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Emerging Stormwater Controls for Critical Source Areas

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Introduction

An extensive literature review and survey of past and current drainage design practices during a recent EPA funded research project found that design standards have not changed significantly during the past 25 years, but that there has been a shift towards the use of more sophisticated design tools (Pitt, *et al*. 1999). Unfortunately, current practices were identified as inadequately addressing water quality issues, even though almost all survey respondents recognized the significance of wet weather flow impacts. The use of long-term continuous simulation and addressing small storms that can be responsible for important receiving water quality problems is a recommended improvement in current design practices. Important changes in urban water management will also be needed in coming years to balance the needs for both water quality and quantity control in developing areas.

This recent EPA research, along with many other current literature sources, found that it is possible and best to develop stormwater management design guidelines based on local rain conditions. Small events, making up the majority of rain events, commonly exceed bacteria and metal criteria, but are relatively easy to control through simple infiltration or on-site reuse of the stormwater. Moderate sized rains, however, are responsible for the majority of the runoff volumes and pollutant discharges. The runoff from these events can also be significantly reduced, but certainly not eliminated, through infiltration, but larger flows will have to be treated to reduce pollutant concentrations and excessive discharge rates. Large rains that approach and may exceed the capacities of the drainage system produce little of the annual flows and are rare. In addition, significant pollutant concentration reductions during these large events would be difficult and very expensive because of the very large flows involved. However, runoff flow rates should be reduced to produce instream flowrate distributions less than critical values in order to protect in-stream habitat.

Factors Relevant to Oil/Water Separator Performance

Many factors affect separator performance, including: the quantity of oil, oil density, water temperature and other wastestream characteristics. The most important characteristic affecting oil removal performance is oil droplet size, from which the critical rise rate can be determined. After determining the rise rate, design flow rate, and effective horizontal separation area, the separator can be appropriately sized.

Oil/water mixtures are usually divided into four categories:

- free-floating oil, with oil droplet sizes of 250 µm or more, is evidenced by an oil slick or film on the water surface. In this case, the oil has separated from the water.
- oil droplets and globules ranging in size from 10-300 µm. This range is the most important range when dealing with oil/water separation.
- emulsions, which have sizes in the 1-30 µm range, and
- "dissolved" oil with diameters of less than 10 µm.

The largest oil droplets are easily separated from water using a basic spill trap or separation device. Smaller droplets cause wide ranging differences in performance from different separation devices. Emulsions are of two types: stable and unstable. Stable emulsions are usually the result of surfactants (i.e. soaps and detergents) which hold the droplets in solution. This type of emulsion is often present in cleaning operations and can often be very difficult to remove. Unstable emulsions are created by shearing forces present in mixing: the oil is held in suspension when the interfacial tension of the drops' surface is equal to the force acting on the drops. These will generally separate by physical methods such as extended settling times or filtration methods. Oil/water separators are not able to treat stable emulsions or dissolved oil.

Gravity Separation

Gravity separation relies on the density differences between oil and water. Oil will rise to the water surface unless some other contributing factor such as a solvent or detergent interferes with the process. For gravity units, this density difference is the only mechanism by which separation occurs. Other technologies, such as air flotation, coalescing plates, and impingement coalescing filters, enhance the separation process by mechanical means.

Gravity separators are the most basic type of separator and are the most widely used. They have few, if any, moving parts and require little maintenance with regard to the structure or operation of the device. Usually, separators are designed to meet the criteria of the American Petroleum Institute (API), and are fitted with other devices such as coalescing plate interceptors (CPI) and filters. Even though these separators are effective in removing free and unstable oil emulsions, they are ineffective in removing most emulsions and soluble oil fractions (Ford 1978). Furthermore, it is important to remember that no gravity oil/water separation device will have a significant impact on many of the other important stormwater pollutants, requiring additional treatment (Highland Tank).

Conventional American Petroleum Institute (API) Oil/Water Separator

The conventional API oil/water separator consists of a large chamber divided by baffles into three sections. The first chamber acts as an equalization chamber where grit and larger solids settle and turbulent flow slows before entering the main separation chamber. Often, manufacturers suggest the use of a catchbasin or interceptor tank as a pretreatment device so that coarse material will be kept from entering the oil/water separation tank. After entering the main chamber, solids settle to the bottom and oil rises to the top, according to Stokes' law. Larger API oil/water separators contain a sludge scraper which continually removes the captured settled solids into a sludge pit. The oil is also removed by an oil skimmer operating on the water surface. At the end of the separation chamber, all oil particles having a diameter of larger than the critical size have theoretically risen to the surface and have been removed by an oil skimmer. Small API units usually do not contain an oil skimmer, sludge scrapper, or sludge pit. While they are less costly due to the absence of moving parts, they require more frequent cleaning and maintenance. These smaller units have been shown to be as effective as the larger more expensive units, if they receive proper maintenance at regular intervals.

The API (1990) stipulates that if their design criteria are met, then the separator will remove all oil droplets greater than about 150 μm in diameter. The API reports that retention times are usually greater than the actual design values since actual flows are usually smaller than design flows, hence smaller droplets are removed most of the time. This finding is confirmed by Ruperd (1993) in a study of an oil/water separator treatment device in the community of Velizy, France. Also, API tanks are known to effectively remove large amounts of oil, including slugs of pure oil, and will not be overwhelmed (Tramier 1983). Studies have also shown that these separators can produce effluents down to 30 ppm (Delaine 1995), routinely at 30-150 ppm, with occasional concentrations above 150 ppm, depending upon the flow rate, and hence the retention times (Ford 1978).

The API has stated that very few separators with ratios of surface area to flow within the API design range achieved effluent oil concentrations lower that 100 ppm (API 1990). Therefore, the API separator is a recommended system for the removal of solids and gross oil as a pretreatment device upstream of another treatment system, if additional pollutants of concern are present, or if more stringent effluent standards are to be met.

Maintenance of Oil/Water Separators

Problems with oil/water separators can be attributed largely to poor maintenance by allowing waste materials to accumulate in the system to levels that hinder performance and to levels that can be readily scoured during intermittent high flows. When excess oil accumulates, it will be forced around the oil retention baffle and make its way into the discharge stream. Also, sludge buildup is a major reason for failure. As waste builds up, the volume in the chamber above the sludge layer is reduced and therefore the retention time is also reduced, allowing oil to be discharged. Therefore, the efficiency of oil/water separators in trapping and retaining solids and hydrocarbons depends largely upon how they are maintained. They must be designed for ease of maintenance and be frequently maintained. Apparently, few oil/water separators built for stormwater control are adequately maintained.

Ease of maintenance must be considered when designing separators, including providing easy access. Maintenance on these devices is accomplished by using suction equipment, such as a truck mounted vacuum utilized by personnel trained to handle potentially hazardous waste. The vacuum is used to skim off the top oil layer and the device is then drained. In larger devices, the corrugated plates are left in place, but otherwise, they are lifted out along with any other filter devices that are present. The sludge is then vacuumed out or shoveled out and any remaining solids are loosened by spraying hot water at normal pressure.

Performance of Oil/Water Separators for Treating Stormwater

Manufacturers state that efficiencies observed during testing of oil/water separators are on the order of 97 – 99% for the removal of oil from wastewater. The test method typically applies oil to a paved washpad, with water added via a sprinkler system to simulate rainfall. Oil is of a specified density (typically 0.72 – 0.95). These synthetic events are necessary to evaluate the performance of a separator but do not necessarily reflect the processes which occur during actual rainfall conditions where rapidly changing flows rates, unknown oil mixtures, and other pollutants are present. Published research is difficult to find on how these units actually perform once placed in operation.

Interception of solid particles through settling, and flotation of oils and other floatables are processes occurring within an oil/water separator. French studies have shown that the average suspended solids removal efficiency of separators is about 50% (Aires and Tabuchi 1995). Oil/water separation requires an ascending speed of about 8 m/h, while the settling velocity of solids require descending velocities on the order of 1 to 3 m/h. At rates of 20% of the design flow rate, about 80% of the solids are removed; at 30% of the design flow rate, about 50% of the solids are removed. Negative removals also occur as the result of resuspension of previously settled material (Legrand, *et al*. 1994).

When the concentration of the oil in the wastewater is high, the oil removal efficiency increases. In Velizy, France, Ruperd (1993) found that oil/water separators fitted with cross current separators had removal efficiencies ranging from zero to 90%, with an average of 47%. Low efficiencies were associated with low influent levels and greater efficiencies were associated with higher influent levels. This finding supports those of Tramier (1983), stated earlier, that separators are effective in removing large amounts of oil when the oil concentrations are elevated.

The Metropolitan Washington Council of Governments (Washington, D.C.) has conducted a survey of 109 separator vaults in suburban Maryland and subsequently examined 17 in detail to determine their long-term effectiveness (Schueler and Shepp 1993). These separators were used for controlling runoff from areas associated with automobile usage. These separators were either pre-cast or poured in place concrete structures consisting of one, two or three chambers. The results of this study revealed that the amount of trapped sediments within separators varied from month to month and that the contained waters were commonly completely displaced during even minor storms (Shepp and Cole 1992). Of the original 109 separators that were observed in the survey, devices less than one year old were effective in trapping sediments. Devices older than one year appeared to lose as much sediment than they retained. Not one of these separators had received maintenance since their installation. Survey observations suggested no net accumulation of sediment over time, in part because they received strong variations in flow. Of the 109 separators surveyed in this suburban Maryland study, 100% had received no maintenance, 1% needed structural repair, 6% were observed to have clogged trash racks, 84% contained high oil concentrations in the sediments trapped in their first chamber, 77% contained high oil concentrations in the sediments trapped in their second chambers, 27% contained high oil and floatables loading in their first chambers, and 23% contained high oil and floatables loading in their second chambers.

Numerous manufacturers have developed small prefabricated separators to remove oils and solids from runoff. These separators are rarely specifically designed and sized for stormwater discharges, but usually consist of modified oil/water separators. Solids are intended to settle and oils are intended to rise within these separators, either by free fall/rise or by counter-current or cross-current lamella separation. Many of these separators have been installed in France, especially along highways (Rupperd 1993). Despite the number of installations, few studies have been carried out in order to assess their efficiency (Aires and Tabuchi 1995).

The historical use of oil/water separators to treat stormwater has been shown to be ineffective for various reasons, especially lack of maintenance and poor design for the relatively low levels of oils present in most stormwaters (Schueler 1994). Stormwater treatment test results from Fourage (1992), Rupperd (1993) and Legrand, *et al*. (1994) show that these devices are usually greatly under-sized. They may possibly work reasonably well at flow rates between 20 and 30% of their published design hydraulic capacities. For higher flow rates, the flow is very turbulent (the Reynolds numbers can be higher than 6000), and improvements in settling by using lamella plates is very poor. These devices need to be cleaned very frequently. If they are not cleaned, the deposits are scoured during storm events, with negative efficiencies. However, the cleaning is usually manually conducted, and expensive. In addition, the maintenance job is not very easy because the separators are very small. Some new devices are equipped with automatic sediment extraction pumps which should be a significant improvement. Currently, these researchers have found that the cleaning frequencies are very insufficient and the stormwater quality benefits from using oil/water separators are very limited.

The Multi-Chambered Treatment Train (MCTT), described later in this chapter, was developed to specifically address many of the stated problems found for oil/ water separators used for stormwater treatment at critical source areas (Pitt, *et al*. 1999). It was developed and tested with specific stormwater conditions in mind, plus it has been tested at several sizes for the reduction of stormwater pollutants of concern. The MCTT is intended to reduce organic and metallic toxicants, plus suspended solids, in the stormwater. Oil/water separators are intended to reduce very large concentrations of floating oils that may be present in industrial wastewaters . The extremely high concentrations of oils that the oil/water separators are most effective in removing are very rare in stormwater, even from critical source areas. If a site has these high levels, then an oil/water separator may be needed, in addition to other controls to reduce the other critical pollutants likely present. The MCTT can remove the typically highest levels of oils that may be present in stormwater from most critical source areas, plus also provide control of the trace toxicants present.

Street Cleaning

Street cleaning was extensively studied during early EPA-funded research projects. It was thought to be an effective runoff water quality control practice because of the large quantities of pollutants found on streets during early stormwater research in the U.S. (Sartor and Boyd 1972). Because streets were assumed to contribute most of the urban runoff flows and pollutants, street cleaning was assumed to be a potentially effective practice. Unfortunately, few data have shown street cleaning to be effective because of the different sized particles that street cleaners remove compared to the particles that are mostly removed by rains. Furthermore, in many areas, rains are relatively frequent and keep the streets cleaner than typical threshold values that most street cleaners can remove. However, in the arid west of the U.S., rains are very infrequent, allowing streets to become quite dirty during the late summer and fall. Extensive street cleaning during this time has been shown to result in important suspended solids and heavy metal reductions in runoff (Pitt 1979, Pitt and Shawley 1982). In other areas of the U.S., especially in the wet southeast where large and frequent rains occur, street cleaning is likely to have much less direct water quality benefits, beyond possible important litter and floatable control. Obviously, street cleaning is most effective in areas having large fractions of pavement in good condition that can be assessed by street cleaners. Many critical source areas (especially large parking areas, paved equipment storage yards, etc.) could likely benefit with more frequent cleaning, especially with new equipment designed for better removal of fine particulates.

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 northern regions. Leaf cleanup by street cleaning is also necessary in most areas in the fall.

Factors significantly affecting street cleaning performance include street dirt loadings, street texture, litter and 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, the removals also increase: 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.

Particles of different sizes "behave" quite differently on streets. Typical street dirt total solids loadings show a "saw-tooth" pattern with time between street cleaning or rain washoff events. The patterns for the separate particle sizes vary considerably for different particle sizes. Typical mechanical street cleaners remove much (about 70 percent) of the coarse particles in the path of the street cleaner, but they remove very little of the finer particles (Sartor and Boyd 1972; Pitt 1979). Rains, however, remove very little of the large particles, but can remove large amounts (about 50 percent) of the fine particles (Bannerman, *et al*. 1983; Pitt 1985; Pitt 1987). The intermediate particle sizes show reduced removals by both street cleaners and rain. Conventional street cleaning therefore does not have a very positive effect on stormwater quality because conventional street cleaners preferentially remove the large particles, and the smaller particles from the street that are most effectively removed during rains. Valiron (1992) confirmed the many earlier U.S. studies by showing that street cleaners only remove about 15% of the finest particles (less than 40 µm), while close to 80% of the largest particles (>2,000 µm) are removed.

Enhanced street cleaner performance was obtained with a modified regenerative-air street cleaner, especially at low loadings during tests in Bellevue, WA (Pitt 1985). The improved performance was much greater for the 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.

Ellis (1986) concluded that street cleaning is most efficient if conventional street sweeping (using broom operated equipment) is conducted in a tandem operation with vacuuming, and if it is done three times per week. He did find that conventional tandem sweeping-vacuum machines are very sensitive to the clogging of their filters and to street moisture levels which causes particles to adhere to the street surface, preventing their efficient removal. General street cleaning efficiency depends on the speed of the machines, the number of passes, the street loading and street texture, and interference from parked vehicles (Pitt 1979).

Much information concerning street cleaning productivity has been collected in many areas. The early tests (Clark and Cobbin 1963; and 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. The following list briefly describes these large-scale street cleaning performance tests that have been conducted in the U.S.:

- 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, tests during 1979 and 1980 (Pitt and Shawley 1982) considered street slopes, mechanical and regenerative-air street cleaners, and several cleaning frequencies. This was an early Nationwide Urban Runoff Program (NURP) project of the U.S. EPA (EPA 1983).
- 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, 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. This was also a NURP project (EPA 1983).
- Champaign-Urbana, Illinois, 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. This was also a NURP project (EPA 1983).
- Milwaukee, Wisconsin, 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. This was also a NURP project (EPA 1983).
- Winston-Salem, North Carolina, tests during their NURP (EPA 1983) project examined different land-uses and cleaning frequencies.

Sutherland (1996, and with Jelen 1996) conducted 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. The Enviro Whirl I, from Enviro Whirl Technologies, Inc. is capable of much improved removal of fine particles from the streets compared to any other street cleaner ever 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. Model analyses for Portland, OR, indicate that monthly cleaning in a residential area may reduce the suspended solids discharges by about 50%, compared to only about 15% when using the older mechanical street cleaners that were tested during the early 1980s. This equipment is currently being evaluated in large-scale tests by the Wisconsin Department of Natural Resources and WI Dept. of Transportation (Bannerman, personal communication).

The pollutant removal benefits of street cleaning is directly dependent on the contributions of pollutants from the streets. In the Pacific Northwest region of the U.S., the large number of mild rains results in much of the runoff pollutants originating from the streets. In the Southeast, in contrast, where the rains are much larger, with greater rain intensities, the streets contribute a much smaller fraction of the annual pollutant loads for the same residential land uses. However, in heavily paved areas, such as on freeways, large parking lots or paved storage areas, street cleaning of these surfaces, especially with an effective machine like the Enviro Whirl, should result in significant runoff improvements.

These many tests have examined a comprehensive selection of alternative street cleaning programs. Not all alternatives have been examined under all conditions, but sufficient information has been collectively obtained to examine many alternative street cleaning control options. Few instances of significant and important reductions in runoff pollutant discharges have been reported during these large-scale tests.

The primary and historical role of street cleaning is for litter control. Litter is also an important water pollutant in receiving waters. Litter affects the aesthetic attributes and recreation uses of waters, plus it may have direct negative biological and water quality effects. Litter has not received much attention as a water pollutant, possibly because it is not routinely monitored during stormwater research efforts. The City of New York conducted a special study to investigate the role of enhanced street cleaning (using intensive manual street sweeping) to reduce floatable litter entering the City's waterways (Newman, *et al*. 1996). During the summer of 1993, the City hired temporary workers to manually sweep near-curb street areas and sidewalks in a pilot watershed area having 240 km of curb face. Two levels of manual sweeping supplemented the twice per week mechanical street cleaning the area normally receives. Continuous litter monitoring was also conducted to quantify the differences in floatable litter loadings found on the streets and sidewalks. An additional four manual sweepings each week to the two mechanical cleanings reduced the litter loadings by about 64% (on a weight basis) and by about 51% (on a surface area basis). Litter loading analyses were also conducted in areas where almost continuous manual sweeping (8 to 12 daily sweeps, 7 days per week) was conducted by special business organizations. In these special areas, the litter loadings were between 73 and 82% cleaner than comparable areas only receiving the twice weekly mechanical cleaning. They concluded that manual sweeping could be an important tool in reducing floatable pollution, especially in heavily congested areas such as Manhattan. New York City is also investigating catch basin modifications and outfall netting for the control of floatable litter.

Normal street cleaning operations for aesthetics and traffic safety purposes are not very satisfactory from a stormwater quality perspective. These objectives are different and the removal efficiency for fine and highly polluted particles is very low. Unless the street cleaning operations can remove the fine particles, they will always be limited in their pollutant removal effectiveness. Some efficient machines are now available to clean porous pavements and infiltration structures, and new tandem machines that incorporate both brooms and vacuums have recently been shown to be very efficient, even for the smaller particles. Conventional street cleaning operations preferentially remove the largest particles, while rain preferentially remove the smallest particles. In addition, street cleaners are very inefficient when the street dirt loadings are low, when the street texture is course, and when parked cars interfere. However, it should also be noted that streets are not the major source of stormwater pollutants for all rains in all areas. Pavement is the major source of pollutants for the smallest rains, but other areas contribute significant pollutants for moderate and large rains. Therefore, the ability of street cleaning to improve runoff quality is dependent on many issues, including the local rain patterns and other sources of runoff pollutants. More research is needed to investigate newer pavement cleaning technologies in areas such as industrial storage areas and commercial parking areas which are critical pollutant sources.

Prevention of Dry-Weather Pollutant Entries into Sewerage Systems

Inappropriate discharges to separate storm drainage systems can be a significant source of the pollutants being discharged to an urban receiving water. It is important that these sources be identified and corrected. Interest in these sources is an outgrowth of investigations into the larger problem of determining the role urban stormwater runoff plays as a contributor to receiving water quality problems. The U.S.EPA's Storm & Combined Sewer Overflow Pollution Control Research and Nationwide Urban Runoff Programs, helped highlight the problem with data confirming pollution found in urban storm drainage systems. Regulations, such as the National Pollution Discharge Elimination System (NPDES), require that certain industries and municipalities conduct investigations to determine the locations of inappropriate dry-weather entries into storm drainage systems.

One example of the magnitude of the problem associated with inappropriate discharges follows. A study in Sacramento, CA. (Montoya 1987) found that slightly less than half the volume of water discharged from a stormwater drainage system was not directly attributable to rainfall induced runoff. Illicit and/or inappropriate entries to the storm drainage system are likely sources of the additional discharges and can account for a significant amount of the pollutants discharged from storm drainage systems.

The methods described in the following discussion were developed through EPA funding and can be applied to detection of inappropriate discharges associated with dry-weather flows (Pitt, *et al*. 1993).

Common non-stormwater entries include: sanitary wastewater; automobile maintenance and operation waste products; laundry wastewater; household toxic substances and pollutants; accident and spill waste streams; runoff from excessive irrigation; and industrial cooling water, rinse water, and other process wastewater. Although these sources can enter the storm drainage system a variety of ways, they generally result from: (1) direct connections, such as wastewater piping either mistakenly or deliberately connected to the storm drains; or (2) indirect connections, which include infiltration into the storm drainage system and spills received by drain inlets. Sources of contamination can be divided into those discharging continuously and those discharging intermittently.

Investigative Procedures

The procedures described here provide an investigative procedure that will allow a user to first determine whether significant non-stormwater entries are present in a storm drain, and then identify the potential source responsible (e.g., industrial, residential, or commercial) as an aid to ultimately locating the source.

Drainage Area Mapping

The mapping exercise is carried out as a desktop operation using existing data/information and field visits to collect additional data/information and/or confirm existing information. It must contain complete descriptions of the drainage areas, including: outfall locations, drainage system layout, subcatchment boundaries for each outfall, critical land-use areas, permitted discharges to the storm drainage system, city limits, major streets, streams, etc.

Tracer Selection

To detect and identify non-stormwater entries, the dry-weather outfall discharge is analyzed for selected tracers. The selected tracers are relatively unique components of the potential contaminating sources and hence provide a means to identify them. An ideal tracer should exhibit the following properties:

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

A review of case studies and literature characterizing potential inappropriate entries led to the recommended tracers (listed below) to identify common pollutant sources (e.g., sanitary wastewater, septic tank effluent, laundry wastewater, vehicle wash wastewater, potable water, and natural waters):

- Specific Conductivity- Specific conductivity can be used as an indicator of dissolved solids. The variation between water and wastewater sources can be substantial enough to indicate the source of a dry-weather flow, and because the measurement is easy, quick, and inexpensive, it is a suggested tracer.

- Fluoride- Fluoride concentration were shown to be a reliable indicator of potable water where fluoride levels in the raw water supply are adjusted to consistent levels and where groundwater has low to non-measurable natural fluoride levels. Fluoride can often be used to separate treated potable water from untreated water sources. Untreated water sources can include local springs, groundwater, regional surface flows or non-potable industrial waters. If the treated potable water has no fluoride added, or if the natural water has fluoride concentrations close to potable water fluoride concentrations, then fluoride may not be an appropriate indicator. Some industrial and commercial wastewaters may contain large concentrations of fluorides, making quantitative analyses difficult, however.

- Hardness- Hardness is useful in distinguishing between natural and treated waters (like fluoride), as well as between clean treated waters and waters that have been subjected to domestic use. It should be noted that hardness of waters varies considerably from place to place, with groundwaters generally being harder than surface waters.

- Ammonia/Ammonium- The presence or absence of ammonia (NH_3), or ammonium ion (NH_4^+), has been commonly used as a chemical indicator for prioritizing sanitary wastewater cross-connection drainage problems. Ammonia should be useful in identifying sanitary wastes and distinguishing them from commercial water usage.

- Potassium- Greater potassium concentrations have been noted for sanitary wastewater compared to potable water. These potassium increases following domestic water usage reveal its potential as a tracer parameter.

- Surfactants - Surfactants from detergents used in household and industrial laundering and other cleaning operations results in its high concentrations in wastewater. Anionic surfactants account for approximately two thirds of the total surfactants used in detergents, and are commonly measured as Methylene Blue Active Substances (MBAS). Some researchers (Alhajjar, *et al*. 1989) have not found surfactants in septic tank effluent suggesting that surfactants can be totally degraded in the septic tanks. Surfactants can be used to identify sanitary or laundry wastewater sources and distinguish between infiltrating septic tank effluent and other washwaters. Surfactants was the most useful tracer to identify problematic waters.

- pH- The pH of most dry-weather flow sources is close to neutral (pH = 7). However, pH values may be extreme (below 6 and above 9) in certain inappropriate commercial and industrial flows or where groundwaters contain dissolved minerals. If unusual pH values are observed, then the drainage system needs to be carefully evaluated. Note that pH values are log-transformed values and therefore flow contributions cannot be proportioned using pH directly in the same way "linear" concentration values can.

- Temperature - An elevated temperature of a receiving water can indicate contamination, particularly in cold weather. Sanitary wastewater and cooling water are examples of causes to temperature elevation and a rough heat balance may be conducted to identify a grossly contaminated outfall.

It is essential that the investigation have adequate local tracer data for all the potential sources in a study area. Local tracer data is obtained by sampling discharges for specific desired tracers at potential pollution sources that produce specific process wastewaters, regardless of whether or not an illicit entry to the storm drainage system is present. This becomes your data base of "local" characteristics of those tracers of that local area for comparison to background flows and storm drainage characteristics of that local area. For each tracer, the concentration means and standard deviations for all the potential source flows, including the natural waters or background waters (e.g., groundwaters). The data is necessary to confirm the source and the proportion of the outfall dry-weather flow contributed by the source (example given later). Without this information the likelihood of identifying the pollutant sources is greatly reduced. It is important to note that the tracer data should not be built up from data obtained for other area investigations.

A number of exotic tracers have also been proposed (cholesterol compounds, caffeine, pharmaceuticals, DNA characteristics of *E. coli* bacteria, stable ion ratios, etc.), but the analytical methods are usually very expensive and the detection sensitivities are inadequate for many of these potential tracers. However, it is likely that some of these, or others, may become very useful through further research and method development.

Field Surveys

Field investigations are used to locate and record all outfalls, and involve physically wadding, boating, etc. the receiving waters in search of all known and unknown outfalls. At each outfall the inspection and sampling should at least include:

- Accurate location of outfall and assignment of ID number;
- Photographs of outfall;
- Outfall discharge flow rate estimate (and note whether continuous or intermittent discharge);
- Physical inspection and record of outfall characteristics including odor, color, turbidity, floatable matter (fecal matter, sanitary discards, solids, oil sheen, etc.), deposits, stains, vegetation effected by pollutants, damage to outfall structure, and discharge water temperature; and

- Collection of dry-weather discharge samples for tracer analyses in the laboratory (specific conductivity and temperature can be field measured).

Intermittent flows will be more difficult to confirm and sample. Additional field visits, use of automatic samplers, and/or flow damming or screening techniques must be utilized for indicating and obtaining samples of intermittent flows.

Analyses of Data/Samples

The recommended analytical procedures and associated equipment in Pitt, *et al*. (1993) have been selected based on laboratory and field testing of analytical methods using the following criteria:

- Appropriate detection limits;
- Freedom from interferences;
- Good analytical precision (repeatability);
- Low cost and good durability; and
- Minimal operator training.

For consistent results the analyses should be carried out in the laboratory and not in the field, except for temperature and specific conductivity. Field analyses may be conducted for pH by using portable pH meters or litmus paper depending upon the degree of accuracy required and time constraints. Note that pH is a support tracer and not a primary parameter. The analysis method must provide adequate detection limits (i.e., measurement of the lowest required concentration) and precision (i.e., consistent results). In order to estimate the required detection limit it is necessary to know or estimate the tracer mean concentration and standard deviation.

Investigation and Remediation

The investigation of pollutant sources are divided into two major areas:

1. Analysis of outfall dry-weather data/observations to correlate with potential sources.
   - Observable parameters;
   - Simple check list for major flow component identification;
   - Flow chart for most significant flow component identification;
   - Matrix algebra solution of simultaneous equations; and
   - Matrix algebra considering probability distributions of library data using Monte Carlo statistical modeling

2. Upstream surveys to progressively narrow down the drainage area(s) of concern and locate the pollutant source(s).

Observable parameters are items covered by physical inspection, consisting of odor, color, turbidity, floatables, stains, vegetation, etc. These parameters will be clearly visible and indicate gross contamination at outfalls and may be indicators of intermittent flows. Observable parameters cannot be relied upon as a sole method for the evaluation of outfalls. A contaminated discharge may not be visible and can only be determined by other methods (Lalor 1993, Pitt, *et al*. 1993).

Summary

There are numerous stormwater treatment options available. General approaches for stormwater control can be described based on site specific rainfall and runoff distributions and a knowledge of local receiving water problems and use goals. The following general strategy could be reasonably followed, with numerous exceptions and substitutions available. On-site infiltration can be utilized to completely control (and eliminate) runoff from the smallest, and most common storms. This would significantly reduce the number of events occurring (and decrease the violations of bacteria and some heavy metals), while helping to match the pre-development hydrology of the area (protecting in-stream habitat). Moderate to large events are most effectively controlled through wet detention ponds where the water is treated before discharge. The large events are the basis for storm drainage design to prevent flooding damage. The largest events that may occur in an area will exceed the capacity of the storm drainage system. Therefore, site development must provide for these failures by directing excess water through safe secondary drainage systems and away from homes and primary transportation corridors. This general approach is most suitable in developing areas. Retro-fitting stormwater controls is much more challenging, less effective, and more costly.

In addition to the general approach outlined above, special consideration needs to be applied to critical source areas. These areas have higher than normal unit area pollutant loadings, especially for toxicants. Typical critical source areas include areas have some of the following characteristics: large amounts of pavement, storage of equipment or materials, scrap yards, frequent automobile starts, vehicle maintenance areas, etc. Public works practices (catchbasin inlets, oil/water separators, and street cleaning) have been used in these areas to control stormwater. However, these practices are mostly limited to litter and gross pollution control (obvious needed objectives), but have limited pollutant control for most pollutants of interest (such as nutrients, bacteria, solids, and toxicants). Emerging critical source area controls have been developed to provide a much greater level of treatment for stormwater from these areas. These controls must be applicable to small isolated areas and have minimal disturbance to site activities. Some of the most commonly used controls suitable for this use are stormwater filters. Newly developed information for different types of stormwater filters (and combination practices) indicate that moderate to high levels of treatment is possible for runoff from these critical areas.

Therefore, a successful stormwater management program for an area must be driven on site knowledge and objectives and may include numerous and different stormwater control practices.

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