CHALLENGING URBAN BMP ASSUMMPTIONS

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ABSTRACT

Records from nearly two thousand field operations for maintenance and cleaning on water quality vaults have shown trends in the effectiveness of Best Management Practices (BMPs). Strategies have been developed in the design and evaluation of BMPs that work counter to providing effective water quality results in space-limited structures in an urban setting. Currently accepted testing protocols are not capable of recognizing the weakness of these poor strategies. These strategies include: Limiting treatment to the “first flush” storm; using “bypass” as a technique to reduce the size of structures by avoiding high flows: and using indirect automated sampling devices to evaluate these types of structures.

INTRODUCTION

There are two broad classifications of structural BMPs. This paper is concerned with devices or techniques that are intended to capture and hold materials that can be separated by gravity, buoyancy, screening and skimming. These will be termed, “Physical Separators”. The other classification of structural BMPs relies on long term settling, filtration, precipitation, chemical, or similar means to capture and hold particles that are dissolved, in suspension, small in diameter, similar in relative density to water, or that for other reasons do not lend themselves to physical separation. These types of devices will be termed, “Low Energy Separators”.

Early in the development of techniques intended to separate pollutants from storm water, two pillars of thought were developed that provided great benefits for those attempting to engineer solutions for this problem. The first pillar was the concept that most of the harmful material in storm water was contained in, or associated with, the smallest particles or that the material was dissolved. The second pillar, built upon the first, was that most of the small particles and dissolved chemicals were transported immediately off of surfaces in a “first flush” phenomenon. Together, they led to the idea that simply treating the “first flush” of water from a site would meet water quality goals. Opinions about what constituted the “first flush” varied from one quarter inch of rainfall in twenty four hours, to two and a half inches of rainfall in twenty four hours. The standard practice became to design all BMPs in light of these assumptions, and test them with automated samplers to evaluate performance. Both the tests and the sampling devices were biased towards Low Energy Separators, and targeted the pollutants they were intended to capture. While this may be an effective way to evaluate these technologies, it is the wrong way to evaluate Physical Separators. As a result, Physical Separators have been assumed to be ineffective, when the opposite may actually be true. If most of the pollutants are contained in the larger fractions of material transported by storm water, then it certainly is true.

THE DATA

Data in this report came from two sources. The major source of data was physical measurements taken from nearly two thousand maintenance operations on Physical Separators by CrystalStream Technologies’ field crews doing on-going cleaning and disposal for these devices.

These data are supported by disposal manifests, documenting the source, data, and the amount of materials discharged. This data was collected in the southeastern United States, and represents over four hundred device-years of operation at 160 locations. The types of sites represented include mostly commercial, some residential and office, and a few industrial sites. Almost all of the sites were in an urban environment. A secondary source of data is a detailed study on one device located in a public right-of-way. The watershed for this device is a public highway and adjacent lands. This data is verified under the "Environmental Technology Verification Report" (in draft, March 2005) for this device, prepared by NSF International (Ann Arbor, Michigan, www.nsf.org)[2] under a cooperative agreement with the U.S. Environmental Protection Agency. This data will be utilized to present principles of sediment transport and indirect testing, and is in no way an endorsement of any device or type of product.

SUSPENDED SEDIMENTS LOADING ESTIMATES VERSUS FIELD DATA

Many studies have been conducted to estimate the sediment loadings for storm water runoff. The *"National Urban Runoff Program" (NURP, EPA, 1983)*[1] characterized loadings for residential and commercial sites at 101 mg/L and 69 mg/L respectively, but numerous studies have followed, along with models to estimate loadings for various types of sites. Almost all fall in a range from 50 to 250 mg/L. These estimates vary by a large amount, but this is due to the nature of the data that the estimates are based upon. When dealing with sediment transported by water, it is very difficult to collect a representative sample at any given moment. Once samples are collected, the method of analysis is problematic at best. If the samples are truly representative, and the analysis correct, designating any single site or group of sites as typical is a very difficult decision. Finally, rainfall is predictable over long periods and large areas, but the patterns on small sites during short events are chaotic.

With the very large body of data associated with the efforts to make loading estimates, the range should be useful for analyzing the performance of BMPs, if not definitive. The field data collected for the Physical Separators in this study were reported in pounds per acre per year (PAY). To convert the range of loadings in the literature to PAY, the following method was used. If the annual rainfall in inches is known, and the sediment loading in mg/L is known, a simple calculation with a conversion factor will give the annual sediment transported by runoff. The annual rainfall in inches can be multiplied by the loadings and divided by 4.412799 to give annual pounds per acre. The rainfall depth should be adjusted downward to the percentage that runs off of a site. Using this method to look at a one acre impervious site with 90 per cent annual runoff and a 48 inch annual rainfall total, we see that the PAY associated with the loading range is from 489.5 to 2,447.4 pounds per acre per year. In the study area, annual rainfall rates are reported at an average of 54 inches per year, so the loading range for the study area would be from 550.7 to 2,753.4 pounds per acre per year.

The field data was collected from March 31, 2000 through December 30, 2004. There were 154 devices involved with 1,842 maintenance operations. Figure 1 shows the PAY for each site plotted against the acres tributary. All sites are shown, even though some sites include offsite acreage, and the Physical Separators used external bypassing to allow the excess flow to pass untreated. Other sites were implemented for spill protection only, and served more acreage than a device dedicated solely to water quality. Some sites were forced to bypass by regulation. The PAY data points shown were determined for each site individually by taking the total pounds removed, and dividing by the acres tributary and the number of years in service. The average site had 5,277 PAY, taking each site's performance and weighing it equally (Calculate PAY for each site, then take the mean (average) of the sites as a group).

Overall, there was more than 1.7 million pounds of material removed over a total of 116,556 device-days. If all the sites are taken as a whole, so that the data would reflect one large site, the overall removal rate would be 2,340 PAY (Take the total weight removed, divide by the total acres and divide by the average years of service). This compares well to the high range of predicted sediment loadings for this group of sites, although it is biased low, due to flows bypassing the devices. The individual site average of 5,277 PAY suggests that the predicted loadings may be low.

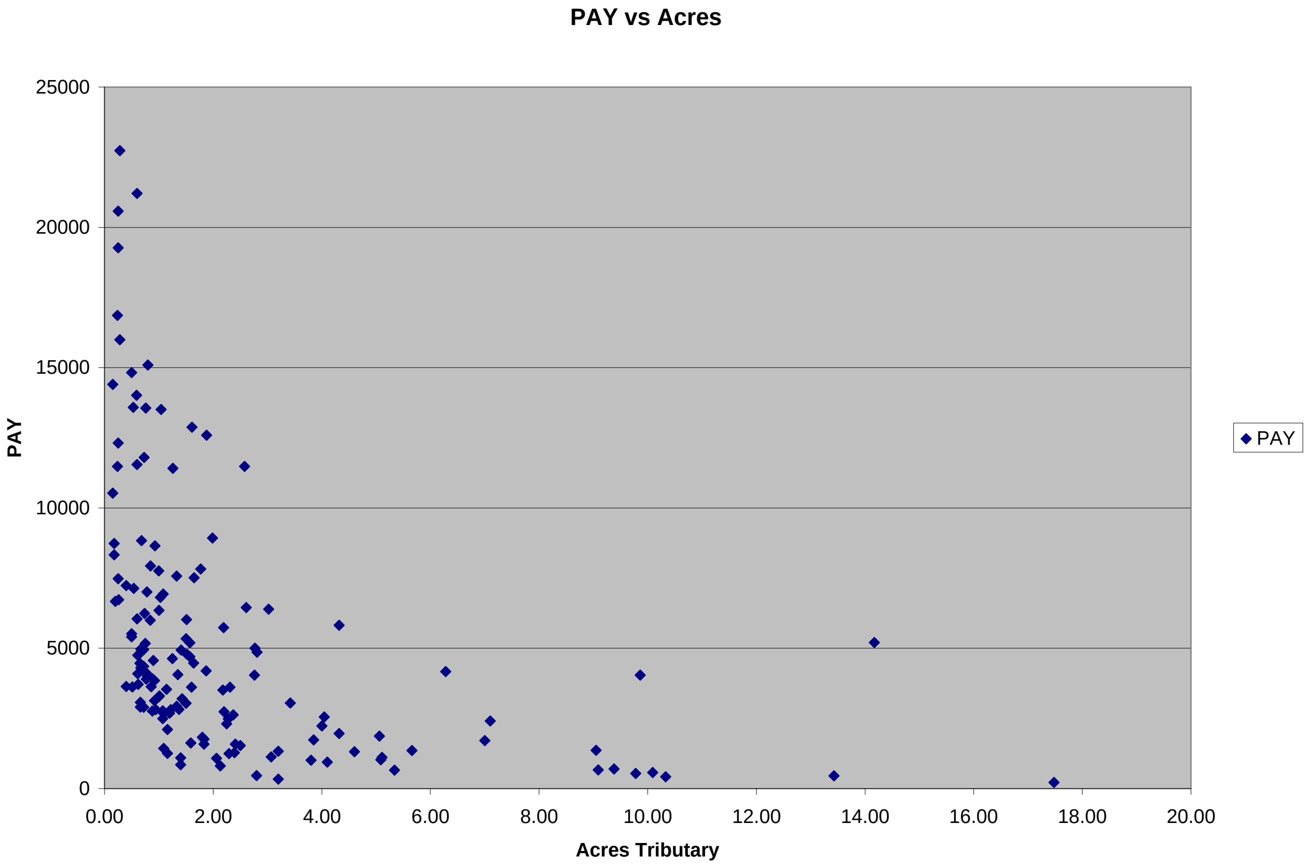

Figure 1 PAY versus Acres Tributary

Figure 2 shows the same data, with the bypass sites identified in a lighter color. The bypass sites treated only the flow designated as the “water quality” flow, and higher flows physically bypassed the device. In all cases for this data set, the “water quality” storm was either the 1 inch, or the 1.2 inch first flush event. The pattern of lower removal rates for the bypass sites is readily apparent. The average bypass site removed 2,353 PAY while the average non-bypass site removed 6,346 PAY. The theoretical advantage of bypassing high flows is that re-suspension of materials already captured can be avoided, but the data shows that while that may be true, more material is missed than is “saved”. Our knowledge of sediment transport backs up the idea of staying “on line” to treat higher flows. The ability of water to transport material increases as the flow increases. At the same time, the danger of re-suspension increases as the flow increases.

There is a point somewhere between bypassing at a selected water quality storm, and treating all flows that is the perfect point of treatment. At this point, the maximum amount of material is removed, with the least loss due to re-suspension. In this data set, the devices were inspected every 90 days, and cleaned as necessary. The average device was cleaned 2.2 times yearly. The aggressive inspection and cleaning regimen minimized losses due to re-suspension, by limiting exposure to high flows. The data indicates that requiring or allowing bypass for all sites reduces the effectiveness for Physical Separators.

The average removal of 6,346 PAY for the non-bypass sites suggests that at least for this group of sites, the predicted loading rates are low. There are several factors that may be at work to produce the higher removal rates. One major factor is the bias toward selecting Physical Separators for ultra-urban and “dirty” sites. The small footprint of urban sites, and the high percentage of impervious surfaces, which provide good transport capabilities also may have an effect. In general, these types of sites will have higher sediment loadings and better material delivery.

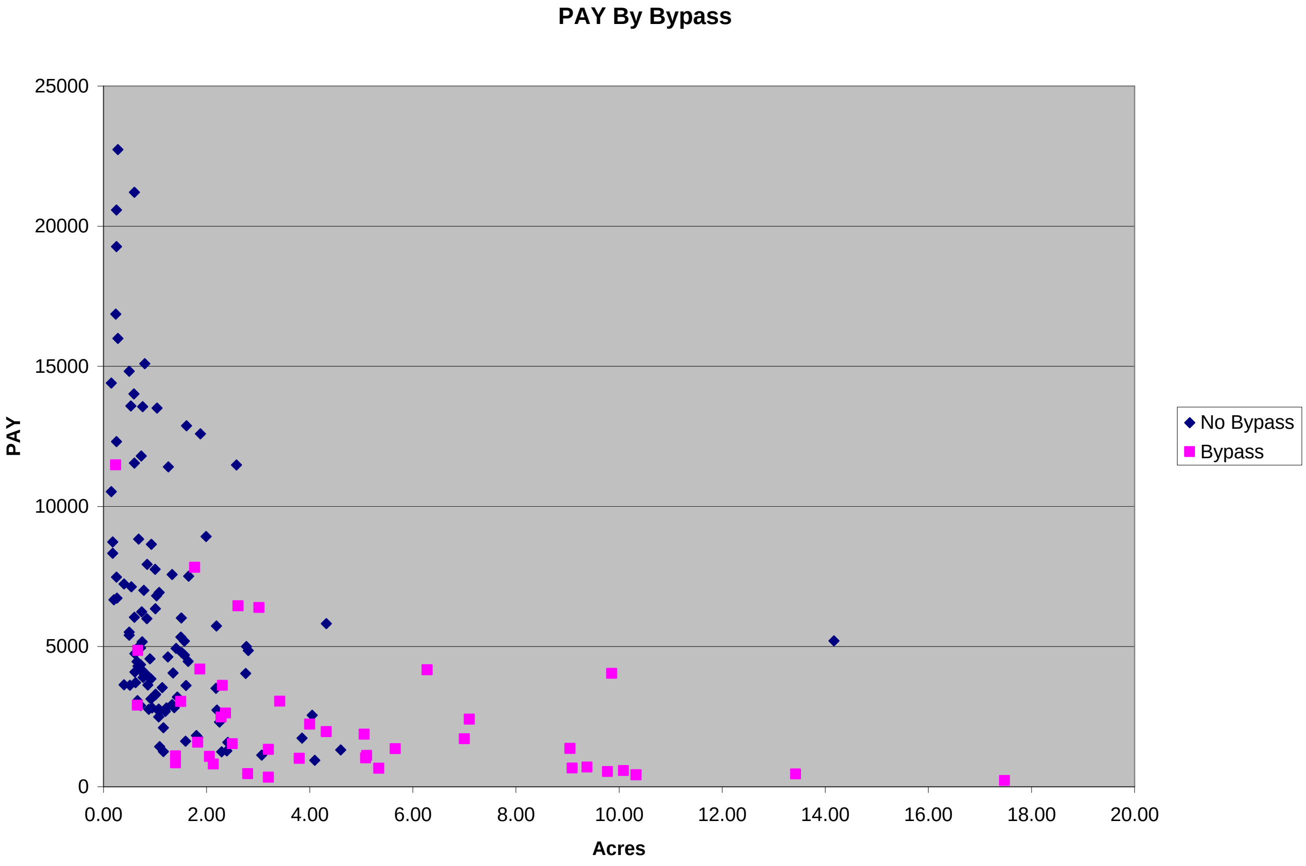

Figure 2 Bypass versus No Bypass

SAMPLING AND TESTING METHODS

In looking at the field data, and comparing the removal results with the predicted loadings, it is useful to assess the entire data set, but when the data is examined in the light of “average loadings”, it is wrong to include the bypass sites which had no chance to capture the entire sediment load. In addition, the physical separators certainly did not capture all suspended sediments, so the actual load carried by the run-off must have been higher than the material retained in the devices. The non-bypass sites averaged 6,346 PAY captured with all sites weighted equally (see methodology above), which is far in excess of the predicted loadings. If the devices were considered 90 per cent effective at capture, the sediment load would be 7,054 PAY. If the entire non-bypass data site is considered as one large site (as above) the average capture rate is 3,825 PAY, adjusted to 4,250 for 90 per cent capture efficiency. This disparity cannot be explained away simply by the bias to more urban sites. The NURP estimates from 1983, for example, actually attribute a lower loading of 69 mg/L to commercial sites while attributing a 101 mg/L loading to residential sites. A loading of 69 mg/L with 54 inches of annual rainfall would estimate 844.4 PAY or 12 per cent of the observed removal weights.

There are several major factors in the sampling and testing programs that develop estimated loadings, all of which act to under-report the sediment loads in storm water. The most challenging aspect of sampling storm water run-off is to get a representative sample. Due to the nature of sediment wash-off, which is by no means steady and constant from impervious surfaces, a sample taken at any given moment cannot be considered representative. If the moment of sampling were, by chance, representative, it is difficult to sample the entire water column, which tends to sort the particles by size, with the largest (and heaviest) near the bottom. If the sampling point did happen to be perfectly representative, an automated sampler equipped with a small suction line and a strainer would not have the power to lift the largest particles into the sample bottle. Gravel and pebble size particles are (2000 microns to 64,000 microns) are routinely found in materials removed from Physical Separators, none of which could pass the strainer, much less be lifted by the pump in the sampler. With a grab sample, or other types of samplers, these materials could be collected. Given the sample actually contained all particles, taken at the perfect sample point and a representative time, the next hurdle for determining the sediment loading would be the method of testing.

For the devices in this data set, only one device was involved in a controlled, well documented third party study. In that study, which utilized strict quality assurance and quality control, two test methods were employed to measure the suspended sediments in the samples. The samples were scientifically split, and tested for sediment concentration by the TSS method (EPA 160.2, *EPA Methods and Guidelines for the Analysis of Water* procedures) and the SSC method (ASTM D3977-97, *American Society of Testing and Materials* procedures). Figure 3 is the raw numerical data for the storm events in the study.

			TSS		SSC	
Event No.	**Date**	**Outlet Runoff Volume (gal)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Inlet (mg/L)**	**Outlet (mg/L)**
1	3/26/03	13,800	12	12	138	195
2	5/5/03	32,900	30	36	4430	103
3	1/25/04	2,890	32	29	NA	NA
4	4/13/04	20,240	190	141	157	120
5	4/26/04	10,600	34	61	241	139
6	4/30/04	16,600	46	30	155	91
7	6/25/04	4,265	99	92	143	109
8	6/28/04	9,730	59	50	205	55
9	6/30/04	44,800	16	14	38	34
10	7/12/04	9,040	56	64	220	82
11	7/17/04	9,700	64	70	113	78
12	7/25/04	22,400	104	54	177	52
13	8/5/04	15,400	60	22	1172	33
14	8/12/04	17,100	24	52	320	74
15	8/21/04	5,870	50	16	235	61

Figure 3 Sediment Loadings in ETV study

The data overall show that on identical samples, the TSS test consistently under-reported sediment concentrations. Figure 4 is a chart that compares the influent sediment concentrations for both methods. Event two, where TSS under-reported by the largest margin, was omitted to make the chart more readable, and Event 3 was omitted as the SSC data was not available.

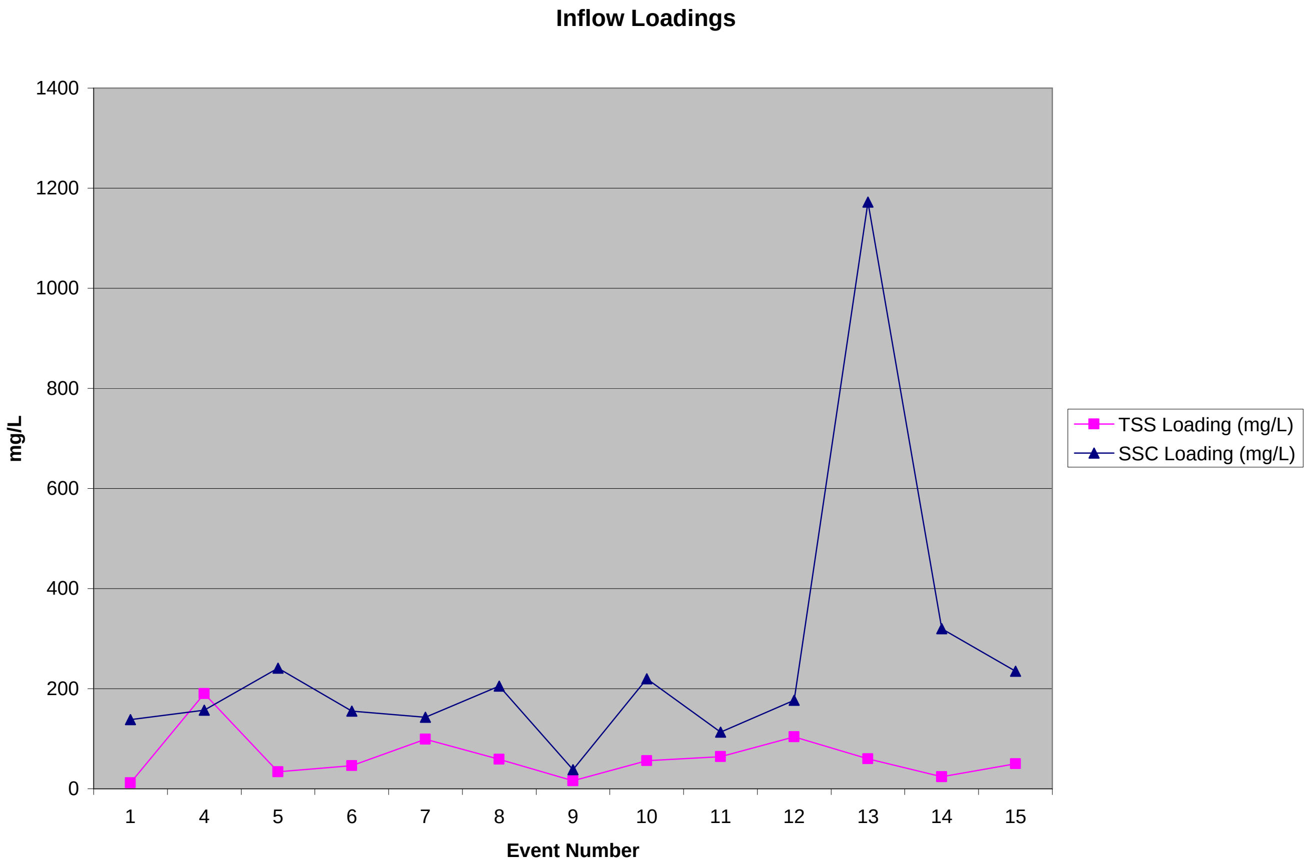

Figure 4 TSS versus SSC Influent Concentrations

Figure 4 clearly shows the consistent nature of the inability of the TSS test to accurately identify the amount of sediment in the samples. Figure 5 is a chart similar to Figure 4 that compares the effluent concentrations for the samples.

These data reveal an inherent weakness in the TSS method to detect larger particles. The ETV study determined an average particle size ratio of sand to fines of 78 per cent sand to 22 percent fines (silt and clay) for the influent, and an average ratio of 13 per cent sand to 87 per cent fines for the effluent. Clearly, when the reported concentrations in the effluent samples are compared, where the content of the sediment load contained more small particles, the TSS test tracked the SSC test much more closely, although it still consistently under-reported. In the influent comparison, the TSS was simply unable to detect the larger particles present in the sample.

The two methods each attempt to measure sediment concentrations in water, but the TSS test requires the analyst to withdraw an aliquot from the sample container, where the SSC test requires the use of the entire contents of the sample container. When the sample contains a large percentage of large, settleable particles, it may be difficult to acquire a representative sample. Overall in the testing procedures, the TSS test showed low precision on duplicate samples, and the results fell outside of the “relative percent difference” (RPD) parameters established for the testing. The SSC testing was well within RPD limits.

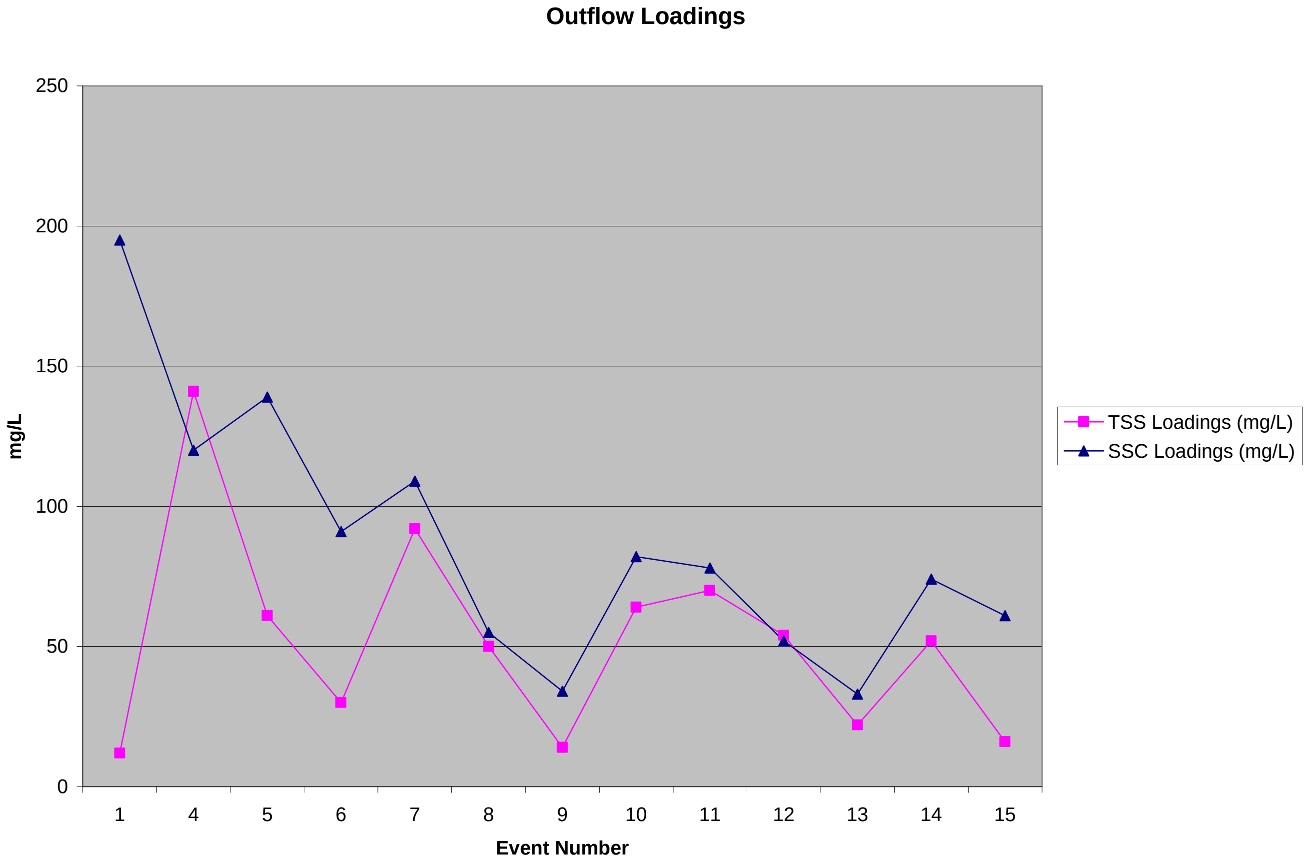

Figure 5 TSS versus SSC Effluent Concentrations

Until recently, the bulk of the measurements for sediment loading concentrations relied on the TSS test method, which may help explain why the average loadings reported are below the field data compiled on the devices in this study.

SUMMARY

Although the field data set spans over 4 years, more study is needed to verify observed removal weights over time. Data will continue to come in as additional cleanings occur. The manufacturer is entering new markets nationwide, which will produce data from various climate zones, including arid and semi-arid areas. Analysis of sites by use, and by site geometry is also indicated, to better establish entrainment and transportation rates for various types of areas.

The existing data indicates that limiting the treatment flows to Physical Separators lowers the overall performance of these devices. The data also clearly indicates that by-passing flows as a general policy also limits performance.

The physical field data, when compared with estimated loadings from studies and models, shows that the models and estimates under-estimate the amount of material available for removal, at least for this data set. The low estimates may stem from sampling and testing protocols which are biased towards small particle sizes, and which may be inappropriate for evaluating the sediments in storm water run-off. This theory was supported by documented data from a 3rd party test utilizing TSS and SSC testing methods to analyze samples collected from a device studied under the ETV protocol.

1. U.S. Environmental Protection Agency, Final Report of the Nationwide Urban Runoff Program, Water Planning Division, Washington, D.C.,1983

2. Environmental Technology Verification Report (Draft), Stormwater Source Area Treatment Device, Practical Best Management of Georgia Inc., CrystalStream ™ Water Quality Vault, Model 1056, Prepared by: NSF International, 2005