchbasins will accumulate sediments until the sediments reach about 60% of the total sump capacity (or to about 0.3 m under the catchbasin outlet). After that level, the sediment is at an equilibrium, with scour balancing new deposition.

Butler, *et al*. (1995) found that the median particle size of the sump particles was between about 300 and 3,000 µm, with less than 10% of the particles smaller than 100 µm, near the typical upper limit of particles found in stormwater. Catchbasin sumps therefore trap the largest particles that are flowing in the water, and allow the more contaminated finer particles to flow through the inlet structure. Butler, *et al.* (1995) and Butler and Karunaratne (1995) present sediment trapping equations for sediment in gully pots (small catchbasin sumps), based on detailed laboratory tests. The sediment trapping performance was found to be dependent on the flow rate passing through the gully pot, and to the particle sizes of the sediment. The depth of sediment in the gully pot had a lesser effect on the capture performance. In all cases, decreased flows substantially increased the trapping efficiency and larger particles had substantially greater trapping efficiency than smaller particles, as expected.

Pitt (1985) statistically compared catchbasin supernatant with outfall water quality and did not detect any significant differences. However, Butler, *et al.* (1995) have recently investigated gully pot supernatant water and have found that it may contribute to the more greatly polluted first flush of stormwater reported for some locations. Specific problems have been associated with the anaerobic conditions that rapidly form in the supernatant water during dry weather, causing the release of oxygen demanding material, ammonium, and possible sulfides. These anaerobic conditions also affect the bioavailability of the heavy metals in the flushed water.

New Jersey Catchbasin Insert Tests

More recent catchbasin inlet tests were conducted by Pitt, *et al.* (1994 and 1999) as part of an EPA-sponsored research project to examine critical source areas and to develop appropriate controls. The activities summarized in this section included the testing of three representative stormwater control devices that were located at storm drainage inlets. Two proprietary devices utilized screening and filtering (using filter fabric and a coarser mesh). A conventional catchbasin inlet, having a sump, was also tested for comparison. These inlet devices were located in in a residential area of Stafford Township, NJ, to evaluate their removal effectiveness for stormwater pollutants. Twelve manually collected paired samples collected at each device represented composite inflow and outflow stormwater. The samples were split into filtered and unfiltered components for extensive analyses of conventional and toxic pollutants. A total of 144 analyses were therefore conducted for each parameter that was partitioned into unfiltered and filtered portions, and 72 analyses were conducted for the samples that were not partitioned. In addition to these field tests, controlled tests were also conducted in the laboratory to further evaluate filter fabrics used in some inlet devices. The experimental design was capable of identifying significant pollutant removals of at least 15 to 50% at a 95% confidence level, depending on the pollutant. The only significant pollutant removals were found during tests of a conventional catchbasin having a suitable sump. The median removal rates were about 30% for suspended solids, about 40% for turbidity, about 15% for color, and about 20% for total solids. No other pollutants were found to be significantly reduced. However, the coarse screened inlet device was found to significantly reduce the discharges of trash and other large debris. Unfortunately, flows passing through trapped material caught on the screen had increased concentrations of suspended solids and volatile solids, probably due to washing of decomposing large organic material through the screen. The filter fabrics tested in the laboratory showed about 50% removals for suspended solids and COD, but they rapidly clogged, significantly shortening their run times and minimizing any benefit from their use. This research was conducted in partial fulfillment of cooperative agreement no. CR 819573 under the sponsorship of the U.S. Environmental Protection Agency.

Samples were analyzed for a wide range of toxicants using very low detection limits (about 1 to 10 µg/L). The constituents analyzed include heavy metals and organics (phenols, PAHs, phthalate esters, and chlorinated pesticides). Particle size distributions, using a Coulter Multi-Sizer II, were also made, in addition to conventional analyses for COD, major ions, nutrients, suspended and dissolved solids, turbidity, color, pH, and conductivity. All samples were also partitioned into filterable and non-filterable components before COD and toxicant analyses to better estimate fate and treatability. All samples were also screened using the Microtox toxicity test to measure relative reductions in toxicity associated with the inlet devices.

Description of Inlet Devices Tested

Conventional Catchbasin with Sump

A sump was installed in the bottom of an existing storm drain inlet by digging out the bottom and placing a section of 36 inch concrete pipe on end. The outlet pipe was reduced to 8 inches and the sump depth was 36 inches. Inlet water was sampled before entering the catchbasin, while outlet water was sampled after passing through the unit.

Filter Fabric Unit

A filter fabric unit, having a set of dual horizontal trays, each containing about 0.1 m^2 of filter fabric, was retro-fitted into one of the existing inlets for testing. When the filter fabric clogged on the upper tray, the stormwater overflowed through a small rectangular weir, onto another similar tray located beneath the upper tray. Again, paired samples were obtained above and under the unit for analyses. According to the manufacturer, this system can handle up to 300 gallons per minute. The unit tested has mostly been replaced by the manufacture with a new type of catchbasin filter that also includes a selection of filtering media.

Coarse Filter Unit

A coarse filter was also retro-fitted into an existing stormdrain inlet. This unit used a relatively coarse foam material (about 1mm cell diameter and 8 mm thick) that was sandwiched between two pieces of galvanized screening for support. This unit was fitted in the inlet, sealed along the bottom and sides on the outlet side, forcing any water through the unit before it was discharged. The filter was placed in front of the catchbasin outlet in a near vertical position. Its main purpose was to filter debris, including leaves and grass clippings, from stormwater. As with the other units, the inlet and outlet water was simultaneously sampled for analyses.

Results

Measuring the reduction of pollutants by the storm drainage inlet devices was the primary objective of this study. Table 4 indicates the percent reduction in pollutant concentrations from influent to effluent. The numbers in parenthesis indicate the probability that the influent is equal to the effluent. Probability values less than 0.05 are indicated in bold print. Table 5 lists the mean concentrations in the influent and effluent samples, along with the observed coefficients of variations. The catchbasin with the sump was the only device that showed important and significant removals for several pollutants:

> total solids (0 to 50%, average 22%).
> suspended solids (0 to 55%, average 32%).
> turbidity (0 to 65%, average 38%).
> color (0 to 50%, average 24%).

Figures 1 through 3 are example box plots for the three inlet devices for suspended solids and COD.

Table 4 highlights the significant concentration changes observed for the three storm drain inlet devices tested, using a paired sample, Wilcoxon Signed Rank test. Only the catchbasin with a sump was found to have significant (and important) concentration reductions for major parameters. The coarse screen unit showed consistent washout of material, while both the coarse screen unit and the catchbasin showed slight increases for several major ions, most likely associated with contact with concrete and other drainage system materials. The catchbasin performance (32% removal for suspended solids) is within the range reported during earlier studies, as reported previously.

None of the other parameters or inlet devices demonstrated significant differences between the influent and effluent water (at the 95% confidence level, or better), except for the filter fabric unit which showed a small removal for nitrate. Several significant and large increases in major ion concentrations were noted for the catchbasin (bicarbonate, magnesium, and calcium) and for the coarse screen unit (bicarbonate, and potassium). These increases, which are not believed to be very important, may have been due to the runoff water being affected by the concrete in the inlet devices. These increases are likely part of the general process where runoff water increases its alkalinity and buffer capacity as it flows through urban areas.

The significant and large increases in total solids, suspended solids, volatile solids, and conductivity for the coarse screen unit imply washout of decomposing collected organic solids (mostly leaves). The coarse screen unit traps large debris, including decomposable organic material, behind the screen. Stormwater then flows through this material as it passes through the screen, as in most inlet screening/filtering devices. If not frequently removed, this organic material may decompose and wash through the screen in subsequent storms. The large debris was not represented in the influent water samples, but after partial decomposition, this material could have added to the solids concentrations in the effluent samples.

The catchbasin did not exhibit this increase in solids concentrations likely because the collected material was trapped in the sump and not subjected to water passing through the material. Previous catchbasin tests (Pitt 1979) found that collected debris easily or commonly scoured from the sump. The filter fabric unit did not exhibit this increase in solids, possibly because it trapped relatively small amounts of debris, and the overflow weirs allowed the subsequent stormwater to flow over the trapped debris instead of being forced through the debris.

Summary of Recently Reported Litter and Floatable Controls

Characterization of Litter and Floatables in Storm Drainage

The report titled *The Removal of Urban Litter from Stormwater Conduits and Streams* (Armitage, *et al.* 2000a and 2000b) noted that little data was available on the nature and quantity of litter in stormwater drainage systems (Marais, *et al.* 2001). Armitage and Rooseboom (2000a) demonstrated that large quantities of litter are being transported in South African stormwater runoff, and that the amount of litter produced was related to land use, vegetation, the level of street cleaning, and type of rainfall. The benefits of litter reduction were documented using their work in Australia and New Zealand, and design equations for sizing litter traps were proposed (Armitage and Rooseboom 2000b). The Council for Scientific and Industrial Research estimated in 1991 that 780,000 tonnes of waste a year entered the drainage systems of South Africa.

The Solids Transport and Deposition Study (STDS) characterized the rates and patterns of solids transfer to, and the collection within, stormwater drain inlets located along Caltrans highway facilities (Quasebarth, *et al.* 2001). The primary objective was to determine if certain distinguishable site characteristics controlled the transport and deposition of sediment, metals, vegetation, litter, and petroleum hydrocarbons to highway drain inlets. The ANOVA results indicated that the four primary factors (erosion control/sediment loading [vegetation factor], litter management [litter factor], toxic pollutant generation potential [adjacent land use factor], and roadway design [design factor]) likely had little overall control on solids accumulation or metals mass accumulation, although roadway design and litter management were possibly important in some cases.

The principal source of litter on the Bristol Channel of the United Kingdom was expected to originate from sanitary-wastewater debris originating from CSOs (Williams and Simmons 1997a). Williams and Simmons (1999) also investigated the sources of litter in and along the river Taff, South Wales, UK. The greatest inputs of sewage-derived solids were introduced to the river by CSOs. While sewage-derived material constituted approximately 23% of all items on the river Taff, large quantities of waste, especially plastic sheeting, originated from fly tipping sites (illegally dumped rubbish in public places).

Control of Litter and Floatables in Storm Drainage Systems

Because more than 780,000 tonnes of solids is washed into the drainage systems in South Africa, the Water Research Commission of South Africa and the Cape Metropolitan Council funded a four year investigation into the reduction of urban litter in the drainage systems through the development of catchment-specific litter management plans (Armitage, *et al*. 2001). A physical model of the design of litter traps for urban storm sewers was also carried out at the hydraulic laboratories at the Universities of Cape Town and Stellenbosch (Armitage and Rooseboom 2000). They conducted a review of about 50 designs for litter traps which have been suggested for urban drainage systems. A preliminary assessment of the seven most promising trapping structures concluded that three designs, two utilizing declined self-cleaning screens, and the other using suspended screens in tandem with a hydraulically actuated sluice gate, are likely to be the optimal choice in the majority of urban drainage situations in South Africa (Armitage and Rooseboom 2000a and 2000b).

The California Department of Transportation (Caltrans) conducted a 2-year litter management pilot study in the Los Angeles area to investigate the characteristics of highway litter and the effectiveness of stormwater controls for removing the litter (Lippner, *et al*. 2001). Half the catchments were treated with one of five stormwater controls; the others were left alone for comparison. The controls tested were increased street cleaning frequency, increased frequency of manual litter pickup, a modified drain inlet, a bicycle grate inlet, and a litter inlet deflector (LID). Roughly half the freeway stormwater litter was paper, plastic, and Styrofoam. Except for cigarette butts, the origins of most of the litter could not be identified because of its small size. Of the five controls tested, only increased litter pickup and the modified drain inlet demonstrated some apparent reduction of litter in the stormwater runoff, although the data were highly variable.

Some people have suggested annually removing sediment, vegetation, and litter from storm drain inlet vaults to improve the quality of Caltrans runoff before it enters the receiving waters (Dammel, *et al*. 2001; Irgang, *et al.* 2001). In response, Caltrans implemented an annual storm drain inlet inspection and cleaning program in selected urban areas to evaluate if this practice improved stormwater quality. Catchbasins within two of the four drainage areas were cleaned at the beginning of the study, while those within the other two areas were not cleaned. Pollutant concentrations and runoff loadings were compared between the two areas. Fine particle deposits remaining in catchbasins after cleaning could cause higher pollutant concentrations and loadings for several months, when compared to areas where catchbasins were not cleaned.

Caltrans also conducted limited laboratory- and full-scale tests of inserts (Fossil Filter and StreamGuard, plus an oil/water separator) to evaluate their ability to remove trash and debris, suspended solids and oil and grease in stormwaters (Othmer, *et al*. 2001 Lau, *et al*. 2001). The results showed some reductions in metals, hydrocarbons, and solids; however, frequent flow bypasses due to clogging required more maintenance than anticipated. The oil/water separator results showed no discernable differences between influent and effluent hydrocarbon concentrations at the low levels measured.

Memon and Butler (2002) used a dynamic model to assess the impact of a series of water management scenarios on the quality of runoff discharged through catchbasins/gully pots. The simulation showed that the catchbasins/gully pots were effective at retaining solids, but they had an almost neutral performance in terms of removing dissolved pollutants. Improved solids retention was predicted if larger sumps with modified shapes were used. Lau and Stenstrom (2002) also conducted limited catchbasin insert tests to determine their ability to remove particulate pollutants, litter, and debris. Laboratory tests with used motor oil showed that the inserts could remove large amounts of oils, if present in large concentrations. Sand particles larger than the insert’s screen mesh were completely removed, as expected. Field tests showed that median oil and grease, turbidity and total suspended solids concentrations in stormwater were reduced by 30 to 50%. The inserts were more effective in reducing maximum concentrations than low or median concentrations. Some of the inserts plugged and bypassed stormwater without treatment, but did not cause any surface ponding on the streets.

Grey, *et al.* (1999) examined the role of catchbasins in the CSO floatables control program in New York City. There are approximately 130,000 catchbasins, distributed over 190,000 acres, in New York City. They found that catchbasins were simple and very effective in controlling floatable material. The most important aspect of the catchbasins for enhanced floatable control was the presence of a hood covering the catchbasin’s outlet. Their research found floatable retention efficiencies of 70 to 90% when the hoods were used. Catchbasin hoods were also very cost-effective, at a cost of about $100 per acre. New York City therefore implemented a catchbasin inspection, mapping, cleaning, and hooding program as part of its CSO control program. Newman, *et al.* (1999) also reported that New York City improved its ability to control one source of floatables to New York Harbor through its “Illegal Dumping Notification Program.” This program takes advantage of coordinated efforts between different department personnel. They found that this program likely will reduce the number of illegal dumping sites by 15%.

Phillips (1999) described how the State Government of Victoria (Australia) provided funding to develop a litter trap (the In-line Litter Separator, or ILLS). The ILLS can be retrofitted into the drainage system downstream of shopping areas for better control of floatables.

Siegel and Novak (1999) reported on the successful use of the microbial larvicide VectoLex CG (R) (*Bacillus sphaericus*) for the control of mosquitoes in 346 tested Illinois catchbasins.

CSO Floatable Controls Potentially Useful in Separate Storm Drainage Systems

The vertical (rise) velocity of CSO floatable material, in addition to other basic measurements, was investigated by Cigana, *et al.* (1999) in Montreal (Canada). They found that 80% of the floatables had a vertical velocity greater than 0.07 m/s. They also found that an exponential relationship exists for underflow baffles between the vertical velocity and the turbulent component of the horizontal velocity. Dimensioning analysis indicated that long chambers with intensive designs would be required in order to achieve an 80% floatables removal efficiency (Cigana, *et al*. 1998a, 1998b and 1998c).

Fischer and Turner (2002) reviewed the North Bergen, NJ, CSO Solids and Floatables Control Facility, which uses a system of nine Netting TrashTrap® units and one mechanical screen. Irvine (2002) described the Buffalo River (NY) floatables control program which uses a floatables trap and continuous water quality monitoring. The traps had more wood and less plastic than the floatables traps in New Jersey. The average mass trapped per unit volume was also less for the Buffalo watershed than for the two monitored New Jersey watersheds.

Suggestions for Optimal Storm Drainage Inlet Use

The best catchbasin configuration for a specific location would be dependent on site conditions and would probably incorporate a combination of features from several different inlet designs. The primary design should incorporate a catchbasin with a sump, as described by Lager, *et al.* (1977), with an inverted (hooded) outlet. Early EPA research by Lager, *et al.* (1977) found that an optimal catchbasin design should have the following dimensions: if the outlet pipe is D in diameter, its bottom should be located about 2.5D below the street level and 4D from the bottom of the catchbasin sump. The overall height of the catchbasin should therefore be 6.5D, with a diameter of 4D.

If large enough, catchbasins with sumps have been shown to provide a moderate level of suspended solids reductions in stormwater under a wide range of conditions in many studies in the U.S. and Europe. The use of filter fabrics in catchbasins is not likely to be beneficial because of their rapid clogging from retained sediment and trash. The use of coarser screens in catchbasin inlets is also not likely to result in water quality improvements, based on conventional water pollutant analyses. However, well designed and maintained screens can result in substantial trash and litter reductions. It is important that the screen not trap organic material in the flow path of the stormwater. Prior research (Pitt 1979 and 1985) has shown that if most of the trapped material is contained in the catchbasin sump, it is out of the direct flow path and unlikely to be scoured during high flows, or to degrade overlying supernatant water. Storm drainage inlet devices also should not be considered as leaf control options, or used in areas having very heavy trash loadings, unless they can be cleaned after practically every storm.

The goal is a storm drainage inlet device that:

- does not cause flooding when it clogs with debris,
- does not force stormwater through the captured material,
- does not have adverse hydraulic head loss properties,
- maximizes pollutant reductions, and
- requires inexpensive and infrequent maintenance.

The following suggestions and design guidelines should meet some of these criteria. These options are all suitable for retro-fitting into existing simple storm drainage inlets. However, the materials used should be concrete, plastic, aluminum or stainless steel; especially do not use galvanized metal or treated woods. Catchbasins in newly developing areas could be more optimally designed than the suggestions below, especially by enlarging the sumps and by providing large and separate offset litter traps.

1) The basic catchbasin (having an appropriately sized sump with a hooded outlet) should be used in most areas. This is the most robust configuration. In almost all full-scale field investigations, this design has been shown to withstand extreme flows with little scouring losses, no significant differences between supernatant water quality

and runoff quality, and minimal insect problems. It will trap the bed-load from the stormwater (especially important in areas using sand for traction control) and will trap a low to moderate amount of suspended solids (about 30 to 45% of the annual loadings). The largest fraction of the sediment in the flowing stormwater will be trapped, in preference to the finer material that has greater amounts of associated pollutants. Their hydraulic capacities are designed using conventional procedures (grating and outlet dimensions), while the sump is designed based on the desired cleaning frequency. Figure 4 is this basic recommended configuration.

An estimate of the required catchbasin sump volume and cleanout frequency can be estimated. For example, assume the following conditions:

- paved drainage area: 1.3 ha (3.3 acres),
- 250 mg/L suspended solids concentration, and
- 640 mm (25 in) of rain per year.

The sediment accumulation rate in the catchbasin sump would be about 0.24 m^3/ha (3.4 ft^3/acre) of pavement per year. For a 1.3 ha (3.3 acre) paved drainage area, the annual accumulation would therefore be about 0.3 m^3 (10 ft^3). The catchbasin sump diameter should be at least four times the diameter of the outlet pipe. Therefore, if the outlet from the catchbasin is a 250 mm (10 in) diameter pipe, the sump should be at least 1 m (40 in) in diameter (having a surface area of 0.8 m^3, or 9 ft^2). The annual accumulation of sediment in the sump for this situation would therefore be about 0.4 m (1.3 ft). If the sump was to be cleaned about every two years, the total accumulation between cleanings would therefore be about 0.8 m (2.6 ft). An extra 0.3 m (1 ft) of sump depth should be provided as a safety factor because of potential scour during unusual rains. Therefore, a total sump depth of at least 1.1 m (3.6 ft) should be used. In no case should the total sump depth be less than about 1 m (3 ft) and the sump diameter less than about 0.75 m (2.5 ft). This would provide an effective sump volume of about 0.8 m^3 (9 ft^3) assuming a safety factor of about 1.6.

2) A relatively safe add-on to the basic recommended configuration is an adverse slope inclined screen covering the outlet side of the catchbasin, as shown in Figure 5. The inclined screen would be a relatively coarse screening that should trap practically all trash of concern. The bottom edge of the inclined screen would be solidly attached to the inside wall of the catchbasin below the inverted outlet. The screen would tilt outwards so it covers the hooded outlet. The sides of the screen need to be sealed against the side of the catchbasin. The top edge of the screen would extend slightly above the normal water surface. A solid top plate would extend out from the catchbasin wall on the outlet side covering the top opening of the inclined screen. This plate would overhang the top of the screen, but provide a slot opening above the screen for an overflow in case the screen was clogged. The slot opening should be several inches high and extend the width of the catchbasin. This design will also capture grit and the largest suspended solids, plus much of the trash. This design would allow the trapped material to fall into the sump instead of being forced against the screen by out-flowing water.

3) Another option that may be suitable for trapping large litter, such as Styrofoam cups and fast food wrappings, and that also minimizes flow obstructions, uses a bar screen. The inclined coarse screen, described in the above option, will trap smaller litter, such as cigarette butts. This is the same catchbasin inlet with sump and inclined coarse screen as shown above, but it also has a bar screen under the whole area of the inlet grating, especially under large curb openings. In almost all cases, storm drainage inlets have gratings that have moderate sized openings which would prevent large trash from entering the inlet. However, most also have wide openings along the curb face where litter can be washed into the inlet. The bar screen is designed to capture litter that would enter through the wide openings. The bar screen is steeply sloped towards a covered litter trap, preferably in an adjacent chamber.

The bars should be spaced no less than ¼ inch and possibly as much as one inch apart, as the objective is to capture large debris. Water passing through the bars should wash the debris towards the covered litter trap, with minimal clogging problems. The covered litter trap should be as large as possible and located above the water level, with drain holes. Since much of the debris would be floatables, any underwater storage volume would have minimal benefit. A nylon net bag, for example, could be inserted into a frame to make litter removal easy and to allow drainage. The litter trap is covered and offset to minimize water flowing directly through it and it is held above the water to minimize water contact with the litter before it is removed.

Plastic bags, large pieces of paper, and large leaves may still fall through the bar screen, or wrap around the bars and cause partial blockages. Therefore, frequent inspections and cleanups will be needed. In addition, the size of the trap is limited and may fill quickly, also requiring frequent inspections and cleanups. This option should only be used in areas having trash that needs to be controlled, not in areas having large amounts of leaf or other vegetative trash that would overload the unit. The obvious locations for this option would be in strip commercial and other downtown areas having minimal landscaping that would contribute organic debris, but having large amounts of litter. Urban freeways, downtown malls and night club districts would be examples of suitable locations. Commitments to inspect (and possibly clean) after most storms, especially those having long interevent periods where trash accumulations may be high, must be made before this option is viable.

4) The use of filter fabrics as an integral part of a storm drain inlet is not recommended. Their biggest problem is their likelihood of quickly clogging. Tests during this research showed that they may provide important reductions (about 50%) in suspended solids and COD. However, the filter fabrics can only withstand about 1 to 2 mm accumulation of sediment before they clog. This is about 4 kg of sediment per square meter of fabric. If runoff had a suspended solids concentration of 100 mg/L, the maximum loading of stormwater tolerated would be about 40 meters. For a typical application (1 ha paved drainage area to a 1 m^2 filter fabric in an inlet box), only about 5 to 10 mm of runoff could be filtered before absolute clogging.

References

Allison, R.A.; Walter, K.A.; Marx, D.; Lippner, G.; and Churchwell, R. A Method for Monitoring and Analyzing Litter in Freeway Runoff as Part of the Caltrans Litter Management Pilot Study. *2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management,* July 2000, Minneapolis, MN. American Society of Civil Engineers, CD-ROM. 2000.

Armitage, N.P., and Rooseboom, A. The Removal of Litter from Stormwater Conduits in the Developing World. *Water Sci. Technol.* (G.B.). 39, 9, 277. 1999.

Armitage, N., and Rooseboom, A. The Removal of Urban Litter from Stormwater Conduits and Streams: Paper 1 - The Quantities Involved and Catchment Litter Management Options. *Water SA*. **26**, 181. 2000a.

Armitage, N., and Rooseboom, A. The Removal of Urban Litter from Stormwater Conduits and Streams: Paper 2 - Model Studies of Potential Trapping Structures. *Water SA*. **26**, 189. 2000b.

Armitage, N.; Marais, M.; and Pithey, S. Reducing Urban Litter in South Africa through Catchment Based Litter Management Plans. *Models and Applications to Urban Water Systems, Monograph 9*. 37. 2001.

Aronson, G., D. Watson, and W. Pisano. Evaluation of Catchbasin Performance for Urban Stormwater Pollution Control. U.S. EPA. Grant No. R-804578. EPA-600/2-83-043. 78 pages. Cincinnati, June 1983.

Ashley R.M.; Hvitved-Jacobsen, T.; Vollertsen, J.; McIlhatton, T.; and Arthur S. Sewer Solids Erosion, Washout, and a New Paradigm to Control Solids Impacts on Receiving Waters. *Proc. the Eighth International Conference on Urban Storm Drainage*. August 30 – September 3, 1999, Sydney, Australia. Edited by IB Joliffe and JE Ball. The Institution of Engineers Australia, The International Association for Hydraulic Research, and The International Association on Water Quality, 171. 1999.

Ashley, R.; Crabtree, B.; and Fraser, A. Recent European Research into the Behavior of Sewer Sediments and Associated Pollutants and Processes. *2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management,* July 2000, Minneapolis, MN. American Society of Civil Engineers, CD-ROM. 2000.

Ashley, R.M.; Dudley, J.; Vollertsen, J.; Saul, A.J.; Blanksby, J.R.; Jack, A. The effect of extended in-sewer storage on wastewater treatment plant performance. *Water Science and Technology*, **45**(3), 239-246. 2002.

Butler, D. and S.H.P.G. Karunaratne. “The suspended solids trap efficiency of the roadside gully pot.” Wat. Res. Vol. 29, No. 2. pp. 719-729. 1995.

Butler, D., Y. Xiao, S.H.P.G. Karunaratne, and S. Thedchanamoorthy. "The gully pot as a physical and biological reactor." Wat. Sci. Tech. Vol. 31, No. 7, pp. 219-228. 1995.

Cigana, J.; Couture, M.; Lefebvre, G.; and Marche, C. Evidence of a Critical Velocity in Underflow Baffle Design for Floatables Control in Combined Sewer Overflows (CSOs). Proc. Adv. in Urban Wet Weather Pollut. Reduction, Cleveland, Ohio, WEF (CP3805), 275. 1998a.

Cigana, J.; Lefebrve, G.; Marche, C.; and Couture, M. Design Criteria of Underflow Baffles for Control of Floatables. *IAWQ 19th Biennial Int. Conf.*, Vancouver, Can., 8, 58. 1998b.

Cigana, J.; Lefebrve, G.; Marche, C.; and Couture, M. Design Criteria of Underflow Baffles for Control of Floatables. *Water Sci. Technol.* (GB), 38, 10, 57. 1998c.

Cigana, J.; Couture, M.; Meunier, C.; and Comeau, Y. Determination of the Vertical Velocity Distribution of Floatables in CSOs. *Water Sci. Technol.* (G.B.). 39, 2, 69. 1999.

Cigana, J.F.; Lefebvre, G.; and Marche, C. Experimental Capture Efficiency of Floatables using Underflow Baffles. *Collection Systems Wet Weather Pollution Control: Looking into Public, Private, and Industrial Issues*, May 2000, Rochester, NY. Water Environment Federation, CD-ROM. 2000.

Cigana, J.; Lefebvre, G.; and Marche, C. Critical Velocity of Floatables in Combined Sewer Overflow (CSO) Chambers. *Water Sci. Tech*. **44**:287. 2001.

Dammel, E.E.; Berger, B.J.; Regenmorter, L.C.; and Lippner, G.S. Evaluating Drain Inlet Cleaning as a Stormwater Best Management Practice. *5th International Conf.: Diffuse/Nonpoint Pollution and Watershed Management*. CD-ROM. 2001.

Davis, D.P.; MacArthur, D.; Martin, S. CSO floatables abatement: How Onondaga County is screening, booming and bagging its way to floatables control. *WEF/CWEA Collection Systems 2002 Conf. Proc., May 2002*. Water Environment Federation. CD-ROM. 2002.

EDP (Environmental Design and Planning, Inc.). Evaluation of Catchbasin Monitoring. Contract No. R804578010, U.S. Environmental Protection Agency, Cincinnati, Ohio, March 1980.

Fischer, R.; Turner, R. Operation and maintenance experience with CSO Floatables control facilities. *WEF/CWEA Collection Systems 2002 Conf. Proc., May 2002*. Water Environment Federation. CD-ROM. 2002.

Grey, G. and Oliveri, F. Catchbasins - Effective Floatables Control Devices. Proc. Adv. in Urban Wet Weather Pollut. Reduction , Cleveland, Ohio, WEF (CP3805), 267. 1998.

Grey, G.M.; Oliveri, F.; and Rozelman, S. The Role of Catchbasins in a CSO Floatables Control Program. *Proc. Water Environ. Fed. 72nd Annu.Conf. Exposition*, [CD-ROM], New Orleans, LA. 1999.

Grottker, M. "Pollutant removal by gully pots in different catchment areas." The Science of the Total Environment. Vol. 93. pp. 515-522. 1990.

Irgang, L.M.; Atasi, K.Z.; and Scholl, J.E. Effects of a Catchbasin Cleaning on Stormwater Quality: a BMP Demonstration Project. *WEFTEC 2001 Conf. Proc*. CD-ROM. 2001.

Irvine, K.N. Chapter 10: Buffalo River floatables control and continuous water quality monitoring. *Best Modeling Practices for Urban Water Systems.* Vol. 10 in the Monograph Series. W. James, Ed. 151. 2002.

Lager, J.A., W.G. Smith, W.G. Lynard, R.M. Finn, and E.J. Finnemore. Urban Stormwater Management and Technology: Update and Users' Guide. U.S. Environ. Protection Agency, EPA-600/8-77-014, 313 p. Cincinnati, Ohio, September 1977.

Lau, S.L., and Stenstrom, M.K. Solid-phase Extraction for Oil and Grease Analysis. *Water Environ. Res.*, **69**, 3, 368. 1997.

Lau, S.L.; Khan, E.; and Stenstrom, M.K. Catchbasin Inserts to Reduce Pollution from Stormwater. *Water Sci. Tech*. **44**:23. 2001.

Lippner, G.; Johnston, J.; Combs, S.; Walter, K.; and Marx, D. Results of California Department of Transportation Litter Management Pilot Study. *Transportation Res. Record*. **1743**:10. 2001.

Marais, M.; Armitage, N.; and Pithey, S. A Study of the Litter Loadings in Urban Drainage Systems - Methodology and Objectives. *Water Sci. Tech*. **44**:99. 2001.

Memon, F.A.; Butler, D. Assessment of gully pot management strategies for runoff quality control using a dynamic model. *Science of the Total Environment*, **295**(1-3), 115-129. 2002.

Newhouse, W.R.; Maisch, F.E.; Bizzarri, R.E. Hydraulic Design Provides Low Maintenance CSO Floatables Control. *Proc. Water Environ. Fed. 72nd Annu.Conf. Exposition*, [CD-ROM], New Orleans, LA. 1999.

Newman, T.L.; Leo, W.M.; and Gaffoglio, R. A No Cost, Best Management Practice for Floatables Control in New York City. *Proc. Water Environ. Fed. 72nd Annu.Conf. Exposition*, [CD-ROM], New Orleans, LA. 1999.

Newman, T.L., II; Leo, W.M.; and Gaffoglio, R. Characterization of Urban-Source Floatables. *Collection Systems Wet Weather Pollution Control: Looking into Public, Private, and Industrial Issues,* May 2000, Rochester, NY. Water Environment Federation, CD-ROM. 2000.

Newman, T.L. A Methodology to Design and/or Assess Baffles for Floatables Control. *Models and Applications to Urban Water Systems, Monograph 9*. 51. 2001.

Othmer Jr., E.F.; Friedman, G.; Borroum, J.S.; and Currier, B.K. Performance Evaluation of Structural BMPs: Drain Inlet Inserts (Fossil Filter and StreamGuard) and Oil/Water Separator. *Proc. ASCE EWRI Conf.* **-** *Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges*. CD-ROM. 2001.

Phillips, D.I. A New Litter Trap for Urban Drainage Systems. *Water Sci. Technol.* (G.B.), 39, 2, 85. 1999.

Pitt, R. Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices. U.S. EPA. Grant No. S-804432. EPA-600/2-79-161. 270 pages. Cincinnati, August 1979.

Pitt, R. and G. Shawley. A Demonstration of Non-Point Source Pollution Management on Castro Valley Creek. Alameda County Flood Control and Water Conservation District (Hayward, CA) for the Nationwide Urban Runoff Program, U.S. Environmental Protection Agency, Water Planning Division, Washington, D.C., June 1982.

Pitt, R. Characterizing and Controlling Urban Runoff through Street and Sewerage Cleaning. U.S. EPA. Contract No. R-805929012. EPA/2-85/038. PB 85-186500/AS. 467 pages. Cincinnati, June 1985.

Pitt, R., S. Clark, and K. Parmer. *Protection of Groundwater from Intentional and Nonintentional Stormwater Infiltration*. U.S. Environmental Protection Agency, EPA/600/SR-94/051. PB94-165354AS, Storm and Combined Sewer Program, Cincinnati, Ohio. 187 pgs. May 1994.

Pitt, R., B. Robertson, P. Barron, A. Ayyoubi, and S. Clark. *Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT).* U.S. Environmental Protection Agency, Wet Weather Flow Management Program, National Risk Management Research Laboratory. EPA/600/R-99/017. Cincinnati, Ohio. 505 pgs. March 1999.

Quasebarth, T.; Schroeder, D.; Chappell, R.; Churchwell, R.; and Lippner, G. An Investigation of Factors Influencing Solids Transport and Deposition into Highway Drain Inlets. *Proc. ASCE EWRI Conf.* **-** *Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges*. CD-ROM. 2001.

Sartor, J. and G. Boyd. Water Pollution Aspects of Street Surface Contaminants. U.S. EPA. Contract No. 14-12-921. EPA-R2-72-081. 236 pages. Washington, D.C., November 1972.

Siegel, J.P., and Novak, R.J. Duration of Activity of the Microbial Larvicide VectoLex CG (R) (*Bacillus sphaericus*) in Illinois catchbasins and waste tires. Journal of the American Mosquito Control Association. 15, 3, 366. 1999.

Sutherland, R.C. and Jelen, S.L. Quantiyfing the optimum urban runoff pollutant load reductions associated with various street and catchbasin cleaning practices. *Proc. 9th Int. Conf. Urban Drainage – Global Solutions for Urban Drainage*. CD-ROM. 2002.

Walker, D.E.; Heath, G.R.; and Kubiak, D.A. CSO Floatables Control Using Underflow Baffles. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition*, Chicago, Ill., **2**, 665. 1997.

Walker, D. E.; Heath, G. R.; and Kubiak, D. A. (1998) Floatables Control. *Water Environ. Technol.*, 10, 2, 45. 1998.

Williams, A.T., and Simmons, S.L. Estuaries Litter at the River/beach Interface in the Bristol Channel, United Kingdom. *J. Coastal Res.* (U.K.), **13**, 4, 1159. 1997a.

Williams, A.T., and Simmons, S.L. Movement Patterns of Riverine Litter. *Water, Air, Soil Pollut*. (Neth.), **98**, 1-2, 119. 1997b.

Williams, A.T., and Simmons, S.L. Sources of Riverine Litter: The River Taff, South Wales, UK. *Water, Air, & Soil Pollution*, 112, 1-2, 197. 1999.

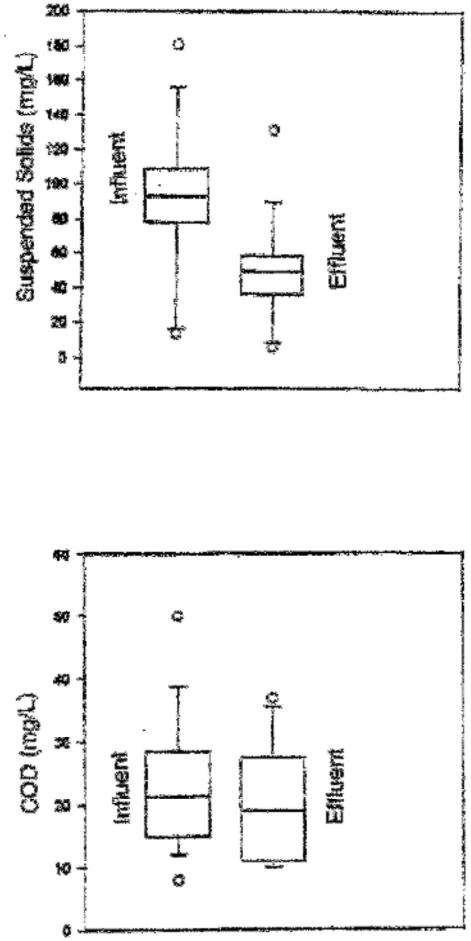


Figure 1. Box and whisker plot for catchbasin with sump.

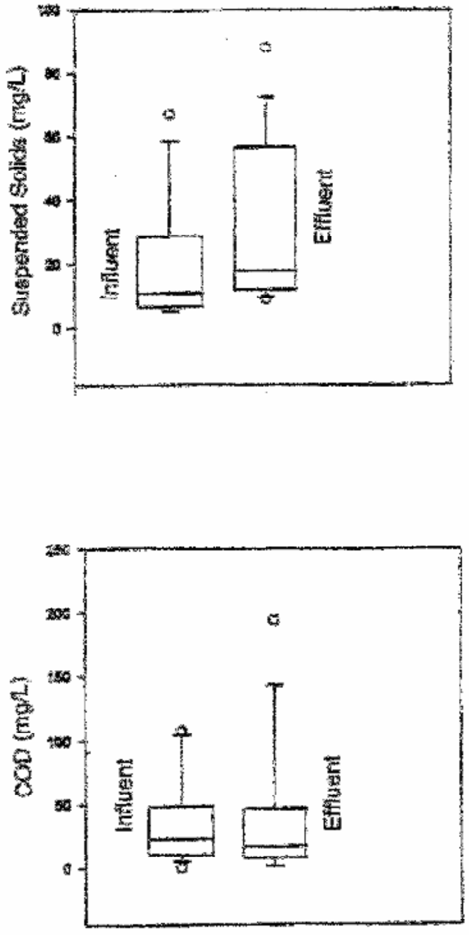


Figure 2. Box and whisker plot for coarse screen unit.

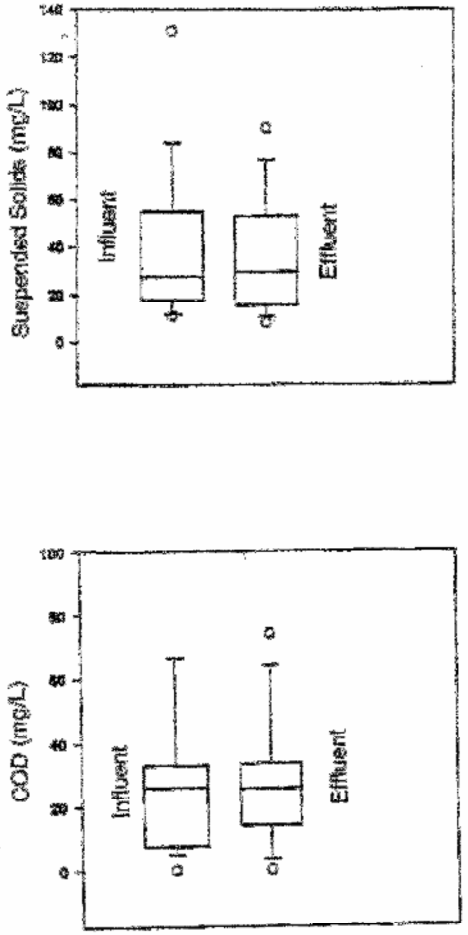


Figure 3. Box and whisker plot for filter fabric unit.

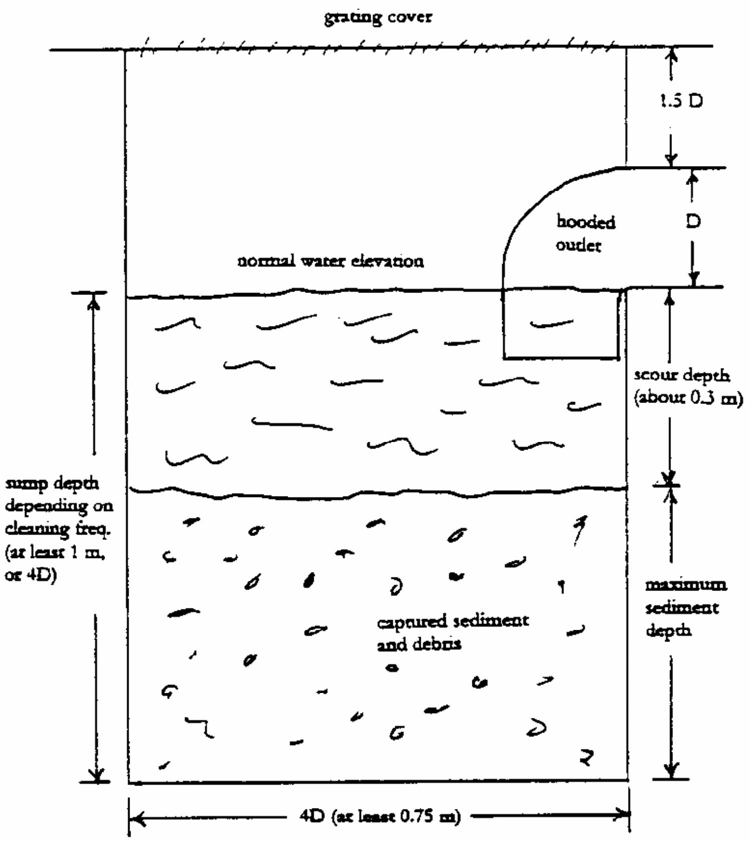


Figure 4. Conventional catchbasin with inverted sump and hooded outlet.

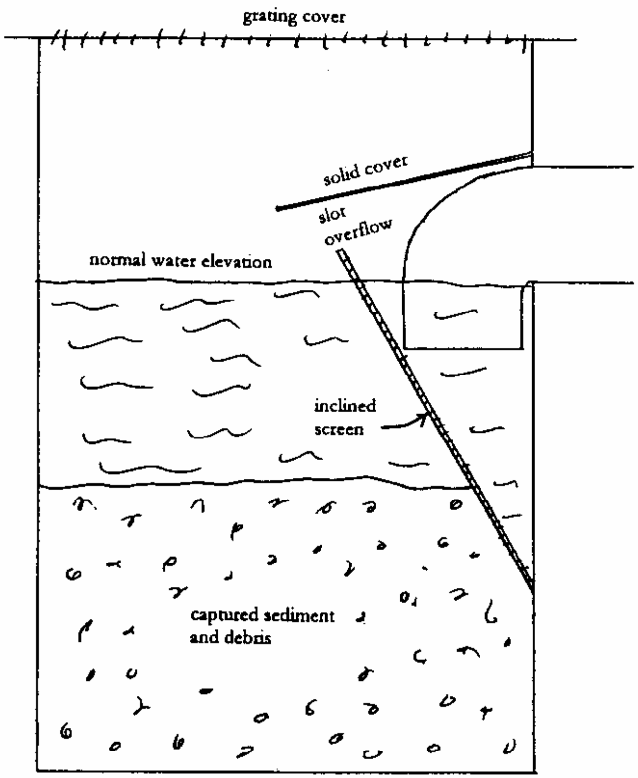


Figure 5. Conventional catchbasin with inverted sump, hooded outlet, and inclined screen.

Table 4. Storm Drain Inlet Device Performance Summary for Selected Pollutants (Percent Reduction and Statistical Probability that Difference is Random)

Pollutant	Catchbasin with Sump % Reduction (p)	Coarse Screen Unit % Reduction (p)	Filter Fabric Unit % Reduction (p)
Total Solids	22 (**0.03**)	-28 (**0.014**)	5.6 (0.28)
Dissolved Solids	8.3 (0.68)	-16 (0.13)	3.4 (0.32)
Suspended Solids	32 (**0.0098**)	-56 (**0.054**)	8.1 (0.70)
Volatile Total Solids	6.3 (0.62)	-40 (**0.049**)	0.0 (0.95)
Volatile Dissolved Solids	6.8 (0.77)	-21 (0.32)	4.4 (0.97)
Volatile Suspended Solids	34 (0.43)	-42 (0.55)	-8.3 (1.00)
Differential Volume >4 and <5	-46 (0.81)	-67 (1.00)	-2.2 (1.00)
Differential Volume >15 and <20	26 (1.00)	-23 (0.44)	43 (0.22)
Differential Volume >50 and <65	-46 (0.13)	-87 (0.23)	-23 (0.69)
Toxicity - unfiltered	7.8 (0.91)	-33 (0.15)	18 (0.20)
Toxicity - filtered	1.6 (0.92)	-2.9 (0.57)	-18 (0.62)
Turbidity - unfiltered	38 (**0.019**)	-6.6 (0.30)	0.95 (0.32)
Turbidity - filtered	34 (0.70)	12 (0.27)	-18 (0.62)
Color - unfiltered	16 (0.083)	-14 (0.15)	-1.1 (0.73)
Color - filtered	24 (**0.052**)	-36 (0.68)	-3.0 (0.85)
Conductivity - unfiltered	-11 (0.084)	-14 (**0.052**)	1.2 (0.91)
pH - unfiltered	0.2 (0.64)	-1.0 (0.10)	-0.58 (0.13)
COD - unfiltered	11 (0.47)	-19 (0.58)	-0.91 (0.85)
COD - filtered	-49 (0.42)	-36 (0.41)	19 (0.79)
Carbonate - unfiltered	-42 (0.27)	-22 (0.56)	14 (0.43)
Bicarbonate - unfiltered	-27 (**0.0024**)	-21 (**0.019**)	0.08 (0.52)
Fluoride - filtered	-5.6 (0.44)	-114 (1.00)	86 (1.00)
Chloride - filtered	-4.8 (0.97)	-11 (0.46)	0.08 (0.65)
Nitrite - filtered	all nd	all nd	all nd
Nitrate - filtered	-17 (0.12)	-12 (0.28)	6.1 (**0.0024%**)
Sulfate - filtered	-12 (0.79)	-15 (0.41)	2.6 (0.34)
Lithium - filtered	all nd	all nd	all nd
Sodium - filtered	2.8 (0.70)	-9.7 (0.30)	-1.8 (0.32)
Ammonium - filtered	-13 (0.84)	5.2 (0.64)	-19 (0.50)
Potassium - filtered	-6.6 (0.47)	-17 (**0.042**)	-7.1 (0.34)
Magnesium - filtered	-15 (**0.0034**)	-25 (0.24)	2.7 (0.91)
Calcium - filtered	-31 (**0.0005**)	-24 (0.21)	0.8 (0.52)

Table 5. Mean and Coefficient of Variation of Influent and Effluent Samples

		Catchbasin		Coarse Screen Unit		Filter Fabric Unit	
		Mean	**COV**	**Mean**	**COV**	**Mean**	**COV**
Total Solids, mg/L	Influent	122	0.54	73	0.94	86.1	0.57
	Effluent	95	0.52	93	0.92	81.2	0.56
Dissolved Solids, mg/L	Influent	48	0.51	51	1.00	46.2	0.71
	Effluent	44	0.49	59	1.08	44.6	0.76
Suspended Solids, mg/L	Influent	75	0.75	22	0.96	39.9	0.85
	Effluent	51	0.62	34	0.79	36.7	0.72
Volatile Total Solids, mg/L	Influent	28	0.52	20	0.85	21.9	0.49
	Effluent	26	0.51	28	0.77	21.9	0.46
Volatile Dissolved Solids, mg/L	Influent	12	0.41	9	0.87	9.58	0.74
	Effluent	11	0.78	11	1.00	9.17	0.66
Volatile Suspended Solids, mg/L	Influent	16	0.90	12	1.03	12	0.86
	Effluent	15	0.59	17	0.83	13	0.59
Differential Solids Volume >4 and <5 um	Influent	2,219,178	0.89	405,759	0.75	3,477,951	0.92
	Effluent	3,250,458	0.68	678,747	0.95	3,553,763	0.86
Differential Solids Volume >15 and >20 um	Influent	2,821,656	1.47	3,019,100	0.85	2,341,839	0.88
	Effluent	2,096,122	1.15	3,715,339	0.83	1,328,777	0.28
Differential Solids Volume >50 and >65um	Influent	706,713	1.62	1,144,943	0.82	288,749	0.66
	Effluent	1,034,633	1.66	2,139,047	0.97	354,953	0.82
Toxicity - unfiltered, I25% reduction	Influent	9.7	0.92	14.7	0.55	19.3	0.69
	Effluent	8.9	0.91	19.5	0.80	15.8	1.69
Toxicity - filtered, I25% reduction	Influent	15.3	0.60	20.0	0.81	20.3	0.49
	Effluent	15.1	0.67	20.6	0.71	23.9	0.69
Turbidity - unfiltered, NTU	Influent	59.9	0.79	6.9	0.94	21.0	0.69
	Effluent	37.1	0.79	7.3	0.78	20.8	0.78
Turbidity - filtered, NTU	Influent	5.0	0.98	0.678	0.77	1.7	0.92
	Effluent	3.3	1.38	0.597	0.59	1.4	0.72
Color - unfiltered, HACH	Influent	62.6	0.54	25.0	0.85	37.3	0.43
	Effluent	52.6	0.56	28.6	0.83	37.7	0.46
Color - filtered, HACH	Influent	26.2	0.43	19.2	1.19	16.9	0.40
	Effluent	19.9	0.40	20.3	1.18	16.4	0.38
Conductivity - unfiltered, µS/cm	Influent	56.3	0.61	79.0	0.93	71.8	0.69
	Effluent	62.6	0.55	90.4	0.99	71.0	0.71

Table 5. Mean and Coefficient of Variation of Influent and Effluent Samples (Continued)

		Catchbasin		Coarse Screen Unit		Filter Fabric Unit	
		Mean	**COV**	**Mean**	**COV**	**Mean**	**COV**
pH - Unfiltered	Influent	6.96	0.02	6.66	0.03	6.89	0.02
	Effluent	6.95	0.03	6.73	0.03	6.93	0.02
COD - unfiltered, mg/L	Influent	22.8	0.50	35.8	1.03	27.3	0.92
	Effluent	20.3	0.48	42.6	1.38	27.6	0.78
COD - filtered, mg/L	Influent	10.0	0.86	26.6	1.32	15.2	1.20
	Effluent	14.9	1.00	36.1	1.72	12.3	1.29
Carbonate - unfiltered, mg/L	Influent	0.01	0.97	0.005	0.44	0.012	0.72
	Effluent	0.02	0.73	0.006	0.72	0.010	0.65
Bicarbonate - unfiltered, mg/L	Influent	22.26	0.22	14.28	0.28	18.27	0.27
	Effluent	28.20	0.25	17.31	0.32	18.26	0.23
Fluoride - filtered, mg/L	Influent	0.018	2.04	0.003	1.99	0.007	2.30
	Effluent	0.019	2.04	0.011	1.70	0.001	2.38
Chloride - filtered, mg/L	Influent	4.951	0.62	5.151	1.15	7.11	1.17
	Effluent	5.187	0.61	5.739	1.09	7.11	1.17
Nitrate - filtered mg/L	Influent	1.067	0.82	2.457	1.24	1.07	1.29
	Effluent	1.247	0.72	2.749	1.30	1.59	1.37
Sulfate - filtered mg/L	Influent	3.856	0.49	5.800	1.06	4.07	1.08
	Effluent	4.328	0.59	6.651	1.18	3.96	1.14
Sodium - filtered, mg/L	Influent	3.771	0.49	3.946	1.14	6.67	0.88
	Effluent	3.665	0.50	4.327	1.16	6.79	0.87
Ammonium - filtered, mg/L	Influent	0.219	1.03	0.287	1.01	0.37	1.01
	Effluent	0.248	0.91	0.272	1.01	0.44	0.93
Potassium - filtered, mg/L	Influent	0.834	0.37	0.443	0.67	0.48	0.78
	Effluent	0.889	0.44	0.519	0.71	0.51	0.70
Magnesium - filtered, mg/L	Influent	0.725	0.60	0.645	0.78	0.51	0.71
	Effluent	0.834	0.55	0.808	1.06	0.50	0.76
Calcium - filtered, mg/L	Influent	3.60	0.35	3.438	0.65	2.82	0.54
	Effluent	4.72	0.32	4.247	0.82	2.84	0.57
Lead - unfiltered µg/L	Influent	5.28	1.06	3.45	1.79	6.25	1.30
	Effluent	3.36	0.74	4.97	1.41	7.04	0.92
Lead - filtered µg/L	Influent	1.37	1.15	0.944	1.65	0.60	1.11
	Effluent	1.25	1.17	0.587	1.98	0.79	1.31
Copper - unfiltered µg/L	Influent	30.63	0.26	37.79	0.49	24.9	0.38
	Effluent	25.58	0.32	36.34	0.48	24.6	0.39
Copper - filtered µg/L	Influent	15.5	0.59	21.62	0.92	15.8	0.70
	Effluent	16.5	0.55	20.79	0.74	16.5	0.60