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Module 4a: Public Works Practices

Introduction

Numerous public works practices affect stormwater quality and quantity. The most significant being the design, construction, and maintenance of the stormwater drainage system. Obviously, managing stormwater quantity to provide drainage and to prevent flooding must remain the primary objective of stormwater drainage systems. Over the years, addressing this objective, while ignoring other receiving water beneficial uses, has resulted in many problems. It is now possible, as demonstrated by numerous examples from around the world, to provide stormwater drainage that addresses these numerous, and seeming conflicting objectives. Discussions on drainage systems, specifically grass swales, are in a later module.

Other public works practices affecting stormwater quality may include: landscaping maintenance on public rights-of-ways, roadway and utility construction erosion controls, erosion controls at sanitary landfills, runoff control at public works garages, street cleaning, and storm drainage inlet cleaning. This module specifically addresses street and catchbasin cleaning, two commonly recommended stormwater control practices because of their apparent ease of use in existing built-up areas. The control of inappropriate discharges to storm drainage systems is also summarized.

Street Cleaning

There have been many misconceptions concerning street cleaning as a potential stormwater management control. This module examines the limitations of street cleaning, and describes how it can be more effective. Street cleaning plays an important role in most public works departments as an aesthetic and safety control measure. Street cleaning is also important to reduce massive dirt and debris buildups present in the spring in the northern regions. Leaf cleanup by street cleaning is also necessary in most areas in the fall.

Early Street Cleaning Tests

Factors significantly affecting street cleaning performance include particle loadings, street texture, street moisture, parked car conditions, and equipment operating conditions (Pitt 1979). If the 500-1000 µm particle loadings are less than about 75 kg/curb-km for smooth asphalt streets, conventional street cleaning does little good. As the loadings increase, so do the removals: with loadings of about 10 kg/curb-km, less than 25 percent removals can be expected, while removals of up to about 50 percent can be expected if the initial loadings are as high as 40 kg/curb-km for this particle size. The removal performance decreases substantially for smaller particles, including those that are most readily washed off the street during rains and contribute to stormwater pollution.

Much information concerning street cleaning productivity has been collected previously in many areas. The early tests (Sartor and Boyd 1972) were conducted in controlled strips using heavy loadings of simulates instead of natural street dirt at typical loadings. Later tests, from the mid 1970s to mid 1980s, were conducted in large study areas (20 to 200 ha) by measuring actual street dirt loadings on many street segments immediately before and after typical street cleaning. These large-scale tests are of most interest, as they monitored both street surface phenomena and runoff characteristics. Many if these tests were conducted as part of the Nationwide Urban Runoff Program (NURP) directed by the EPA (1983). The following list briefly describes these large-scale street cleaning performance tests:

- San Jose, California, tests during 1976 and 1977 (Pitt 1979) considered different street textures and conditions; multiple passes, vacuum-assisted, and two types of mechanical street cleaners; a wide range of cleaning frequencies; and effects of parking densities and parking controls.

- Castro Valley, California, NURP tests during 1979 and 1980 (Pitt and Shawley 1982) considered street slopes, mechanical and regenerative-air street cleaners, and several cleaning frequencies.

- Reno/Sparks, Nevada, tests during 1981 (Pitt and Sutherland 1982) considered different land-uses, street textures, equipment speeds, multiple passes, full-width cleaning, and vacuum and mechanical street cleaners in an arid and dusty area.

- Bellevue, Washington, NURP tests from 1980 through 1982 (Pitt 1985) considered mechanical, regenerative-air, and modified regenerative-air street cleaners, different land-uses, different cleaning frequencies, and different street textures in a humid and clean area.

- Champaign-Urbana, Illinois, NURP tests from 1980 and 1981 (Terstriep, *et al.* 1982) examined spring clean-up, different cleaning frequencies and land-uses, and used a three-wheel mechanical street cleaner.

- Milwaukee, Wisconsin, NURP tests from 1979 to 1983 (Bannerman, *et al.* 1983) examined various street cleaning frequencies at five study sites, including residential and commercial land-uses and large parking lots.

- Winston-Salem, North Carolina, NURP tests during their NURP project examined different land-uses and cleaning frequencies.

Typical street dirt total solids loadings show a "saw-tooth" pattern with time between street cleaning and rain washoff events (Figure 1).

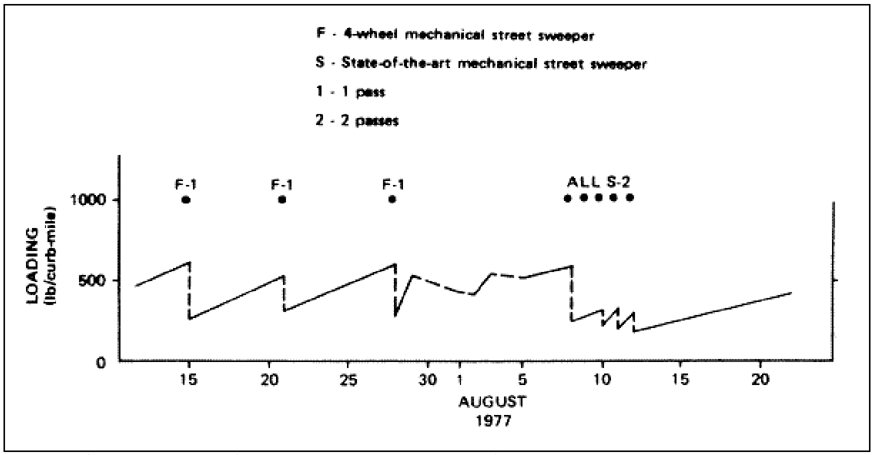


Figure 1. Saw-tooth pattern for accumulation and removal of street dirt by street cleaning, smooth asphalt street test area in San Jose, California, USA. (Pitt 1979).

Rain removes very little of the large particles, but can remove large amounts (about 50%) of the finest particles whose diameter is less than 100μm (Bannerman *et al.*, 1983; Pitt 1985) which contribute most significantly to stormwater pollution. Unfortunately, typical mechanical street cleaners remove much of the coarser particles in the path of the street cleaner, but they remove very little of the finer particles (Sartor and Boyd 1972; Pitt 1979 and 1985) (Table 1).

Table 1. Removal Rates for Street Cleaning for Various Particle Sizes

Particle size (μm)	Removal efficiency (%)
0 – 40	16
40 – 100	0
100 – 250	48
250 – 850	60
850 – 2,000	67
>2,000	79

Factors significantly affecting street cleaning performance include (Pitt 1979):

- particle loadings;
- street texture;
- moisture;
- parked car conditions;
- equipment operating conditions
- frequency of cleaning.

Increased street cleaning performance was obtained with a modified regenerative-air street cleaner, especially at low loadings during tests in Bellevue, WA, as shown in Figure 2 (Pitt 1985). The improved performance was much greater for fine particle sizes, where the mechanical street cleaner did not remove any significant quantities of material. The larger particles were removed with about the same effectiveness for both street cleaner types. Other tests of vacuum street cleaners (Pitt 1979) and regenerative-air street cleaners (Pitt and Shawley 1982) showed very few differences in performance when compared to more standard mechanical street cleaners. These earlier tests were conducted in areas having much higher street loadings, especially for the larger particle sizes, than in Bellevue. It is expected that the high loadings of the large particles armored the small particles, so they could not be removed. For high loadings, it may be best to use a tandem operation, where the streets are first cleaned with a mechanical street cleaner to remove the large particles, followed by a regenerative-air street cleaner to remove the finer particles.

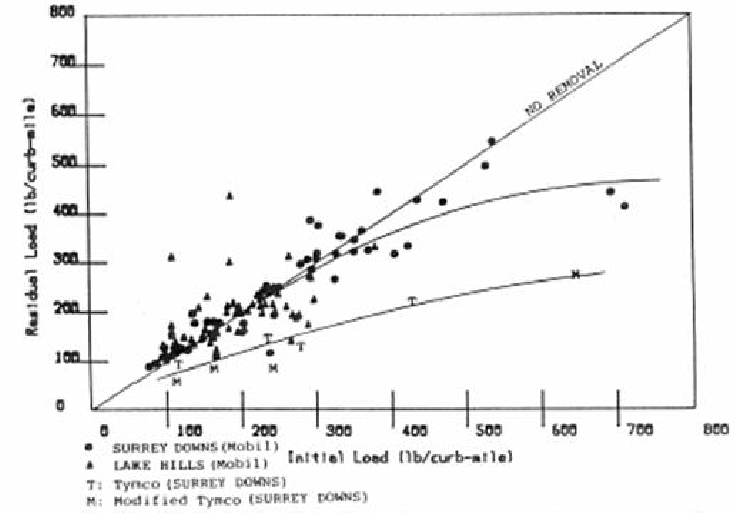


Figure 2. Street cleaner performance as measured in Bellevue, WA (Pitt 1985)

The pollutant removal benefits of street cleaning are a function of the relative contributions of pollutants from the streets. Table 2 shows the approximate contributions of different pollutants from different source areas in a mostly residential area in Bellevue, WA (Pitt 1985). Streets make up less than ten percent of the total solids, but much larger amounts of the COD and heavy metals. If street cleaning was able to completely clean the streets, the total solids at the outfall would have only a very small reduction. These contributions are very site specific, depending mostly on the rains in an area, the amount of directly connected impervious areas, and the erodability of the local soils.

Table 2. Pollutant Contributions from Residential Source Areas, Bellevue, WA (Pitt 1985)

	Percent Outfall Contributions from Source Areas					
Source Area	Total Solids	COD	Phosphate	TKN	Pb	Zn
Streets	9%	45%	32%	31%	60%	44%
Driveways and parking lots	6	27	21	20	37	28
Rooftops	<1	3	5	10	<1	24
Front yards	44	13	22	19	<1	2
Back yards	39	12	20	20	<1	2
Vacant lots and parks	2	<1	<1	<1	<1	<1

In Paris, intensive studies of the Le Marais catchment have included detailed investigations of the solids and metals found from road surface inputs. The daily suspended solids pollutant load removed was found to be similar to the amount removed during one rainfall event. It was also shown that the total mass of pollutants stored on the street surface is significant, even with street cleaning, and the effects of street cleaning may therefore be limited (Gromaire, *et al.* 2000).

Effects of Street Cleaning on Outfall Stormwater Conditions

Figure 3 shows the measured washoff of street surface particulates during actual rains in Bellevue, WA (Pitt 1985). While conventional street cleaning equipment is effective in removing large particles, rains are most effective in removing small particles. Therefore, much of the street dirt that is removed by conventional street cleaning equipment would not contribute to outfall discharges. Pitt (1979) conducted mass balances of street dirt material, showing that much of the material would be removed from the street through fugitive dust, from the turbulence of winds and road traffic. This material can be blown several tens of meters from roads, usually to adjacent landscaped areas.

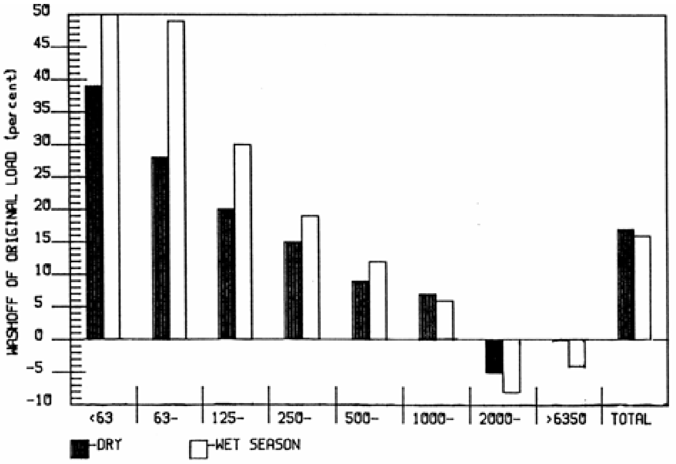


Figure 3. Washoff of street dirt particulates during monitored rains, Bellevue, WA (Pitt 1985).

During NURP (EPA 1983) the many street cleaning projects also compared outfall discharges from areas undergoing various amounts of street cleaning. Figure 4 is an example for Bellevue, WA, showing paired outfall solids concentration values, separated into the appropriate street cleaning categories, and the final fitted regression lines. This final data plot and analysis for the Bellevue street cleaning tests show that the benefits of street cleaning during these tests are ambiguous, although the statistical significance of the results are quite valid. When “no controls” were being used in both areas simultaneously, the outfall total solids concentrations were very similar. When street cleaning was being conducted in Surrey Downs and no controls were occurring in the other watershed, the Surrey Downs outfall total solids concentrations were a constant 100 mg/L (COV of 0.34), irrespective of Lake Hills concentrations. This implies potentially large street cleaning benefits for some of the events having the highest total solids concentrations. These results are both reasonable and support an acceptable hypotheses. Unfortunately, the contrasting situation where street cleaning occurred in Lake Hills and no controls occurred in Surrey Downs indicated almost no change in outfall total solids concentrations. It is possible that some features of the Lake Hills test area hindered street cleaning performance, but that is unlikely due to the careful selection and study of the test sites during this monitoring program. The conclusion is that the beneficial results of street cleaning were not repeatable, even when using a high level of control of the variables, and when obtaining large amounts of data.

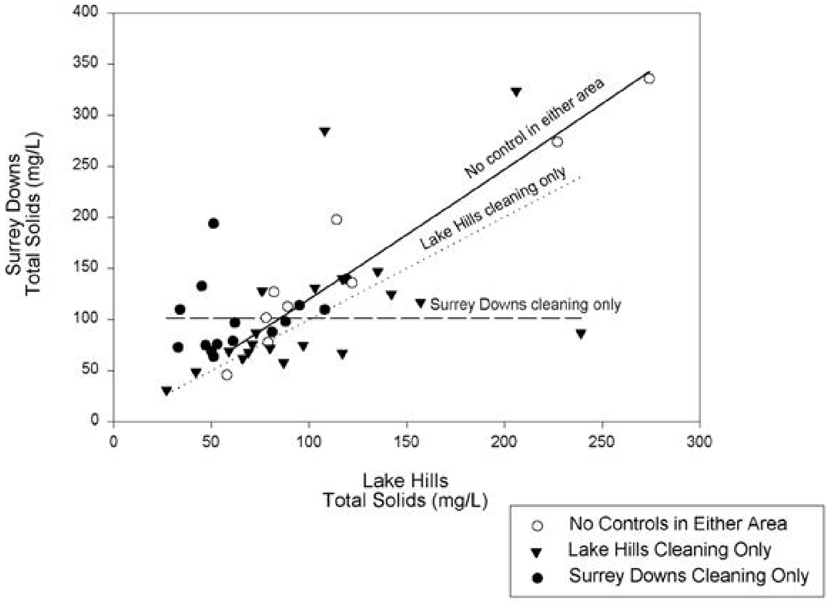


Figure 4. Final suspended solids plots for test and control sites, separated by treatment categories, and showing most appropriate regression relationships (data from Pitt 1985).

Recent Tests using Advanced Street Cleaning Equipment

Sutherland and Jelen (1996) have conducted more recent tests using a new style street cleaner that shows promise in removing large fractions of most of the street dirt particulates, even the small particles that are most heavily contaminated and most likely to be washed off streets during rains. The Enviro Whirl I, from Enviro Whirl Technologies, Inc. (Schwarze Industries) is capable of much improved removal of fine particles from the streets compared to any other street cleaner tested. This machine was also able to remove large fractions of the fine particles, even in the presence of heavy loadings of large particles. This is a built-in tandem machine, incorporating rotating sweeper brooms within a powerful vacuum head. Further field tests were conducted by the USGS and the WI Dept. of Natural Resources (Waschbusch 2003) at a highway test site in Milwaukee, WI. The following section describes some of the results of these tests.

The study area selected was one of the busiest stretches of roadway in the state of Wisconsin on interstate 894 in West Allis, just west of Milwaukee. Within the study area, a test basin and a control basin were monitored. The test basin had the street cleaning program implemented, while the control basin did not. The pavement on this stretch of freeway is concrete and was last resurfaced in the mid 1990s and was considered in generally good condition. The shoulders are concrete and were installed in the late 1970's.

The test basin had a drainage area of 4.56 acres, comprised of 4.31 acres of highway surface, 1.56 of which is shoulder, 2.67 is driving lane and 0.08 acres is median. In addition, 0.25 is non-highway grassy area. The control basin had a drainage area of 5.51 acres, comprised of 3.46 acres of highway surface, 1.45 of which is shoulder, 1.95 is driving lane and 0.06 acres is median. In addition, 2.05 is non-highway grassy area. Because of the slow speed of the street cleaner, only the highway shoulders were swept.

Samples of street dirt were collected from the outside shoulders using a 6-in. wide wand attached to a 9-gal. Milwaukee wet-dry vacuum cleaner. During each sample collection, the wand was pulled from the curb to the edge of the traffic lane twenty four times in each basin, twelve in each traffic direction, similar to the technique used by Pitt (1979) and Bannerman (1983). The street dirt samples were weighed, dried at 105°C and then reweighed. The samples were then sent to the University of Wisconsin Department of Geology Quaternary Laboratory in Madison, Wis., for sieving into 6.37-2.0 mm, 2.0-1.0 mm, 1-0.5 mm, 0.50-0.25 mm, 0.25-0.125 mm, 0.125-0.0625 mm, < 0.0625 mm size fractions. Two samples of the dirt collected by the Enviro Whirl street sweeper were also brought to the Wisconsin State Laboratory of Hygiene for Toxicity Characteristic Leachate Procedure (TCLP) analysis. Area velocity flow meters were the primary method used to measure the flow in the stormdrains. Flow composite water quality samples were collected using refrigerated automatic samplers.

Changes in dirt mass on the street surfaces before and after sweeping are shown in Figure 5. The average change in street dirt mass before and after sweeping at the test site was a 25 percent reduction. At the control site, the average change in street dirt mass on the same collection dates as the test site (although no street sweeping was occurring) was an increase of 160 percent. Figure 5 shows that the Enviro Whirl removed about half of the street dirt when the loading was about 500 lb/curb-mile, and reduced to about zero near 100 lb/curb-mile. This performance plot is very similar to the earlier regenerative air street cleaning tests conducted in Bellevue, and is much better than the conventional mechanical street cleaning equipment shown earlier.

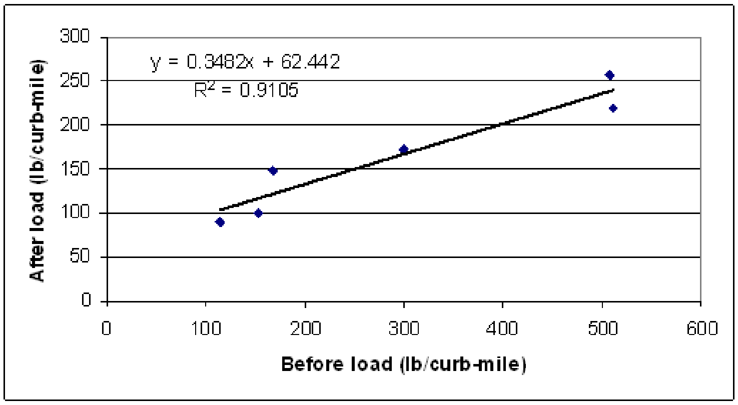


Figure 5. Before and after street dirt loadings during Enviro Whirl street cleaning tests in Milwaukee, WI (Waschbusch 2003).

The runoff particle size data from these test sites indicate that the highway runoff has larger particles than those typically seen at other USGS stormwater sites.

The findings of the study indicate that freeway sweeping with a high efficiency sweeper can be a good stormwater control practice for the reduction of stormwater pollutants from urban freeways. The study showed, at the 90% confidence interval, that there was a reduction in the total suspended sediment concentration in the runoff from a freeway section swept once per week with the EnvoroWhirl EV2 sweeper. Statistically, the suspended solids reduction was a 40% removal at a 80% confidence level. This was the first time that stormwater was statistically shown to benefit from street cleaning. This was likely due to the high efficiency of the street cleaning equipment used, especially for the small particle sizes, and the restricted study area that emphasized the paved area. It is expected that larger pollutant reductions could be obtained at a site having better roadway access for the street cleaning equipment.

A new generation of high efficiency street cleaners has recently been developed in Europe. Utilizing captive hydrology (recycling water), pavements are subjected to a deep cleaning using a high-pressure water-blasting system situated immediately in front of a powerful waste recovery vacuum. In a single pass, fine contaminants are blasted from the pavement and are collected in a debris container, along with the water, thus leaving the surface cleaned. There is no residual loading on the pavement after treatment with this type of equipment. The pavement is also left in a near-dry condition. Refer to this website for more information: http://www.veegservice.nl/.

High efficiency street cleaners are appropriate for roadways that are sufficiently accessible, need fine particulate removal (<250 µm), and for which a sufficient frequency of cleaning can be maintained to achieve proper removals of street dirt. Mobility is a big advantage, as cleaning can be done where and when needed. This equipment is not currently available in the United States and it is much more expensive than traditional cleaners. It performs other tasks, such as porous pavement cleaning and rejuvenation, traditional pavement rejuvenation, paint removal, and surface layer stripping for overlays. A captive hydrology machine is currently being used as the pollutant control device for the controversial Cross Israel Highway.

Summary of Street Cleaning for Stormwater Quality Control

Much information has been collected concerning the effects of street cleaning as a stormwater control practice. Unfortunately, there has been no statistically validated improvement in runoff quality associated with street cleaning until recently where newly available equipment has been tested. Conventional mechanical street cleaning equipment has been most effective in removing large particulates, while rains preferentially remove the small particles. The new equipment promises greater benefits because it can also remove the small particles, and can handle heavy loadings of larger debris. However, even with increased removal of fines, any street cleaning technology will be limited by the amount of the outfall pollutants originating from streets. In many areas, streets contribute less than half of the stormwater pollutants. Street cleaning equipment can be most effective in areas where the surface to be cleaned is the major source of contaminants. These areas include freeways, large commercial parking lots, and paved storage areas.

Storm Drainage System Inlet Structures

This module summarizes the results from past and recent studies of catchbasin inlet devices, and recommends 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 inlet, 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).

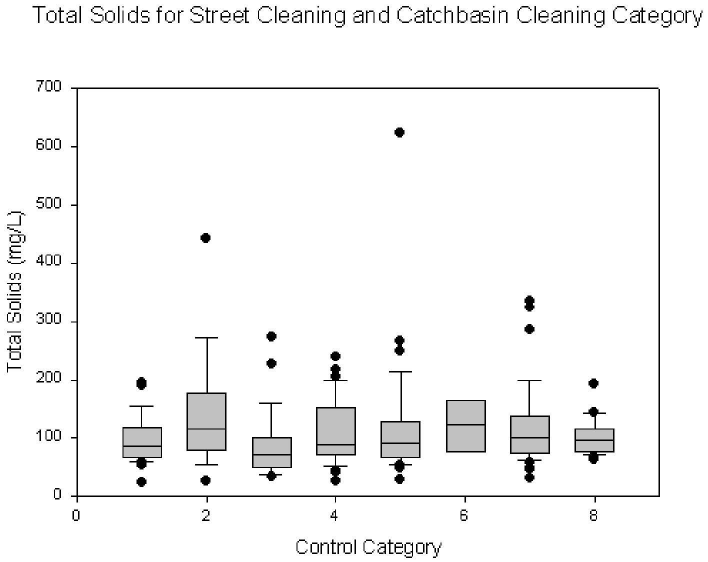
7. Bellevue, Surrey Downs, Full CB, No SC (catchbasins were full and not accumulating material, and no street cleaning operations were being conducted during this project period).

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:



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 fluorescent 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 3. 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 was 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 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 3. 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 close-by 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 equivalent 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 4 and 5 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 simultaneously 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 4. 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 5. 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

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 g/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 storm drain 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 6 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 7 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%).

Table 6. Storm Drain Inlet Device Performance Summary for Selected Pollutants (Percent Reduction and Statistical Probability that Difference is Random)

P 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) -14 (15.1%)	-1.1 (0.73) -1.1* (73.3%)
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 7. 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 7. 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

Figures 6 through 8 are example box plots for the three inlet devices for suspended solids and COD.

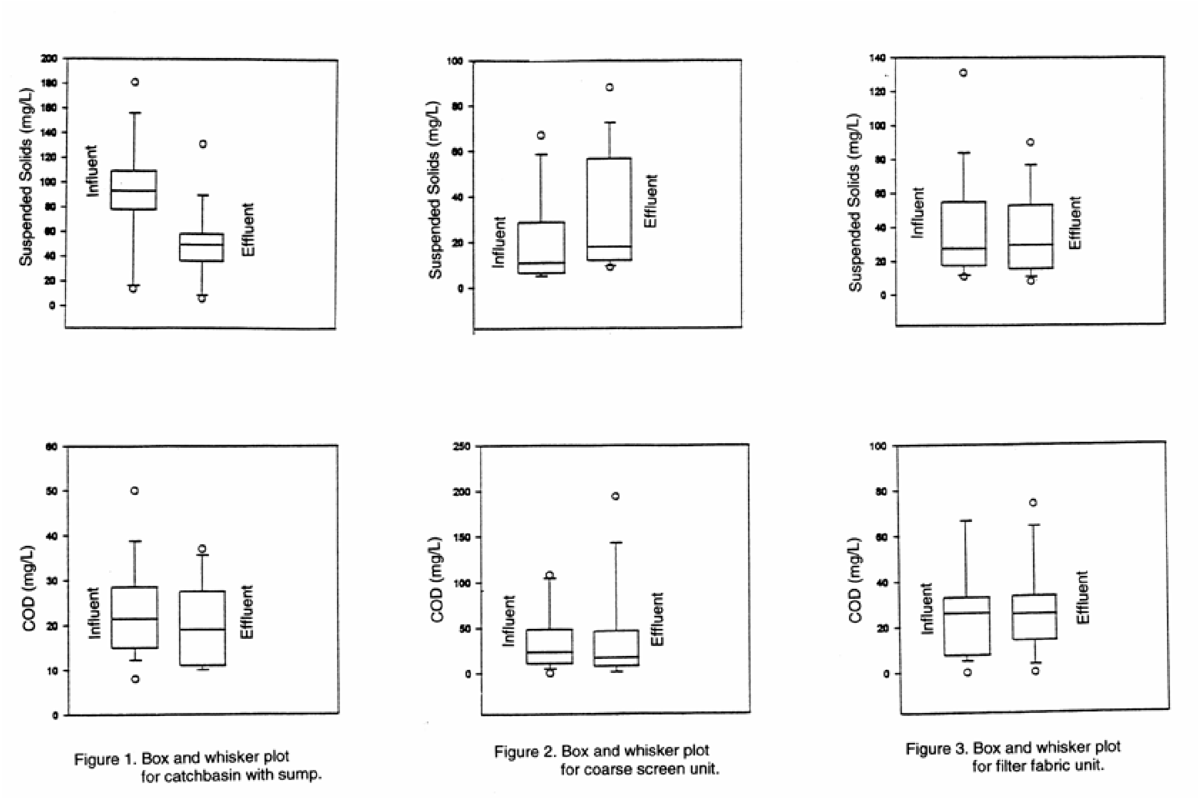


Figure 1. Box and whisker plot for catchbasin with sump.

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

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

Figures 6 – 8. Performance of catchbasin inlet devices.

Table 7 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 stormwater (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 9 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 10. 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.

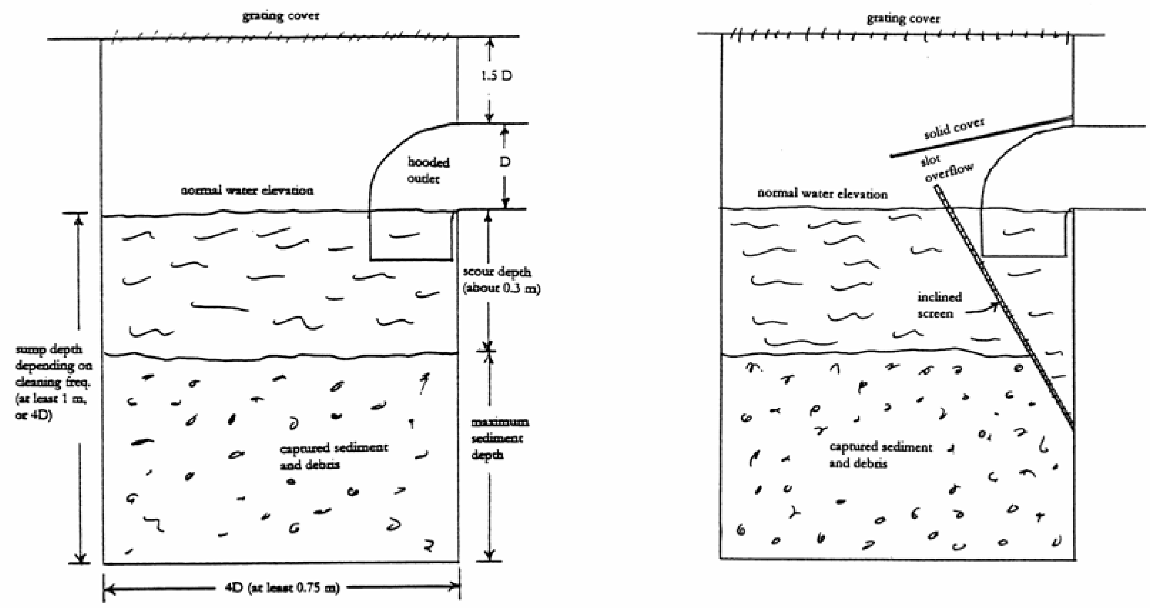


Figure 4. Conventional catchbasin with inverted sump and hooded outlet.

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

Figures 9 and 10. Recommended catchbasin configurations.

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.

Catchbasin Sediment and Supernatant 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.

Summary of Sewerage Inlet Devices as Stormwater Control Practices

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), and an inverted (hooded) outlet. 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. Tests during recent research found that stormwater flowing through decomposing leaves degraded the stormwater quality (Pitt, *et al.* 1997). 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.

Dry-Weather Pollutant Entries into Sewerage Systems

Introduction

This paper describes procedures that have been used to identify sources of inappropriate ("illicit") discharges in storm drainage systems. Also included is a review of emerging techniques that may also be useful, especially in future years as they become more accessible and become proven technologies. This paper also describes a series of tests where the original methods developed previously for EPA (Pitt, *et al.* 1993), along with selected new procedures, were examined using almost 700 stormwater samples collected from telecommunication manholes from throughout the U.S. About ten percent of the samples were estimated to be contaminated with sanitary sewage using these methods, similar to what is expected for most stormwater systems. The original methods are still recommended as the most useful procedure for identifying contamination of storm drainage systems, with the possible addition of specific tests for *E. coli* and enterococci and UV absorbance at 228 nm. Most newly emerging methods require exotic equipment and unusual expertise and are therefore not very available, especially at low cost and with fast turn-around times for the analyses. These emerging methods may therefore be more useful for special research projects than for routine screening of storm drainage systems.

The Center for Watershed Protection (CWP) and Dr. Robert Pitt with the University of Alabama were funded by EPA to complete a technical assessment of techniques and methods for identifying and correcting illicit and inappropriate discharges geared towards NPDES Phase II communities (CWP and Pitt 2004). The project team developed guidance on methods and techniques to identify and correct illicit connections, tested the efficacy of the draft guidance in different communities, completed a final "User's Manual for Identifying and Correcting Illicit and Inappropriate Discharges," and conducted training and dissemination.

Urban stormwater runoff includes waters from many other sources which find their way into storm drainage systems, besides from precipitation. There are cases where pollutant levels in storm drainage are much higher than they would otherwise be because of excessive amounts of contaminants that are introduced into the storm drainage system by various non-stormwater discharges. Additionally, baseflows (during dry weather) are also common in storm drainage systems. Dry-weather flows and wet-weather flows have been monitored during numerous urban runoff studies. These studies have found that discharges observed at outfalls during dry weather were significantly different from wet-weather discharges and may account for the majority of the annual discharges for some pollutants of concern from the storm drainage system.

There have been numerous methods used to investigate inappropriate discharges to storm drainage systems. Pitt, *et al.* (1993) and Lalor (1994) reviewed many of these procedures and developed a system that municipalities could use for screening outfalls in residential and commercial areas. In these areas, sewage contamination, along with low rate discharges from small businesses (especially laundries, vehicle repair shops, plating shops, etc.) are of primary concern. One of the earliest methods used to identify sewage contamination utilized the ratio of fecal coliform to fecal strep. bacteria. This method is still in use, but unfortunately has proven inaccurate in most urban stormwater applications. The following discussion reviews the methodology developed by Pitt, *et al.* (1993) and Lalor (1994), and some new approaches that were investigated.

Use of Tracers to Identify Sources of Contamination in Urban Drainage Systems

Investigations designed to determine the contribution of urban stormwater runoff to receiving water quality problems have led to a continuing interest in inappropriate connections to storm drainage systems. Urban stormwater runoff is traditionally defined as that portion of precipitation which drains from city surfaces and flows via natural or man-made drainage systems into receiving waters. In fact, urban stormwater runoff also includes waters from many other sources which find their way into storm drainage systems. Sources of some of this water can be identified and accounted for by examining current National Pollutant Discharge Elimination System (NPDES) permit records for permitted industrial wastewaters that can be legally discharged to the storm drainage system. However, most of the water comes from other sources, including illicit and/or inappropriate entries to the storm drainage system. These entries can account for a significant amount of the pollutants discharged from storm sewerage systems (Pitt and McLean 1986).

Permits for municipal separate storm sewers include a requirement to effectively prohibit problematic non-stormwater discharges, thereby placing emphasis on the elimination of inappropriate connections to urban storm drains. Section 122.26 (d)(1)(iv)(D) of the rule specifically requires an initial screening program to provide means for detecting high levels of pollutants in dry weather flows which should serve as indicators of illicit connections to the storm sewers. To facilitate the application of this rule, the EPA's Office of Research and Development's Storm and Combined Sewer Pollution Control Program and the Environmental Engineering & Technology Demonstration Branch, along with the Office of Water's Nonpoint Source Branch, supported research for the investigation of inappropriate entries to storm drainage systems (Pitt, *et al.* 1993). The approach presented in this research was based on the identification and quantification of clean baseflow and the contaminated components during dry weather. If the relative amounts of potential components are known, then the importance of the dry weather discharge can be determined.

The ideal tracer to identify major flow sources should have the following characteristics:

Significant difference in concentrations between possible pollutant sources;
Small variations in concentrations within each likely pollutant source category;
A conservative behavior (i.e., no significant concentration change due to physical, chemical or biological processes); and,
Ease of measurement with adequate detection limits, good sensitivity and repeatability.

In order to identify tracers meeting the above criteria, literature characterizing potential inappropriate entries into storm drainage systems was examined. Several case studies which identified procedures used by individual municipalities or regional agencies were also examined.

Selection of Parameters for Identifying Inappropriate Discharge Sources. Table 8 is an assessment of the usefulness of candidate field survey parameters in identifying different potential non-stormwater flow sources. Natural and domestic waters should be uncontaminated (except in the presence of contaminated groundwaters entering the drainage system, for example). Sanitary sewage, septage, and industrial waters can produce toxic or pathogenic conditions. The other source flows (wash and rinse waters and irrigation return flows) may cause nuisance conditions, or degrade the ecosystem. The parameters marked with a plus sign can probably be used to identify the specific source flows by their presence. Negative signs indicate that the potential source flow probably does not contain the listed parameter in adverse or obvious amounts, and may help confirm the presence of the source by its absence. Parameters with both positive and negative signs for a specific source category would not likely be very helpful due to likely wide variations expected.

Table 8. Candidate Field Survey Parameters and Associated Non-Stormwater Flow Sources

Parameter	Natural Water	Potable Water	Sanitary Sewage	Septage Water	Indus. Water	Wash Water	Rinse Water	Irrig. Water
Fluoride	-	+	+	+	+/-	+	+	+
Hardness change	-	+/-	+	+	+/-	+	+	-
Surfactants	-	-	+	-	-	+	+	-
Florescence	-	-	+	+	-	+	+	-
Potassium	-	-	+	+	-	-	-	-
Ammonia	-	-	+	+	-	-	-	+/-
Odor	-	-	+	+	+	+/-	-	-
Color	-	-	-	-	+	-	-	-
Clarity	-	-	+	+	+	+	+/-	-
Floatables	-	-	+	-	+	+/-	+/-	-
Deposits and stains	-	-	+	-	+	+/-	+/-	-
Vegetation change	-	-	+	+	+	+/-	-	+
Structural damage	-	-	-	-	+	-	-	-
Conductivity	-	-	+	+	+	+/-	+	+
Temperature change	-	-	+/-	-	+	+/-	+/-	-
pH	-	-	-	-	+	-	-	-

Note: - implies relatively low concentration
\+ implies relatively high concentration
+/- implies variable conditions

Parameters Suitable for Indicators of Contamination by Sanitary Sewage

Tracer Characteristics of Local Source Flows. Table 9 is a summary of tracer parameter measurements for Birmingham, AL. This table is a summary of the "library" that describes the tracer conditions for each potential source category. The important information shown on this table includes the median and coefficient of variation (COV) values for each tracer parameter for each source category. Appropriate tracers are characterized by having significantly different concentrations in flow categories that need to be distinguished. In addition, effective tracers also need low COV values within each flow category. The study indicated that the COV values were quite low for each category, with the exception of chlorine, which had much greater COV values. Chlorine is therefore not recommended as a quantitative tracer to estimate the flow components. Similar data must be collected in each community where these procedures are to be used. Recommended field observations include color, odor, clarity, presence of floatables and deposits, and rate of flow, in addition to the selected chemical measurements.

Table 9. Tracer Concentrations found in Birmingham, AL, Waters (mean, standard deviation, and coefficient of Variation, COV) (Pitt, *et al.* 1993 and Lalor 1994)

	Spring water	**Treated potable water**	**Laundry wastewater**	**Sanitary wastewater**	**Septic tank effluent**	**Car wash water**	**Radiator flush water**
Fluorescence	6.8	4.6	1020	250	430	1200	22,000
(% scale)	2.9	0.35	125	50	100	130	950
	0.43	0.08	0.12	0.20	0.23	0.11	0.04
Potassium	0.73	1.6	3.5	6.0	20	43	2800
(mg/L)	0.070	0.059	0.38	1.4	9.5	16	375
	0.10	0.04	0.11	0.23	0.47	0.37	0.13
Ammonia	0.009	0.028	0.82	10	90	0.24	0.03
(mg/L)	0.016	0.006	0.12	3.3	40	0.066	0.01
	1.7	0.23	0.14	0.34	0.44	0.28	0.3

Ammonia/Potassium	0.011	0.018	0.24	1.7	5.2	0.006	0.011
(ratio)	0.022	0.006	0.050	0.52	3.7	0.005	0.011
	2.0	0.35	0.21	0.31	0.71	0.86	1.0
Fluoride	0.031	0.97	33	0.77	0.99	12	150
(mg/L)	0.027	0.014	13	0.17	0.33	2.4	24
	0.87	0.02	0.38	0.23	0.33	0.20	0.16
Toxicity	<5	47	99.9	43	99.9	99.9	99.9
(% light decrease after 25	n/a	20	<1	26	<1	<1	<1
minutes, I_{25})	n/a	0.44	n/a	0.59	n/a	n/a	n/a
Surfactants	<0.5	<0.5	27	1.5	3.1	49	15
(mg/L as MBAS)	n/a	n/a	6.7	1.2	4.8	5.1	1.6
	n/a	n/a	0.25	0.82	1.5	0.11	0.11
Hardness	240	49	14	140	235	160	50
(mg/L)	7.8	1.4	8.0	15	150	9.2	1.5
	0.03	0.03	0.57	0.11	0.64	0.06	0.03
pH	7.0	6.9	9.1	7.1	6.8	6.7	7.0
(pH units)	0.05	0.29	0.35	0.13	0.34	0.22	0.39
	0.01	0.04	0.04	0.02	0.05	0.03	0.06
Color	<1	<1	47	38	59	220	3000
(color units)	n/a	n/a	12	21	25	78	44
	n/a	n/a	0.27	0.55	0.41	0.35	0.02
Chlorine	0.003	0.88	0.40	0.014	0.013	0.070	0.03
(mg/L)	0.005	0.60	0.10	0.020	0.013	0.080	0.016
	1.6	0.68	0.26	1.4	1.0	1.1	0.52
Specific conductivity	300	110	560	420	430	485	3300
(S/cm)	12	1.1	120	55	311	29	700
	0.04	0.01	0.21	0.13	0.72	0.06	0.22
Number of samples	10	10	10	36	9	10	10

Simple Data Evaluation Methods to Indicate Sources of Contamination

Negative Indicators Implying Contamination

Indicators of contamination (negative indicators) are clearly apparent visual or physical parameters indicating obvious problems and are readily observable at the outfall during the field screening activities. These observations are very important during the field survey because they are the simplest method of identifying grossly contaminated dry-weather outfall flows. The direct examination of outfall characteristics for unusual conditions of flow, odor, color, turbidity, floatables, deposits/stains, vegetation conditions, and damage to drainage structures is therefore an important part of these investigations. Table 10 presents a summary of these indicators, along with narratives of the descriptors to be selected in the field.

Table 10. Interpretations of Physical Observation Parameters and Likely Associated Flow Sources (Pitt, *et al*. 1993)

Odor - Most strong odors, especially gasoline, oils, and solvents, are likely associated with high responses on the toxicity screening test. Typical obvious odors include: gasoline, oil, sanitary wastewater, industrial chemicals, decomposing organic wastes, etc.

sewage: smell associated with stale sanitary wastewater, especially in pools near outfall.
sulfur ("rotten eggs"): industries that discharge sulfide compounds or organics (meat packers, canneries, dairies, etc.).
oil and gas: petroleum refineries or many facilities associated with vehicle maintenance or petroleum product storage.
rancid-sour: food preparation facilities (restaurants, hotels, etc.).

Color - Important indicator of inappropriate industrial sources. Industrial dry-weather discharges may be of any color, but dark colors, such as brown, gray, or black, are most common.

yellow: chemical plants, textile and tanning plants.
brown: meat packers, printing plants, metal works, stone and concrete, fertilizers, and petroleum refining facilities.
green: chemical plants, textile facilities.
red: meat packers.
gray: dairies, sewage.

Turbidity - Often affected by the degree of gross contamination. Dry-weather industrial flows with moderate turbidity can be cloudy, while highly turbid flows can be opaque. High turbidity is often a characteristic of undiluted dry-weather industrial discharges.

cloudy: sanitary wastewater, concrete or stone operations, fertilizer facilities, automotive dealers.
opaque: food processors, lumber mills, metal operations, pigment plants.

Floatable Matter - A contaminated flow may contain floating solids or liquids directly related to industrial or sanitary wastewater pollution. Floatables of industrial origin may include animal fats, spoiled food, oils, solvents, sawdust, foams, packing materials, or fuel.

oil sheen: petroleum refineries or storage facilities and vehicle service facilities.
sewage: sanitary wastewater.

Deposits and Stains - Refers to any type of coating near the outfall and are usually of a dark color. Deposits and stains often will contain fragments of floatable substances. These situations are illustrated by the grayish-black deposits that contain fragments of animal flesh and hair which often are produced by leather tanneries, or the white crystalline powder which commonly coats outfalls due to nitrogenous fertilizer wastes.

sediment: construction site erosion.
oily: petroleum refineries or storage facilities and vehicle service facilities.

Vegetation - Vegetation surrounding an outfall may show the effects of industrial pollutants. Decaying organic materials coming from various food product wastes would cause an increase in plant life, while the discharge of chemical dyes and inorganic pigments from textile mills could noticeably decrease vegetation. It is important not to confuse the adverse effects of high stormwater flows on vegetation with highly toxic dry-weather intermittent flows.

excessive growth: food product facilities.
inhibited growth: high stormwater flows, beverage facilities, printing plants, metal product facilities, drug

manufacturing, petroleum facilities, vehicle service facilities and automobile dealers.

Damage to Outfall Structures - Another readily visible indication of industrial contamination. Cracking, deterioration, and spalling of concrete or peeling of surface paint, occurring at an outfall are usually caused by severely contaminated discharges, usually of industrial origin. These contaminants are usually very acidic or basic in nature. Primary metal industries have a strong potential for causing outfall structural damage because their batch dumps are highly acidic. Poor construction, hydraulic scour, and old age may also adversely affect the condition of the outfall structure.
concrete cracking: industrial flows
concrete spalling: industrial flows
peeling paint: industrial flows
metal corrosion: industrial flows

Correlation tests were conducted to identify relationships between outfalls that were known to have severe contamination problems and the negative indicators (Lalor 1994). Pearson correlation tests indicated that high turbidity and obvious odors appeared to be the most useful physical indicators of contamination when contamination was defined by toxicity and the presence of detergents. High turbidity was noted in 74% of the contaminated source flow samples. This represented a 26% false negative rate (indication of no contamination when contamination actually exists), if one relied on turbidity alone as an indicator of contamination. High turbidity was noted in only 5% of the uncontaminated source flow samples. This represents the rate of false positives (indication of contamination when none actually exists) when relying on turbidity alone. Noticeable odor was indicated in 67% of flow samples from contaminated sources, but in none of the flow samples from uncontaminated sources. This translates to 37% false negatives, but no false positives. Obvious odors identified included gasoline, oil, sewage, industrial chemicals or detergents, decomposing organic wastes, etc.

False negatives are more of a concern than a reasonable number of false positives when working with a screening methodology. Screening methodologies are used to direct further, more detailed investigations. False positives would be discarded after further investigation. However, a false negative during a screening investigation results in the dismissal of a problem outfall for at least the near future. Missed contributors to stream contamination may result in unsatisfactory in-stream results following the application of costly corrective measures elsewhere.

The method of using physical characteristics to indicate contamination in outfall flows does not allow quantifiable estimates of the flow components and, if used alone, will likely result in many incorrect determinations, especially false negatives. These simple characteristics are most useful for identifying gross contamination: only the most significantly contaminated outfalls and drainage areas would therefore be recognized using this method.

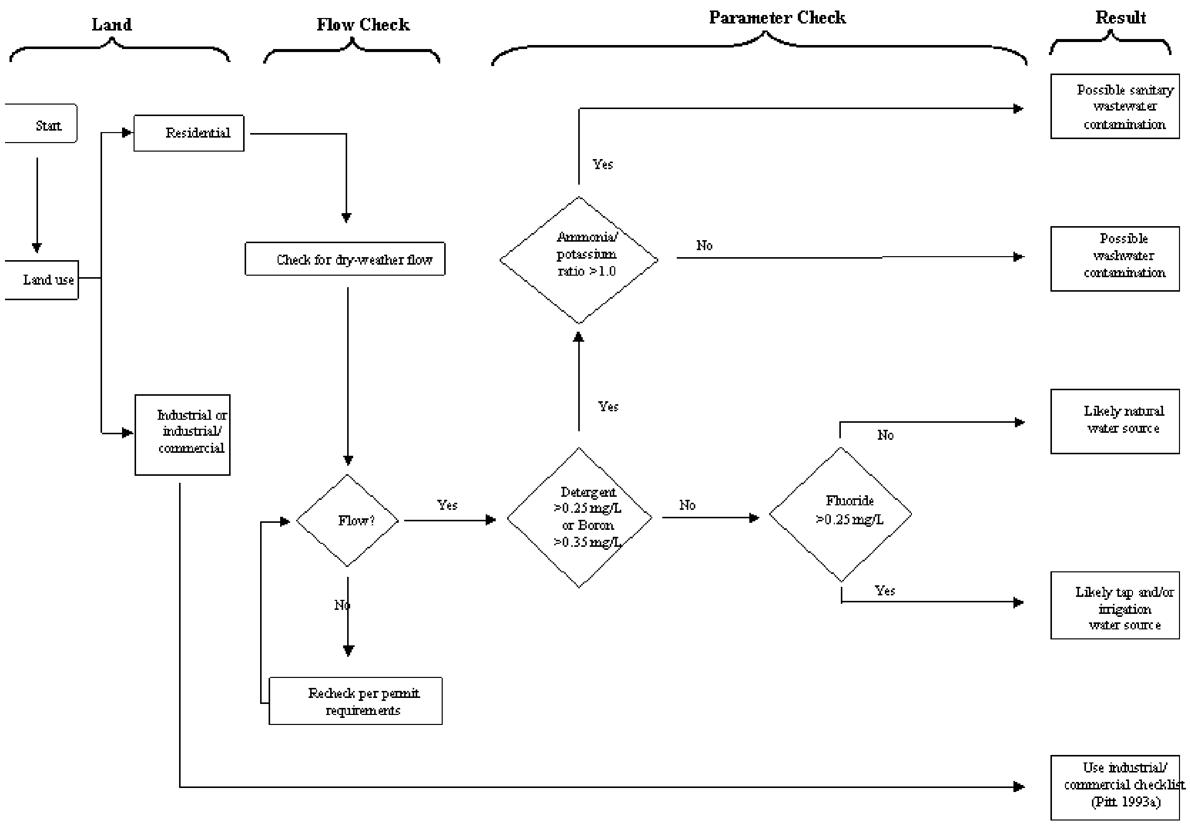
Detergents as Indicators of Contamination

Results from the Mann-Whitney U tests (Lalor 1994) indicated that samples from any of the dry-weather flow sources could be correctly classified as clean or contaminated based only on the measured value of any one of the following parameters: detergents, color, or conductivity. Color and high conductivity were present in samples from clean sources as well as contaminated sources, but their levels of occurrence were significantly different between the two groups. If samples from only one source were expected to make up outfall flows, the level of color or conductivity could be used to distinguish contaminated outfalls from clean outfalls. However, since multi-source flows occur, measured levels of color or conductivity could fall within acceptable levels because of dilution, even though a contaminating source was contributing to the flow. Detergents, on the other hand, can be used to distinguish between clean and contaminated outfalls simply by their presence or absence, using a detection limit of 0.06 mg/L. All samples analyzed from contaminated sources contained detergents in excess of this amount (with the exception of three septage samples collected from homes discharging only toilet flushing water). No clean source samples were found to contain detergents. Contaminated sources would be detected in mixtures with uncontaminated waters if they made up at least 10% of the mixture.

Flow Chart for Most Significant Flow Component Identification

A further refinement is the flow chart shown on Figure 11. This flow chart describes an analysis strategy which may be used to identify the major component of dry-weather flow samples in residential and commercial areas. This method does not attempt to distinguish among all potential sources of dry-weather flows identified earlier, but rather the following four major groups of flow are identified: (1) tap waters (including domestic tap water, irrigation water and rinse water), (2) natural waters (spring water and shallow ground water), (3) sanitary wastewaters (sanitary sewage and septic tank discharge), and (4) wash waters (commercial laundry waters, commercial car wash waters, radiator flushing wastes, and plating bath wastewaters). The use of this method would not only allow outfall flows to be categorized as contaminated or uncontaminated, but would allow outfalls carrying sanitary wastewaters to be identified. These outfalls could then receive highest priority for further investigation leading to source control. This flow chart (CWP and Pitt 2004) was designed for use in residential and/or commercial areas only.

Figure 11. Simple flow chart method to identify significant contaminating sources (CWP and Pitt 2004).



In residential and/or commercial areas, all outfalls should be located and examined. The first indicator is the presence or absence of dry-weather flow. If no dry-weather flow exists at an outfall, then indications of intermittent flows must be investigated. Specifically, stains, deposits, odors, unusual stream-side vegetation conditions, and damage to outfall structures can all indicate intermittent non-stormwater flows. However, frequent visits to outfalls over long time periods, or the use of other monitoring techniques, may be needed to confirm that only stormwater flows occur. If intermittent flow is not indicated, then the outfall probably does not have a contaminated non-stormwater source. The other points on the flow chart serve to indicate if a major contaminating source is present, or if the water is uncontaminated. Component contributions cannot be quantified using this method, and only the “most contaminated” type of source present will be identified.

If dry-weather flow exists at an outfall, then the flow should be sampled and tested for detergents. If detergents are not present, the flow is probably from a non-contaminated non-stormwater source. The lower limit of detection for detergent should be about 0.06 to 0.25 mg/L, depending on the analytical method used.

If detergents are not present, fluoride levels can be used to distinguish between flows with treated water sources and flows with natural sources in communities where water supplies are fluoridated and natural fluoride levels are low. In the absence of detergents, high fluoride levels would indicate a potable water line leak, irrigation water, or wash/rinse water. Low fluoride levels would indicate waters originating from springs or shallow groundwater. Based on the flow source samples tested in this research, fluoride levels above 0.13 mg/L would most likely indicate that a tap water source was contributing to the dry-weather flow in the Birmingham, Alabama, study area.

If detergents are present, the flow is probably from a contaminated non-stormwater source. The ratio of ammonia to potassium can be used to indicate whether or not the source is sanitary wastewater. Ammonia/potassium ratios greater than 1 would indicate likely sanitary wastewater contamination. Ammonia/potassium ratios were above 0.9 for all septage and sewage samples collected in Birmingham (values ranged from 0.97 to 15.37, averaging 2.55). Ammonia/potassium ratios for all other samples containing detergents were below 0.7, ranging from 0.00 to 0.65, averaging 0.11. One radiator waste sample had an ammonia/potassium ratio of 0.65.

Non-contaminated samples collected in Birmingham had ammonia/potassium ratios ranging from 0.00 to 0.41, with a mean value of 0.06 and a median value of 0.03. Using the mean values for non-contaminated samples (0.06) and sanitary wastewaters (2.55), flows comprised of mixtures containing at least 25% sanitary wastes with the remainder of the flow from uncontaminated sources would likely be identified as sanitary wastewaters using this method. Flows containing smaller percent contributions from sanitary wastewaters might be identified as having a wash water source, but would not be identified as uncontaminated.

General Matrix Algebra Methods to Indicate Sources of Contamination through Fingerprinting
Other approaches can also be used to calculate the source components of mixed outfall flows. One approach is the use of matrix algebra to simultaneously solve a series of chemical mass balance equations. This method can be used to predict the most likely flow source, or sources, making up an outfall sample. It is possible to estimate the outfall source flow components using a set of simultaneous equations. The number of unknowns should equal the number of equations available, resulting in a square matrix. If there are seven likely source categories, then there should be seven tracer parameters used. If there are only four possible sources, then only the four most efficient tracer parameters should be used. Only tracers that are linearly related to mixture components can be used. As an example, pH cannot be used in these equations, because it is not additive.

This method estimates flow contributions from various sources using a “receptor model”, based on a set of chemical mass balance equations. Such models, which assess the contributions from various sources based on observations at sampling sites (the receptors), have been applied to the investigation of air pollutant sources for many years (Scheff and Wadden 1993; Cooper and Watson 1980). The characteristic “signatures” of the different types of sources, as identified in the library of source flow data, allows the development of a set of mass balance equations. These equations describe the measured concentrations in an outfall’s flow as a linear combination of the contributions from the different potential sources. A major requirement for this method is the physical and chemical characterization of waters collected directly from potential sources of dry-weather flows (the “library”). This allows concentration patterns (fingerprints) for the parameters of interest to be established for each type of source. Theoretically, if these patterns are different for each source, the observed concentrations at the outfall would be a linear combination of the concentration patterns from the different component sources, each weighted by a source strength term (m_n). This source strength term would indicate the fraction of outfall flow originating from each likely source. By measuring a number of parameters equal to, or greater than, the number of potential source types, the source strength term could be obtained by solving a set of chemical mass balance equations of the type:

$$C_p = \sum_n m_n x_{pn}$$

where C_p is the concentration of parameter p in the outfall flow and x_{pn} is the concentration of parameter p in source type n .

As an example of this method, consider 8 possible flow sources and 8 parameters, as presented in Table 11. The number of parameters evaluated for each outfall must equal the number of probable dry-weather flow sources in the drainage area. Mathematical methods are available which provide for the solution of over specified sets of equations (more equations than unknowns) but these are not addressed here.

Table 11. Set of Chemical Mass Balance Equations

	Source 1	Source 2	Source 3	Source 4	Source 5	Source 6	Source 7	Source 8	Outfall
Parameter 1:	(m1)(x11) +	(m2)(x12) +	(m3)(x13) +	(m4)(x14) +	(m5)(x15) +	(m6)(x16) +	(m7)(x17) +	(m8)(x18) =	C1
Parameter 2:	(m1)(x21) +	(m2)(x22) +	(m3)(x23) +	(m4)(x24) +	(m5)(x25) +	(m6)(x26) +	(m7)(x27) +	(m8)(x28) =	C2
Parameter 3:	(m1)(x31) +	(m2)(x32) +	(m3)(x33) +	(m4)(x34) +	(m5)(x35) +	(m6)(x36) +	(m7)(x37) +	(m8)(x38) =	C3
Parameter 4:	(m1)(x41) +	(m2)(x42) +	(m3)(x43) +	(m4)(x44) +	(m5)(x45) +	(m6)(x46) +	(m7)(x47) +	(m8)(x48) =	C4
Parameter 5:	(m1)(x51) +	(m2)(x52) +	(m3)(x53) +	(m4)(x54) +	(m5)(x55) +	(m6)(x56) +	(m7)(x57) +	(m8)(x58) =	C5
Parameter 6:	(m1)(x61) +	(m2)(x62) +	(m3)(x63) +	(m4)(x64) +	(m5)(x65) +	(m6)(x66) +	(m7)(x67) +	(m8)(x68) =	C6
Parameter 7:	(m1)(x71) +	(m2)(x72) +	(m3)(x73) +	(m4)(x74) +	(m5)(x75) +	(m6)(x76) +	(m7)(x77) +	(m8)(x78) =	C7
Parameter 8:	(m1)(x81) +	(m2)(x82) +	(m3)(x83) +	(m4)(x84) +	(m5)(x85) +	(m6)(x86) +	(m7)(x87) +	(m8)(x88) =	C8

Equations of the Form $C_p = \sum_n m_n x_{pn}$

where: C_p = the concentration of parameter p in the outfall flow
m_n = the fraction of flow from source type n
x_{pn} = the mean concentration of parameter p in source type n

The selection of parameters for measurement should reflect evaluated parameter usefulness. Evaluation of the Mann-Whitney U Test results (Lalor 1994) suggested the following groupings of parameters, ranked by their usefulness for distinguishing between all the types of flow sources sampled in Birmingham, AL:

- First set (most useful): potassium and hardness
- Second set: fluorescence, conductivity, fluoride, ammonia, detergents, and color
- Third set (least useful): chlorine

Emerging Tools for Identifying Sources of Discharges

Coprostanol and Other Fecal Sterol Compounds Utilized as Tracers of Contamination by Sanitary Sewage

A more likely indicator of human wastes than fecal coliforms and other "indicator" bacteria may be the use of certain molecular markers, specifically the fecal sterols, such as coprostanol and epicoprostanol (Eaganhouse, *et al*. 1988). However, these compounds are also discharged by other carnivores in a drainage (especially dogs). A number of research projects have used these compounds to investigate the presence of sanitary sewage contamination. The most successful application may be associated with sediment analyses instead of water analyses. As an example, water analyses of coprostanol are difficult due to the typically very low concentrations found, although the concentrations in many sediments are quite high and much easier to quantify. Unfortunately, the long persistence of these compounds in the environment easily confuses recent contamination with historical or intermittent contamination.

Particulates and sediments collected from coastal areas in Spain and Cuba receiving municipal sewage loads were analyzed by Grimalt, *et al*. (1990) to determine the utility of coprostanol as a chemical marker of sewage contamination. Coprostanol can not by itself be attributed to fecal matter inputs. However, relative contributions of steroid components can be a useful indicator. When the relative concentrations of coprostanol and coprostanone are higher than their 5α epimers, or more realistically, other sterol components of background or natural occurrence, it can provide useful information.

Sediment cores from Santa Monica Basin, CA, and effluent from two local municipal wastewater discharges were analyzed by Venkatesan and Kaplan (1990) for coprostanol to determine the degree of sewage addition to sediment. Coprostanols were distributed throughout the basin sediments in association with fine particles. Some stations contained elevated levels, either due to their proximity to outfalls or because of preferential advection of fine-grained sediments. A noted decline of coprostanols relative to total sterols from outfalls seaward indicated dilution of sewage by biogenic sterols.

Other chemical compounds have been utilized for sewage tracer work. Saturated hydrocarbons with 16-18 carbons, and saturated hydrocarbons with 16-21 carbons, in addition to coprostanol, were chosen as markers for sewage in water, particulate, and sediment samples near the Cocoa, FL, domestic wastewater treatment plant (Holm, *et al.* 1990). The concentration of the markers was highest at points close to the outfall pipe and diminished with distance. However the concentration of C16-C21 compounds was high at a site 800 m from the outfall indicating that these compounds were unsuitable markers for locating areas exposed to the sewage plume. The concentrations for the other markers were very low at this station.

The range of concentrations of coprostanol found in sediments and mussels of Venice, Italy, were reported by Sherwin, *et al*. (1993). Raw sewage is still discharged directly into the Venice lagoon. Coprostanol concentrations were determined in sediment and mussel samples from the lagoon using gas chromatography/mass spectroscopy. Samples were collected in interior canals and compared to open-bay concentrations. Sediment concentrations ranged from 0.2-41.0 μg/g (dry weight). Interior canal sediment samples averaged 16 μg/g compared to 2 μg/g found in open bay sediment samples. Total coprostanol concentrations in mussels ranged from 80 to 620 ng/g (wet weight). No mussels were found in the four most polluted interior canal sites.

Nichols, *et al.* (1996) also examined coprostanol in stormwater and the sea-surface microlayer to distinguish human versus nonhuman sources of contamination. Other steroid compounds in sewage effluent were investigated by Routledge, *et al.* (1998) and Desbrow, *et al.* (1998) who both examined estrogenic chemicals. The most common found were 17β-Estradiol and estrone which were detected at concentrations in the tens of nanograms per liter range. These were identified as estrogenic through a toxicity identification and evaluation approach, where sequential separations and analyses identified the sample fractions causing estrogenic activity using a yeast-based estrogen screen. GC/MS was then used to identify the specific compounds.

Estimating Potential Sanitary Sewage Discharges into Storm Drainage and Receiving Waters using Detergent Tracer Compounds

As described above, detergent measurements (using methylene blue active substance, MBAS, test methods) were the most successful individual tracer to indicate contaminated water in storm sewerage dry-weather flows. Unfortunately, the MBAS method uses hazardous chloroform for an extraction step. Different detergent components, especially linear alkylbenzene sulphonates (LAS) and linear alkylbenzenes (LAB), have also been tried to indicate sewage dispersal patterns in receiving waters. Boron, a major historical ingredient of laundry chemicals, can also potentially be used. Boron has the great advantage of being relatively easy to analyze using portable field test kits, while LAS requires chromatographic equipment. LAS can be measured using HPLC with fluorescent detection, after solid phase extraction, to very low levels. Fujita, *et al*. (1998) developed an efficient enzyme-linked immunosorbent assay (ELISA) for detecting LAS at levels from 20 to 500 μg/L.

LAS from synthetic surfactants (Terzic and Ahel 1993) which degrade rapidly, as well as nonionic detergents (Terzic and Ahel 1993) which do not degrade rapidly, have been utilized as sanitary sewage markers. LAS was quickly dispersed from wastewater outfalls except in areas where wind was calm. In these areas LAS concentrations increased in freshwater but were unaffected in saline water. After time, the lower alkyl groups were mostly found, possibly as a result of degradation or settling of longer alkyl chain compounds with sediments. Chung, *et al*. (1995) also describe the distribution and fate of LAS in an urban stream in Korea. They examined different LAS compounds having carbon ratios of C12 and C13 compared to C10 and C11, plus ratios of phosphates to MBAS and the internal to external isomer ratio (I/E) as part of their research. Gonález-Mazo, *et al.* (1998) examined LAS in the Bay of Cádiz off the southwest of Spain. They found that LAS degrades rapidly (Fujita, *et al*., 1998, found that complete biodegradation of LAS requires several days), and is also strongly sorbed to particulates. In areas close to shore and near the untreated wastewater discharges, there as significant vertical stratification of LAS: the top 3 to 5 mm of water had LAS concentrations about 100 times greater than found at 0.5 m.

Zeng and Vista (1997) and Zeng, *et al*. (1997) describe a study off of San Diego where LAB was measured, along with polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons (AHs) to indicate the relative pollutant contributions of wastewater from sanitary sewage, nonpoint sources, and hydrocarbon combustion sources. They developed and tested several indicator ratios (alkyl homologue distributions and parent compound distributions) and examined the ratio of various PAHs (such as phenanthrene to anthracene, methylphenanthrene to phenanthrene, fluoranthene to pyrene, and benzo(a)anthracene to chrysene) as tools for distinguishing these sources. They concluded that LABs are useful tracers of domestic waste inputs to the environment due to their limited sources. They also describe the use of the internal to external isomer ratio (I/E) to indicate the amount of biodegradation that may have occurred to the LABs. They observed concentrations of total LABs in sewage effluent of about 3 μg/L, although previous researchers have seen concentrations of about 150 μg/L in sewage effluent from the same area.

The fluorescent properties of detergents have also been used as a tracer by investigating the fluorescent whitening agents (FWAs), as described by Poiger, *et al.* (1996) and Kramer, *et al.* (1996). HPLC with fluorescence detection was used in these studies to quantify very low concentrations of FWAs. The two most frequently used FWAs in household detergents (DSBP and DAS 1) were found at 7 to 21 µg/L in primary sewage effluent and at 3 to 9 µg/L in secondary effluent. Raw sewage contains about 10 to 20 µg/L FWAs. The removal mechanisms in sewage treatment processes is by adsorption to activated sludge. The type of FWAs varies from laundry applications to textile finishing and paper production, making it possible to identify sewage sources. The FWAs were found in river water at 0.04 to 0.6 µg/L. The FWAs are not easily biodegradable but they are readily photodegraded. Photodegradation rates have been reported to be about 7% for DSBP and 71% for DAS 1 in river water exposed to natural sunlight, after one hour exposure. Subsequent photodegradation is quite slow.

Other Compounds Found in Sanitary Sewage that may be used for Identifying Contamination by Sewage

Halling-Sørensen, *et al.* (1998) detected numerous pharmaceutical substances in sewage effluents and in receiving waters. Their work addressed human health concerns of these low level compounds that can enter downstream drinking water supplies. However, the information can also be possibly used to help identify sewage contamination. Most of the research has focused on clofibric acid, a chemical used in cholesterol lowering drugs. It has been found in concentrations ranging from 10 to 165 ng/L in Berlin drinking water sampler. Other drugs commonly found include aspirin, caffeine, and ibuprofen. Current FDA guidance mandates that the maximum concentration of a substance or its active metabolites at the point of entry into the aquatic environment be less than 1 µg/L (Hun 1998).

Caffeine has been used as an indicator of sewage contamination by several investigators (Shuman and Strand 1996). The King County, WA, Water Quality Assessment Project is examining the impacts of CSOs on the Duwamish River and Elliott Bay. They are using both caffeine (representing dissolved CSO constituents) and coprostanol (representing particulate bound CSO constituents), in conjunction with heavy metals and conventional analyses, to help determine the contribution of CSOs to the river. The caffeine is unique to sewage, while coprostanol is from both humans and carnivorous animals and is therefore also in stormwater. They sampled upstream of all CSOs, but with some stormwater influences, 100 m upstream of the primary CSO discharge (but downstream of other CSOs), within the primary CSO discharge line, and 100 m downriver of the CSO discharge location. The relationship between caffeine and coprostanol was fairly consistent for the four sites (coprostanol was about 0.5 to 1.5 µg/L higher than caffeine). Similar patterns were found between the three metals, chromium was always the lowest and zinc was the highest. King Co. is also using clean transported mussels placed in the Duwamish River to measure the bioconcentration potential of metal and organic toxicants and the effects of the CSOs on mussel growth rates (after 6 week exposure periods). Paired reference locations are available near the areas of deployment, but outside the areas of immediate CSO influence. *US Water News* (1998) also described a study in Boston Harbor that found caffeine at levels of about 7 µg/L in the harbor water. The caffeine content of regular coffee is about 700 mg/L, in contrast.

DNA Profiling to Measure Impacts on Receiving Water Organisms and to Identify Sources of Microorganisms in Stormwater

This rapidly emerging technique seems to have great promise in addressing a number of nonpoint source water pollution issues. Kratch (1997) summarized several investigations on cataloging the DNA of *E. coli* to identify their source in water. This rapidly emerging technique seems to have great promise in addressing a number of nonpoint source water pollution issues. The procedure, developed at the Virginia Polytechnic Institute and State University, has been used in Chesapeake Bay. In one example, it was possible to identify a large wild animal population as the source of fecal coliform contamination of a shellfish bed, instead of suspected failing septic tanks. DNA patterns in fecal coliforms vary among animals and birds, and it is relatively easy to distinguish between human and non-human sources of the bacteria. However, some wild animals have DNA patterns that are not easily distinguishable. Some researchers question the value of *E. coli* DNA fingerprinting believing that there is little direct relationship between *E. coli* and human pathogens. However, this method should be useful to identify the presence of sewage contamination in stormwater or in a receiving water.

One application of the technique, as described by Krane, *et al*. (1999) of Wright State University, used randomly amplified polymorphic DNA polymerase chain reaction (RAPD-PCR) generated profiles of naturally occurring crayfish. They found that changes in the underlying genetic diversity of these populations were significantly correlated with the extent to which they have been exposed to anthropogenic stressors. They concluded that this rapid and relatively simple technique can be used to develop a sensitive means of directly assessing the impact of stressors upon ecosystems. These Wright State University researchers have also used the RAPD-PCR techniques on populations of snails, pill bugs, violets, spiders, earthworms, herring, and some benthic macroinvertebrates, finding relatively few obstacles in its use for different organisms. As noted above, other researchers have used DNA profiling techniques to identify sources of *E. coli* bacteria found in coastal waterways. It is possible that these techniques can be expanded to enable rapid detection of many different types of pathogens in receiving waters, and the most likely sources of these pathogens.

Stable Isotope Methods for Identifying Sources of Water

Stable isotopes had been recommended as an efficient method to identify illicit connections to storm sewerage. A demonstration was conducted in Detroit as part of the Rouge River project to identify sources of dry weather flows in storm sewerage (Sangal, *et al.* 1996). Naturally occurring stable isotopes of oxygen and hydrogen can be used to identify waters originating from different geographical sources (especially along a north-south gradient). Ma and Spalding (1996) discuss this approach by using stable isotopes to investigate recharge of groundwaters by surface waters. During water vapor transport from equatorial source regions to higher latitudes, depletion of heavy isotopes occurs with rain. Deviation from a standard relationship between deuterium and ^{18}O for a specific area indicates that the water has undergone additional evaporation. The ratio is also affected by seasonal changes. As discussed by Ma and Spalding (1996), the Platte River water is normally derived in part from snowmelt from the Rocky Mountains, while the groundwater in parts of Nebraska is mainly contributed from the Gulf air stream. The origins of these waters are sufficiently different and allow good measurements of the recharge rate of the surface water to the groundwater. In Detroit, Sangal, *et al.* (1996) used differences in origin between the domestic water supply, local surface waters, and the local groundwater to identify potential sanitary sewage contributions to the separate storm sewerage. Rieley, *et al*. (1997) used stable isotopes of carbon in marine organisms to distinguish the primary source of carbon being consumed (sewage sludge vs. natural carbon sources) in two deep sea sewage sludge disposal areas.

Stable isotope analyses would not be able to distinguish between sanitary sewage, industrial discharges, washwaters, and domestic water, as they all have the same origin, nor would it be possible to distinguish sewage from local groundwaters if the domestic water supply was from the same local aquifer. This method works best for situations where the water supply is from a distant source and where separation of waters into separate flow components is not needed. It may be an excellent tool to study the effects of deep well injection of stormwater on deep aquifers having distant recharge sources (such as in the Phoenix area). Few laboratories can analyze for these stable isotopes, requiring shipping and a long wait for the analytical results. Sangal, *et al*. (1995) used Geochron Laboratories, in Cambridge, Massachusetts.

Dating of sediments using ^{137}Cs was described by Ma and Spalding (1996). Arsenic contaminated sediments in the Hylebos Waterway in Tacoma, WA, could have originated from numerous sources, including a pesticide manufacturing facility, a rock-wool plant, steel slags, powdered metal plant, shipbuilding facilities, marinas and arsenic boat paints, and the Tacoma Smelter. Dating the sediments, combined with knowing the history of potential discharges and conducting optical and electron microscopic studies of the sediments, was found to be a powerful tool to differentiate between the different metal sources to the sediments.

Summary of Detecting Inappropriate Discharges

In almost all cases, a suite of analyses is most suitable for effective identification of inappropriate discharges. A recent example was reported by Standley, *et al.* (2000), where fecal steroids (including coprostanol), caffeine, consumer product fragrance materials, and petroleum and combustion byproducts were used to identify wastewater treatment plant effluent, agricultural and feedlot runoff, urban runoff, and wildlife sources. They studied numerous individual sources of these wastes from throughout the US. A research grade mass sperctrophotometer was used for the majority of the analyses in order to achieve the needed sensitivities, although much variability was found when using the methods in actual receiving waters affected by wastewater effluent. This sophisticated suite of analyses did yield much useful information, but the analyses are difficult to conduct and costly and may be suitable for special situations, but not for routine survey work.

Another recent series of tests examined several of these potential emerging tracer parameters, in conjunction with the previously identified parameters, during a project characterizing stormwater that had collected in telecommunication manholes, funded by Tecordia (previously Bellcore), AT&T, and eight regional telephone companies throughout the country (Pitt and Clark 1999). Numerous conventional constituents, plus major ions, and toxicants were measured, along with candidate tracers to indicate sewage contamination of this water. Boron, caffeine, coprostanol, *E. coli*, enterococci, fluorescence (using specific wavelengths for detergents), and a simpler test for detergents were evaluated, along with the use of fluoride, ammonia, potassium, and obvious odors and color. About 700 water samples were evaluated for all of these parameters, with the exception of bacteria and boron (about 250 samples), and only infrequent samples were analyzed for fluorescence. Coprostanol was found in about 25 percent of the water samples (and in about 75% of the 350 sediment samples analyzed). Caffeine was only found in very few samples, while elevated *E. coli* and enterococci (using IDEXX tests) were observed in about 10% of the samples. Strong sewage odors in water and sediment samples were also detected in about 10% of the samples. Detergents and fluoride (at >0.3 mg/L) were found in about 40% of the samples and are expected to have been contaminated with industrial activities (lubricants and cleansers) and not sewerage. Overall, about 10% of the samples were therefore expected to have been contaminated with sanitary sewage, about the same rate previously estimated for stormwater systems.

Additional related laboratory tests, funded by the University of New Orleans and the EPA (Barbe', *et al*. 2000), were conducted using many sewage and laundry detergent samples and found that the boron test was a poor indicator of sewage, possibly due to changes in formulations in modern laundry detergents. Laboratory tests did find that fluorescence was an excellent indicator of sewage, especially when using specialized "detergent whitener" filter sets, but was not very repeatable. We also examined several UV absorbance wavelengths as sewage indicators and found excellent correlations with 228 nm, a wavelength having very little background absorbance in local spring waters, but with a strong response factor with increasing strengths of sewage.

Table 12 summarizes the different measurement parameters discussed above. We recommend that our originally developed and tested protocol, as reported by Pitt, *et al*. (1993), still be used as the most efficient routine indicator of sewage contamination of stormwater drainage systems, with the possible addition of specific *E. coli* and enterococci measurements and UV absorbance at 228 nm. The numerous exotic tests requiring specialized instrumentation and expertise do not appear to warrant their expense and long analytical turn-around times, except in specialized research situations, or when special confirmation is economically justified (such as when examining sewer replacement or major repair options).

Table 12. Comparison of Measurement Parameters used for Identifying Inappropriate Discharges into Storm Drainage

Parameter Group	Comments	Recommendation
Fecal coliform bacteria and/or use of fecal coliform to fecal strep. ratio	Commonly used to indicate presence of sanitary sewage.	Not very useful as many other sources of fecal coliforms are present, and ratio not accurate for old or mixed wastes.
Physical observations (odor, color, turbidity, floatables, deposits, stains, vegetation changes, damage to outfalls)	Commonly used to indicate presence of sanitary and industrial wastewater.	Recommended due to easy public understanding and easy to evaluate, but only indicative of gross contamination, with excessive false negatives (and some false positives). Use in conjunction with chemical tracers for greater sensitivity and accuracy.
Detergents presence (anionic surfactant extractions)	Used to indicate presence of wash waters and sanitary sewage.	Recommended, but care needed during hazardous analyses (only for well-trained personnel). Accurate indicator of contamination during field tests.
Fluoride, ammonia and potassium measurements	Used to identify and distinguish between wash waters and sanitary sewage.	Recommended, especially in conjunction with detergent analyses. Accurate indicator of major contamination sources and their relative contributions.
TV surveys and source investigations	Used to identify specific locations of inappropriate discharges, especially in industrial areas.	Recommended after outfall surveys indicate contamination in drainage system.
Coprostanol and other fecal sterol compounds	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analysis with GC/MSD. Not specific to human wastes or recent contamination. Most useful when analyzing particulate fractions of wastewaters or sediments.
Specific detergent compounds (LAS, fabric whiteners, and perfumes)	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analyses with HPLC. A good and sensitive confirmatory method.
Fluorescence	Used to indicate presence of sanitary sewage and wash waters.	Likely useful, but expensive instrumentation. Rapid and easy analysis. Very sensitive.
Boron	Used to indicate presence of sanitary sewage and wash waters.	Not very useful. Easy and inexpensive analysis, but recent laundry formulations in US have minimal boron components.
Pharmaceuticals (colfibric acid, aspirin, ibuprofen, steroids, illegal drugs, etc.)	Used to indicate presence of sanitary sewage.	Possibly useful. Expensive analyses with HPLC. A good and sensitive confirmatory method.
Caffeine	Used to indicate presence of sanitary sewage.	Not very useful. Expensive analyses with GC/MSD. Numerous false negatives, as typical analytical methods not suitably sensitive.
DNA profiling of microorganisms	Used to identify sources of microorganisms	Likely useful, but currently requires extensive background information on likely sources in drainage. Could be very useful if method can be simplified, but with less specific results.
UV absorbance at 228 nm	Used to identify presence of sanitary sewage.	Possibly useful, if UV spectrophotometer available. Simple and direct analyses. Sensitive to varying levels of sanitary sewage, but may not be useful with dilute solutions. Further testing needed to investigate sensitivity in field trials.
Stable isotopes of oxygen	Used to identify major sources of water.	May be useful in area having distant domestic water sources and distant groundwater recharge areas. Expensive and time consuming procedure. Can not distinguish between wastewaters if all have common source.

E. coli and enterococci bacteria	More specific indicators of sanitary sewage than coliform tests.	Recommended in conjunction with chemical tests. Relatively inexpensive and easy analyses, especially if using the simple IDEXX methods.

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