NON-POINT SOURCE POLLUTION VARIABILITY
Successful Structural BMPs Require Better Site Analysis

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ABSTRACT

There are two obvious parameters that directly affect pollutant delivery, capture, resuspension, and eventual removal for any given site. One parameter cannot be controlled, and that is the rainfall patterns for the site. The second parameter is the physical characteristics of the pollutants generated on the site which are in large part controlled by the nature of the site's physical characteristics, but which also can be affected by the storm drainage system design. This study normalizes, as much as possible, these factors by concentrating on sediments as the pollutant of concern, and by only using data within one geographical area. Although these two parameters (weather and pollutant loading) are mostly beyond the control of the BMP (Best Management Practice) designer, it is important to understand how differing site conditions affect performance. There are parameters that are completely controllable by the BMP designer, such as the size and configuration of the structure. In this study, the internal components of the structures were essentially identical, and the one variable parameter was the size of the vault. The relationship of theoretical design flow versus the actual site flows has been shown to be the single most important parameter affecting performance. This parameter is typically expressed as the "hydraulic loading rate" for the structure, or "HLR." In addition to the field data presented here, full scale laboratory testing was conducted on one of these vaults, where the removal of a known particle size distribution was studied from 40 percent to 200 percent of calculated treatment flows to simulate conditions from ideal to extreme.

The data used in this study were derived from over 4,000 cleaning and maintenance operations on 238 water quality vaults. The pounds of sediment per acre per year (PAY) removed from the devices was the parameter analyzed for performance comparisons. In addition to basic HLR evaluations, other parameters such as the percentage of impervious pavement, the overall size of the site, and the category of the site usage were also compared to understand how they affect the pollutants washed off by stormwater. Very definitive trends have emerged that give support to some basic assumptions about non-point source pollution control, and that call others into question.

DESIGN FLOW, CAPTURE RATES AND RESUSPENSION

Theoretical science tells us that, given a certain rate of flow, larger vaults will have a longer resident time and slower velocities than smaller vaults. Surface loading, which is defined as the ratio of the flow rate to the surface area, has been demonstrated to govern the capture of particles for vaults that are equal in volume, but that differ in "footprint." For an equal volume, a vault that is shallower will be longer and/or wider than a deeper vault. Equal volume produces the same residence time for a given flow, but the deeper vault (with less surface area) will require more time for a certain particle to settle out to the greater depth. Surface loading is unquestionably the biggest factor in particle capture, but other parameters come into play. For this study, surface loading is described as "Design Percentage," in that each vault has a measured surface loading, and has a rated maximum flow capacity. The "Design Percentage" is the ratio of actual flow to the design flow, and while it is not exactly equal to the surface loading, it will correspond to, and will vary in direct proportion to surface loading.

Theoretical science also tells us that higher velocities will scour and resuspend larger particles than lower velocities. The Design Percentage parameter used in this study will also track resuspension rates, as vaults with lower Design Percentages will have lower velocities overall.

The formula for surface loading is: HLR = Q/LW; where HLR is the hydraulic loading rate, Q is the flow rate in cubic feet per second (cfs), L is the length of the vault in feet and W is the width of the vault in feet. The HLR (in ft/second) then is the flow in cfs divided by the surface area in square feet (sf). It is equivalent to the fall rate of a particle to be captured. Particles with a lower fall rate require a lower HLR. This means that the capture rate will vary inversely as the flow (Q) varies. As the flow increases, the HLR increases, so two times the flow will give one-half the capture rate. It also means that as area (LW) increases, the hydraulic loading rate (HLR) gets smaller and smaller particles will be captured. The vault that was laboratory tested had a constant surface area, so capture should vary inversely as the Q varies. Figure 1 shows a performance chart for one of the vaults with the removal of a graded particle sample plotted against flow in cfs.

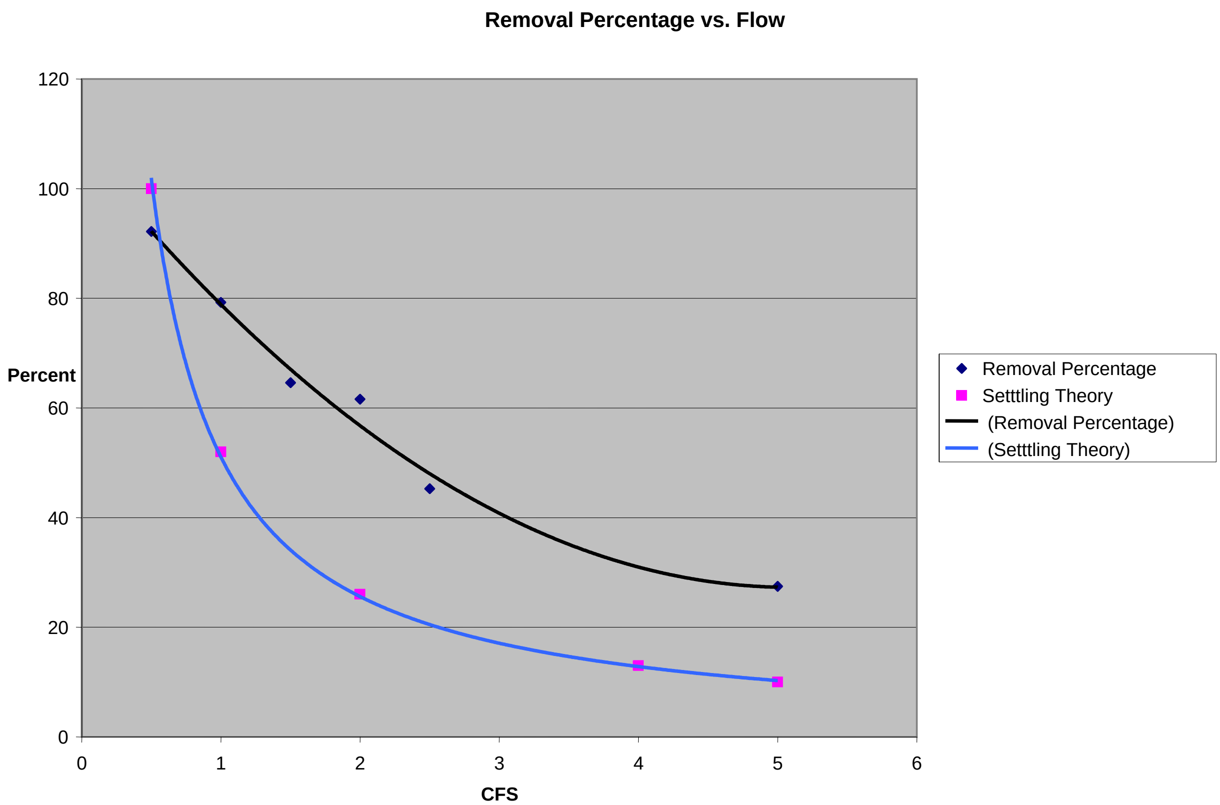

Figure 1

Actual lab test data indicates that for the graded particle sample introduced, the capture rate for the vault studied is a curve with the following data points of interest: ½ cfs = 92.2 % removal, 1 cfs= 79.8 % removal, 2 cfs = 61.60 % removal, 4 cfs = 32 % removal, 5 cfs = 27.44 % removal. These values are plotted on the chart in Figure 1 as “Removal Percentage.”

The vault studied in the lab had a surface area of 37.5 sq. ft, so at the flow rates listed above it had a HLR (in feet per second) of: ½ cfs = .0133, 1 cfs = .0267, 2 cfs = 0.0533, 4 cfs = .1067, 5 cfs = .1333. These values are plotted on Figure 1 as “Settling Theory.” The material introduced had a relatively narrow particle size distribution centering around 90 microns. The falling velocity (V) is equal to the

HLR, so a 90 micron particle which has a V of .013889 according to Stokes Law would be captured at the following percentages, theoretically: ½ cfs = 100%, 1 cfs 52 %, 2 cfs, 26%, 4 cfs 13%, 5 cfs, 10%. Stokes Law does not apply to turbulent conditions, or to conditions during a transition from quiescent to turbulent flow, but it is interesting to note that the removal rate under actual flow in the lab exceeded the predicted removal rates under ideal conditions as can be seen by comparing the "Removal Percentage" curve to the "Settling Theory" curve in Figure 1. The results shown on the chart in Figure 1 do not track well because of the effects of the particle size distribution and because of additional treatment elements in the device, including a fiber filter. Looking at both sets of data, it is obvious that the principle of surface loading is observed in actual particle removal testing, even if it does not exactly correspond. It appears that the vault performs better than predicted by Stokes Law, but this is not the case. As mentioned above, Stokes Law involves essentially quiescent conditions, and a vault under flow exhibits the advantage of mixing upon entry, which effectively lowers the depth of the vault for almost all particles.

DEFINITION OF TERMS

This paper uses "pounds per acre per year (PAY)" as the measurement of performance for the vaults studied. Most models and studies use load concentrations expressed in milligrams per liter (mg/L), which is meaningless to most casual observers. The following is a short explanation of PAY and how it relates to the existing literature.

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.

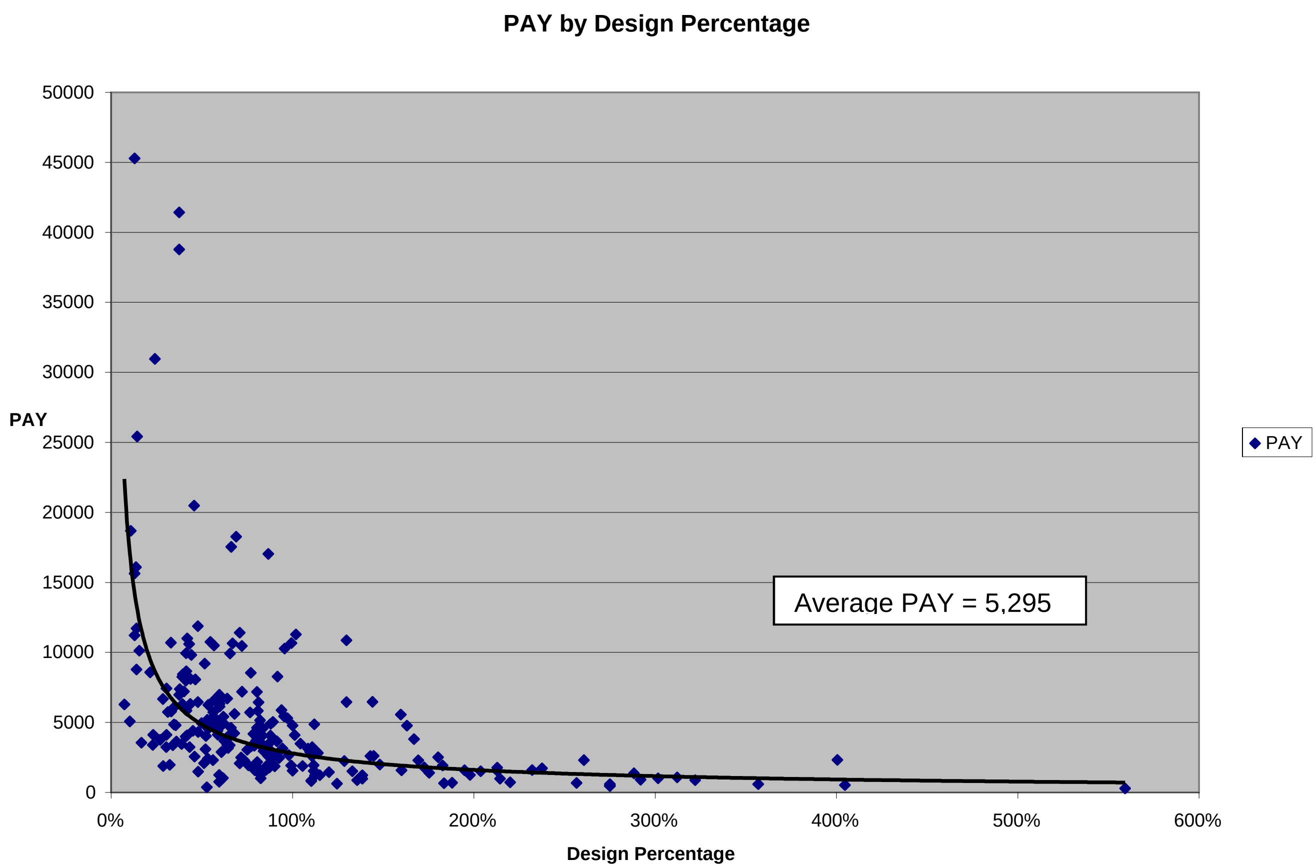

Figure 2

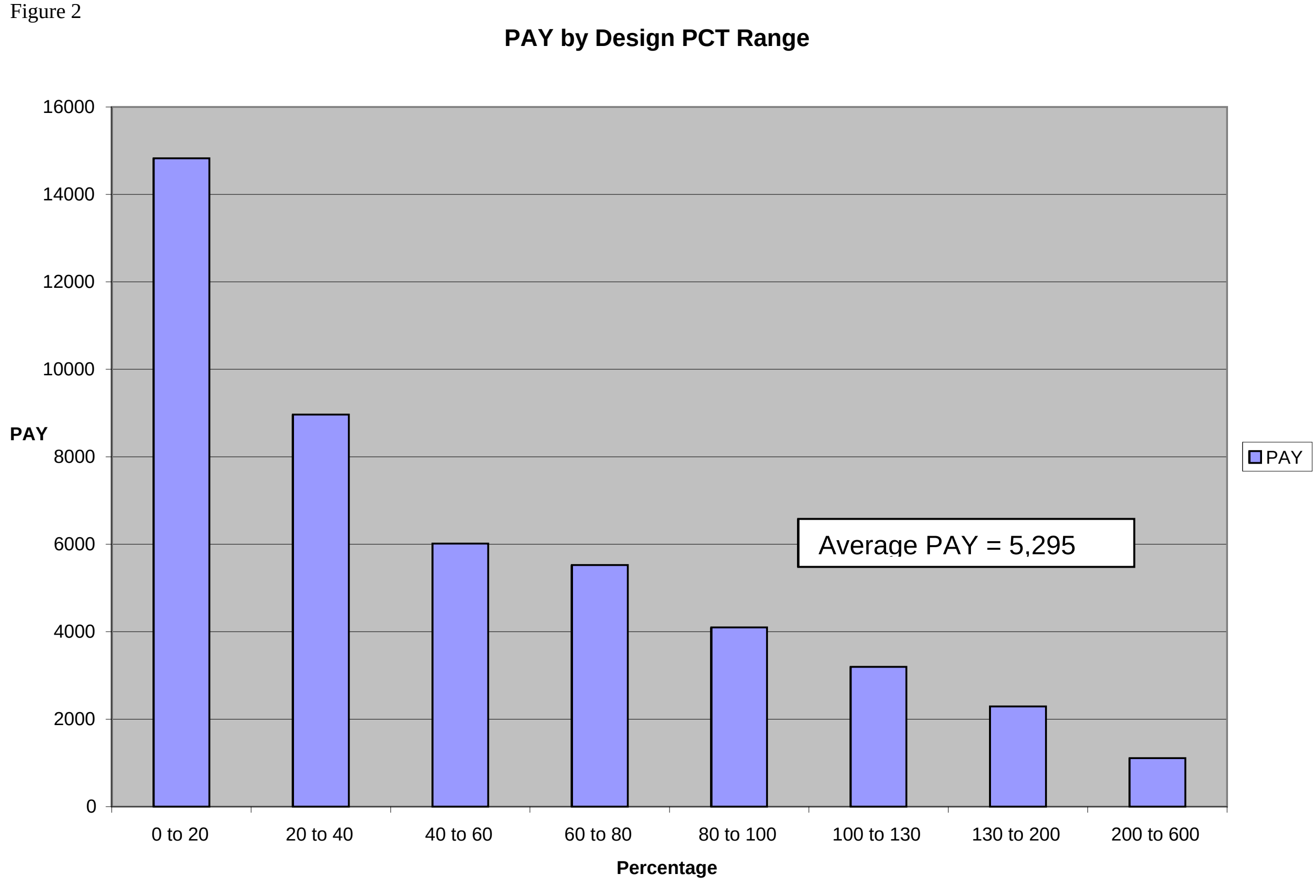

Figure 3

DESIGN PERCENTAGE AS THE DOMINATE PERFORMANCE PARAMETER

Figure 2 shows a trend line for the PAY removal versus design percentage, and illustrates that while a general trend exists, design percentage or surface loading cannot be the only factor at work. The data is much too variable to rely on design percentage alone. The trend of lower removal rates for devices allowing higher flows is statistically obvious, but it does not dominate the removal rates which show considerable variation with points above and below the curve in Figure 2.

To fully illustrate the variability, Figure 3 provides another way of looking at the same data. The PAY removal rate is averaged by range of design percentage. While establishing a trend is good for understanding this data, the data behind the range divisions in Figure 3 show that while the design percentage or HLR may dominate performance, there is more at work here than simply the design percentage effects.

OTHER PARAMETERS AFFECTING OPTIMAL TREATMENT FLOW

The effects of some other parameters were investigated but were not quantified for various reasons. These included the mode of transportation for the storm water, seasonal rainfall patterns, and the frequency of cleaning. The vast majority of sites had pipes as the final conveyance leg to the vaults, and the remaining data set (not pipes) was too small to make valid comparisons against those employing pipes so transportation mode was not studied in detail. The average device was maintained and pumped out 2.2 times yearly, and the distribution of cleanings did not show significant seasonal variations. While there is no doubt that less frequent cleanings will lead to more resuspension and leaching of captured materials, the number of jurisdiction requiring in excess of two cleanings per year are almost nonexistent, and the data set of vaults cleaned more frequently than average was too small to compare statistically.

Parameters that seemed to show significant impact on removal rates in addition to the design percentage or surface loading were: total site acreage, the type of site usage, the percentage of impervious surface, the position in a treatment train, the decision to bypass high flows, and the number of days in service.

SITE ACREAGE

Total site acreage, all other things being equal, determines the flow for a site. Hydrologists determine the characteristics of that flow using several methods, but in general, small sites tend to peak faster and produce higher flows (taken as cfs/acre) than large sites. The extreme example would be watching your front yard flood momentarily during a thunderstorm, and then observing the local creek reaching its peak hours later. Large sites tend to mitigate high flows and spread them over time. Figure 4 shows the PAY removal rate for this data set by size in acres. Figure 5 shows the same data using a bar chart with defined ranges. The trend is obvious, with the smallest sites clearly having the highest removal rates. These small sites are usually commercial, high traffic, and have very high relative flows. There is a lot of material generated which are subjected to high flow velocities with a short distance to travel to the vault. The very large sites usually encompass high percentages of roof or unused parking spaces, lower traffic, relatively lower peak flows (taken is cfs/acre), and a long path to the vault, sometimes through landscaped areas.

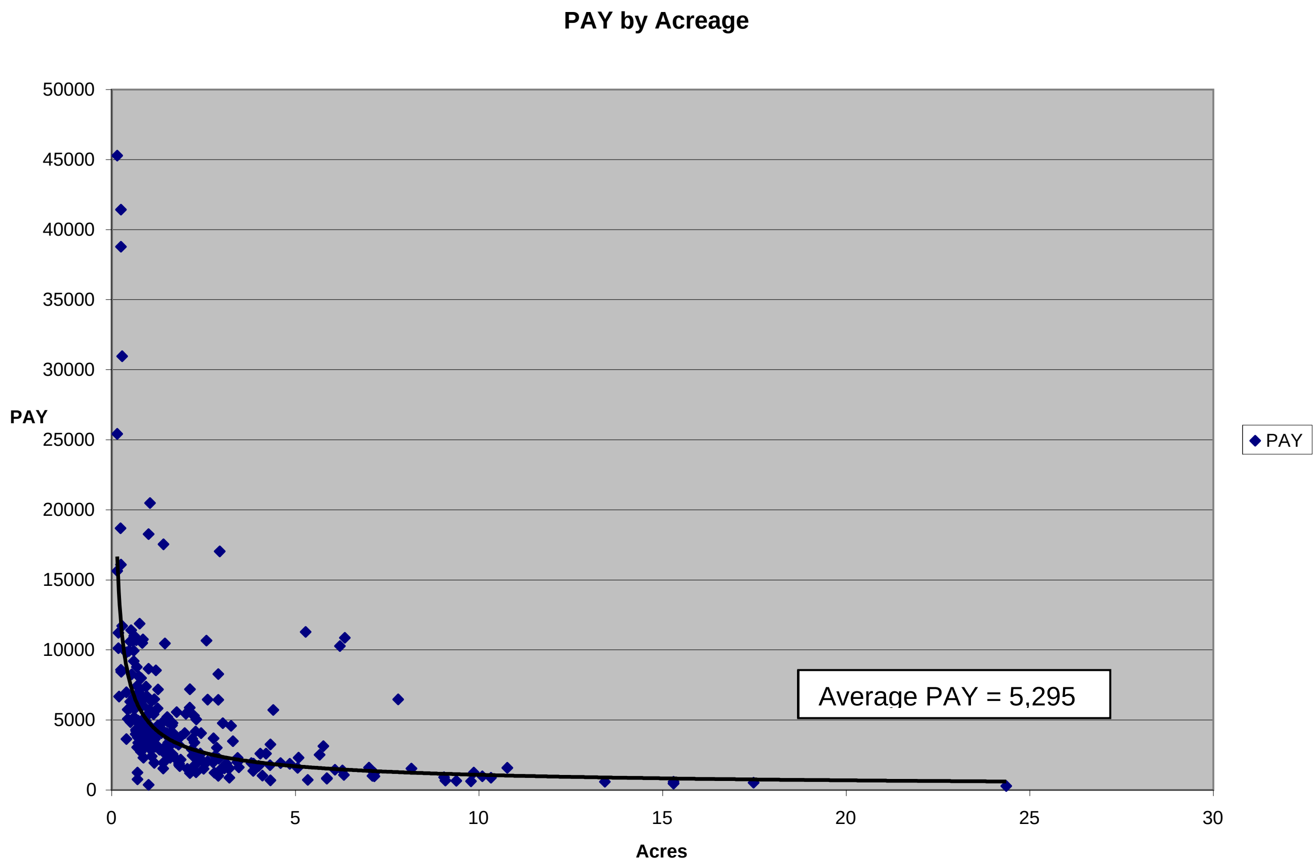

Figure 4

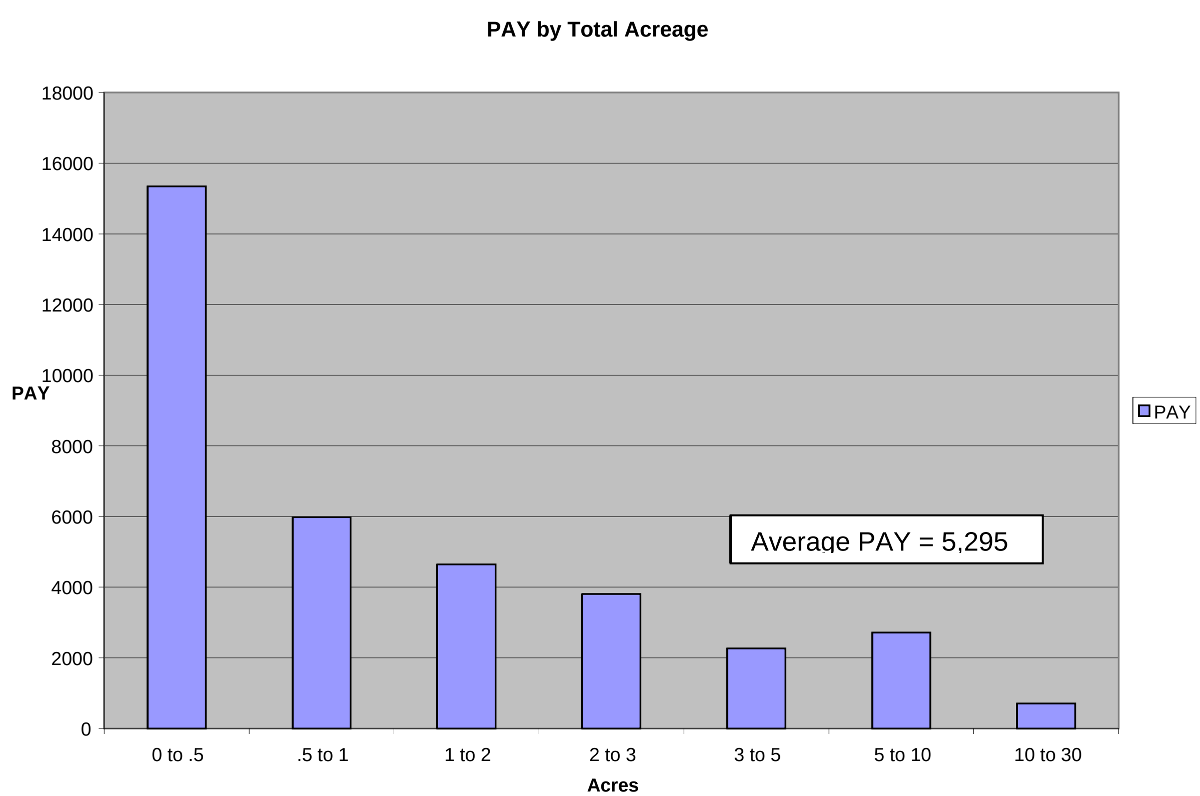

Figure 5

It is notable that there are only a few exceptions where the PAY exceeded the average on sites over 5 acres, and no exceptions over 10 acres. In fact, no site over 10 acres achieved over 2,500 PAY.

A poorly designed vault with a high percentage of design flow might still have high PAY on a small site that contributes a high sediment mass. On the other hand, an over-designed vault with a very low percentage of design flow on a large college campus might appear to have very low PAY, even though it actually out-performs the other vault in every aspect. The size of a site should be a big part of decision making for surface loading/design percentage. The same vault, tested in the same lab, and designed to the same jurisdictional regulations might be over-designed for a large site and completely inadequate for a small site. The principle to apply to system design is that the design flow percentage, which affects removal rates based on flow, is critical on small sites, and may be less important on large sites.

IMPERVIOUS SURFACES

A high percentage of impervious surfaces is often said to produce high pollutant loading. The engineering data, including the total acreage and impervious acreage was available for every site in this study. This parameter was studied in two ways. First, the percentage of impervious was studied regardless of the overall size of the site. Second, the total impervious acreage was studied to see if the connected total surface showed a trend.

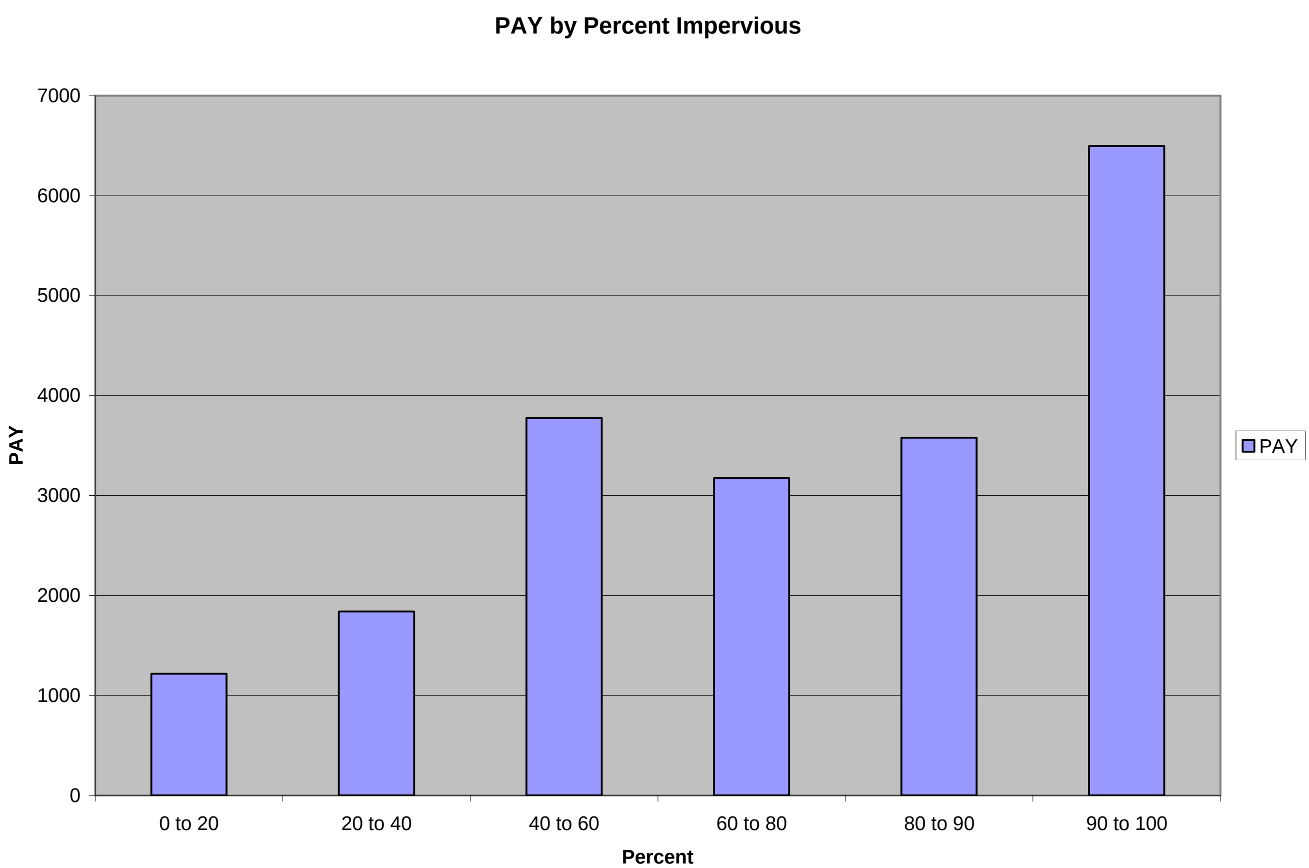

Figure 6

Figure 6 plots the PAY versus the percentage of impervious on the site. This chart shows clearly that there is a relationship between the PAY removal and the amount of impervious on the site. The implications for proper system design are that a highly impervious site may need a more conservative approach to its design percentage, and certainly will need a more aggressive cleaning regimen. Somewhere around 50 per cent impervious is the point where pollutant generation and delivery become critical.

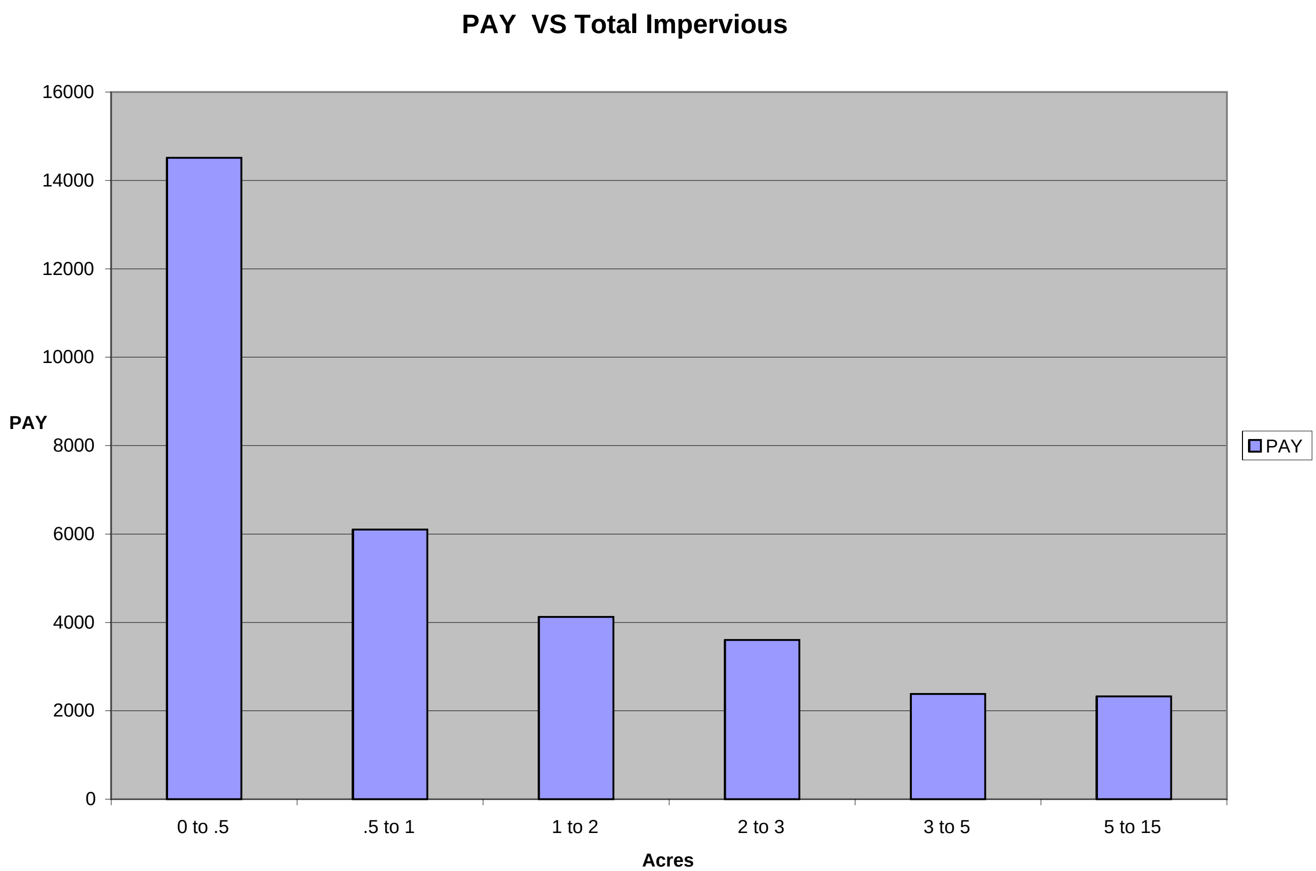

Figure 7

Figure 7 plots the total impervious acreage on a site versus the PAY. This chart shows an interesting pattern in that larger impervious areas do not increase the PAY and, in fact, reduce the PAY. There may be other factors involved here, but there is one very evident trend. Small impervious surfaces have a very high PAY. Overall, Figures 6 and 7 illustrate that the "common knowledge" that high percentages of impervious sites are large pollutant generators, and that small impervious sites are among the highest generators is a valid observation. The implication for system design is that special attention needs to be paid to these types of sites with high loading rates.

FLOW RESTRICTIONS AND IMPAIRMENTS

Often a BMP designer will incorporate a vault as a part of a treatment train, or series of various structures. The position of the vault in the series of structures can be an important factor in the performance of the vault. It is tempting to place a vault downstream of another practice, such as a pond or an infiltration/retention system. This is done to reduce the flow to the device, and to allow the vault to be smaller and less expensive. More often than not, the vault is placed behind an external flow bypass, or has an integral internal bypass to avoid higher flows reaching the device. The general idea is to make the vault smaller and avoid the possibility of resuspension. When the HLR is considered, making a vault smaller would seem to be the wrong tactic. The results of impairments in general have been studied, with specific impairments such as flow restrictions, bypasses, and detention being isolated to measure their effects.

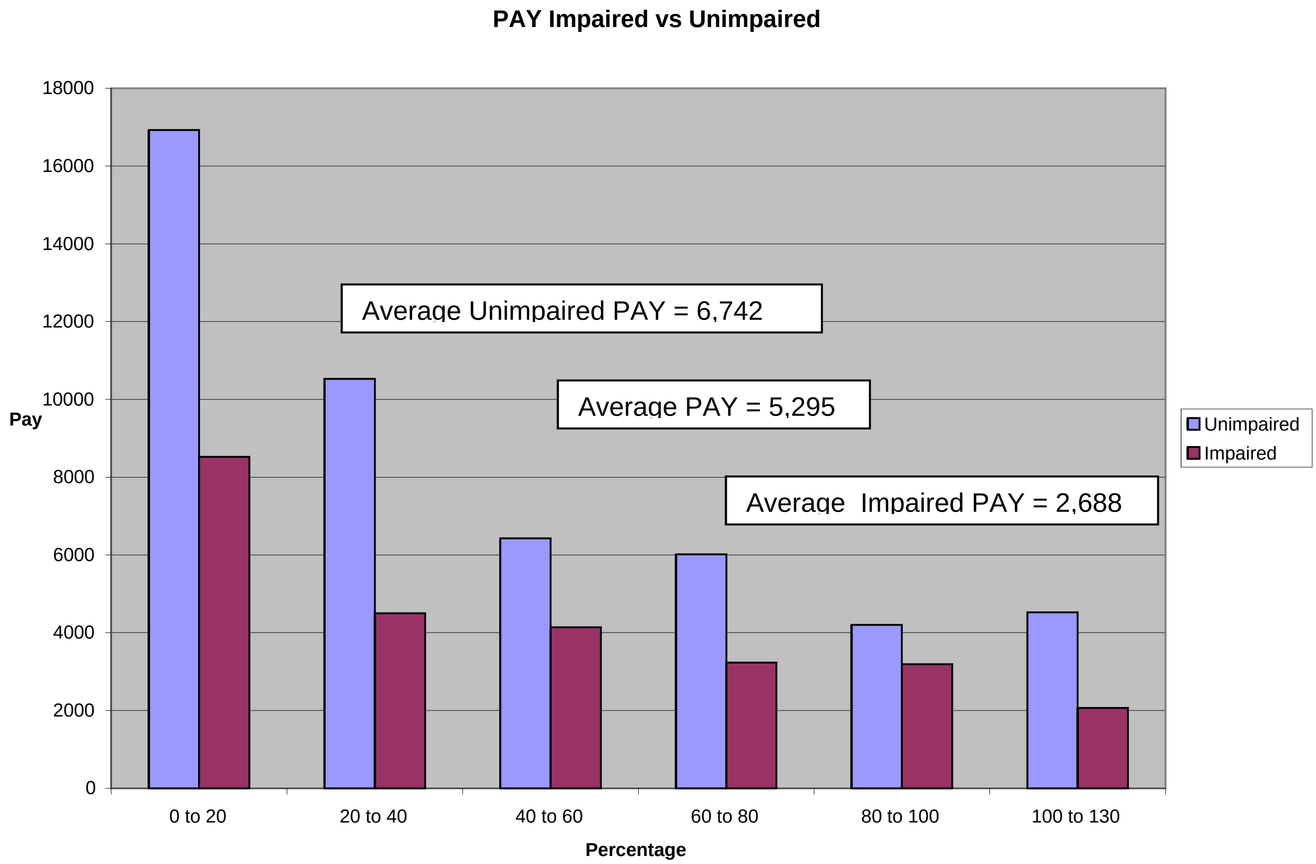

Figure 8

Figure 8 shows the PAY for ranges of design percentage, with one bar representing unimpaired sites, and the other representing impaired sites. An impaired site is defined as a site with a flow restriction, retention, detention, outlet control, or other flow limiting structure upstream. An unimpaired site is defined as a site where the vault is the first BMP in the system, with no flow restriction upstream. On average, an impairment upstream reduces the PAY by over 60 percent. With some of the restrictions trapping sediment on their own, it makes sense that the PAY would go down because there would be less sediment available to remove. This parameter does make it clear that, given a choice, locating a vault upstream of other structures makes the most sense. Many of the other structures are sensitive to sediment, such as sand filters, ponds, wetlands, or other infiltration/retention types of structures. Placing the vault upstream of these structures would reduce the sediment load to these structures by 60%, thus enhancing their operation, and making their maintenance less costly.

To eliminate the effect where upstream structures act to intercept sediment and reduce the performance of a vault, bypasses were isolated and studied to see the effect. The definition of a bypassing vault is a vault where flows are intentionally diverted away from the treatment mechanism at a certain rate of flow. For this study, that flow was the water quality flow as defined by the jurisdiction. Typically, these flows were based on a “1 inch first flush” storm at the minimum. Over 90% of the data in this study was based on the flow from a “1.2 inch first flush storm” as defined in the *Georgia Stormwater Management Manual*.

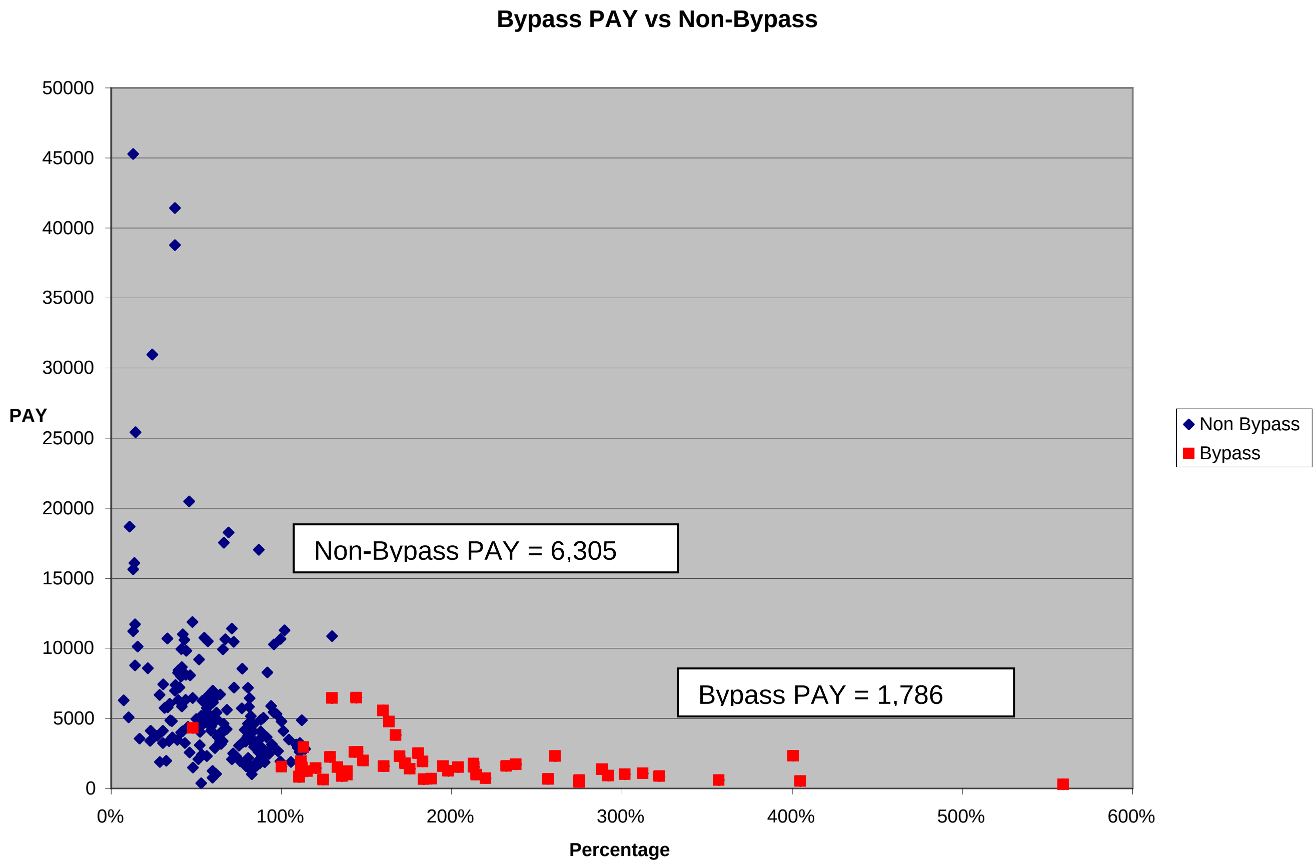

Figure 9

BYPASS RESTRICTIONS

Figure 9 is a scatter chart with the bypass sites shown in red, and the non-bypass sites shown in blue. Note that there is almost no overlap in the data, with the bypass data almost all being over 100% design percentage. This is the definition of bypass, in that the device is effectively "down-sized" by using a smaller device, based on a smaller flow. The effect of bypassing higher flows is obvious, and devastating on the performance of the vaults. No vault employing a bypass has a PAY removal rate of over 7,000, and the average was 1,786 PAY. This was less than 30% of the performance rate for non-bypassing vaults. Unlike the data for all impairments as a group, this parameter had no mechanism for removal of sediments upstream. All of the material lost via the bypass was material that continued downstream unabated. This data goes against conventional wisdom concerning the common practice of bypassing flows for vaults.

While the data exposes the weakness of a vault that bypasses, it does not expose the weakness of the vaults that do not bypass. Vaults that do not bypass risk exposing their contents to resuspension brought on by higher flows. It is obvious that the net effect of bypassing is a huge loss in overall performance, which requires further study to quantify the exact reasons for the deficiency. There are several obvious factors that affect performance. The dominant factor is the ability of low flows to mobilize materials off the surface and into the drainage system. The energy gradient of higher flows increases the ability of water to wash off and transport materials. This principle is the cornerstone of sedimentation theory, and demonstrates why a bypass may divert large percentages away from an otherwise effective vault. In many cases, the vault is simply not on line when the bulk of the material washes past it. The other part of the bypass effect is the possibility of resuspending materials already collected. Engineers like to think in terms of peak flows, not sustained flows. In most larger storms, the higher flows do not last for a long period of time. Over the course of a year, high flows may exist for only a few minutes. During those few minutes, only the materials on the surface of the sediment bed in a vault are exposed to the high flows, so resuspension is very limited. Of course, most vaults are on a periodic cleaning cycle, so that the materials already removed have no exposure to high flows. This is unlike many land-based systems where materials are left in place for years without removal, and where resuspension and leaching is inevitable. The issue of resuspension in long term detention/retention facilities is studied in the following section.

DETENTION IMPAIRMENTS

There is no doubt that detention or retention facilities gather some measure of sediments. While some jurisdictions give no "credit" for dry detention, most allow some type of removal rate. In most jurisdictions, a slow-release (extended) detention system, or a permanent pool wet detention pond is the preferred method of water quality treatment. These systems are routinely assigned a removal rate of 80%, regardless of site characteristics, site usage, or site geometry. Figure 10 shows the PAY for vaults above detention ponds and for vaults below detention ponds.

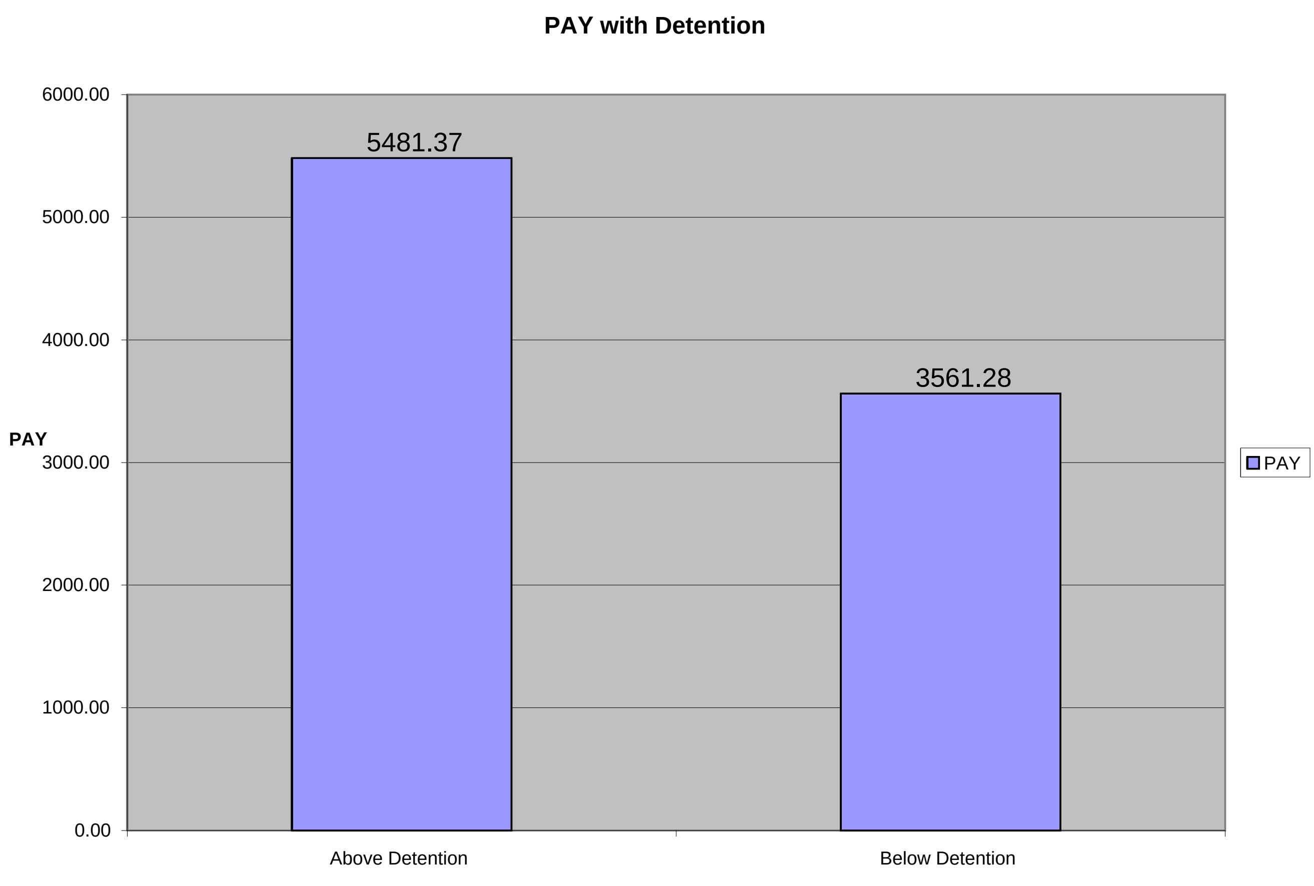

Figure 10

As a group, the vaults below detention ponds removed 35% less material, but they still captured over 3,500 PAY on average. If the entire load were the 5,481 PAY caught by the vault, the data indicates that the ponds only caught 1,920 PAY and passed on more than they caught. While this study makes no distinction as to the type of pond, at least 25% of the ponds in the study were extended detention facilities. Science tells us (correctly) that the above ground ponds have a larger surface area than the vaults, and thus should catch more material. Field observation, however, exposes a weakness of many surface ponds at the entry and exit points. Typically, there is little or no energy dissipation control at either point, and high flows turn the pond into a sediment suspension machine. The pond then lowers the flow velocity by using an outlet control structure, and the vault benefits as the lower flow results in a lower effective HLR for the vault, and it removes the materials suspended in the pond effluent. Even with extended detention ponds that hold a certain quantity of water (the water quality volume) and release it slowly, can suffer this resuspension phenomenon when they go on "overflow".

A relatively new effect is beginning to be seen in underground detention facilities. Some of these facilities are also slow release "extended" ponds, where a certain water quality volume is detained and metered out. These facilities are literally sealed chambers where sediments are trapped and which are almost impossible to effectively clean. They are a confined space that is literally out of sight, and often out of mind. It is only a matter of time, before a high energy event produces the mixing needed to remove a large percentage of the material over the high flow weirs.

This grouping needs further study where the type of pond configuration, fore bay, energy dissipation, outlet control structure, etc., are broken out to better understand the limitation of ponds as water quality devices.

FLOW IMPAIRMENTS

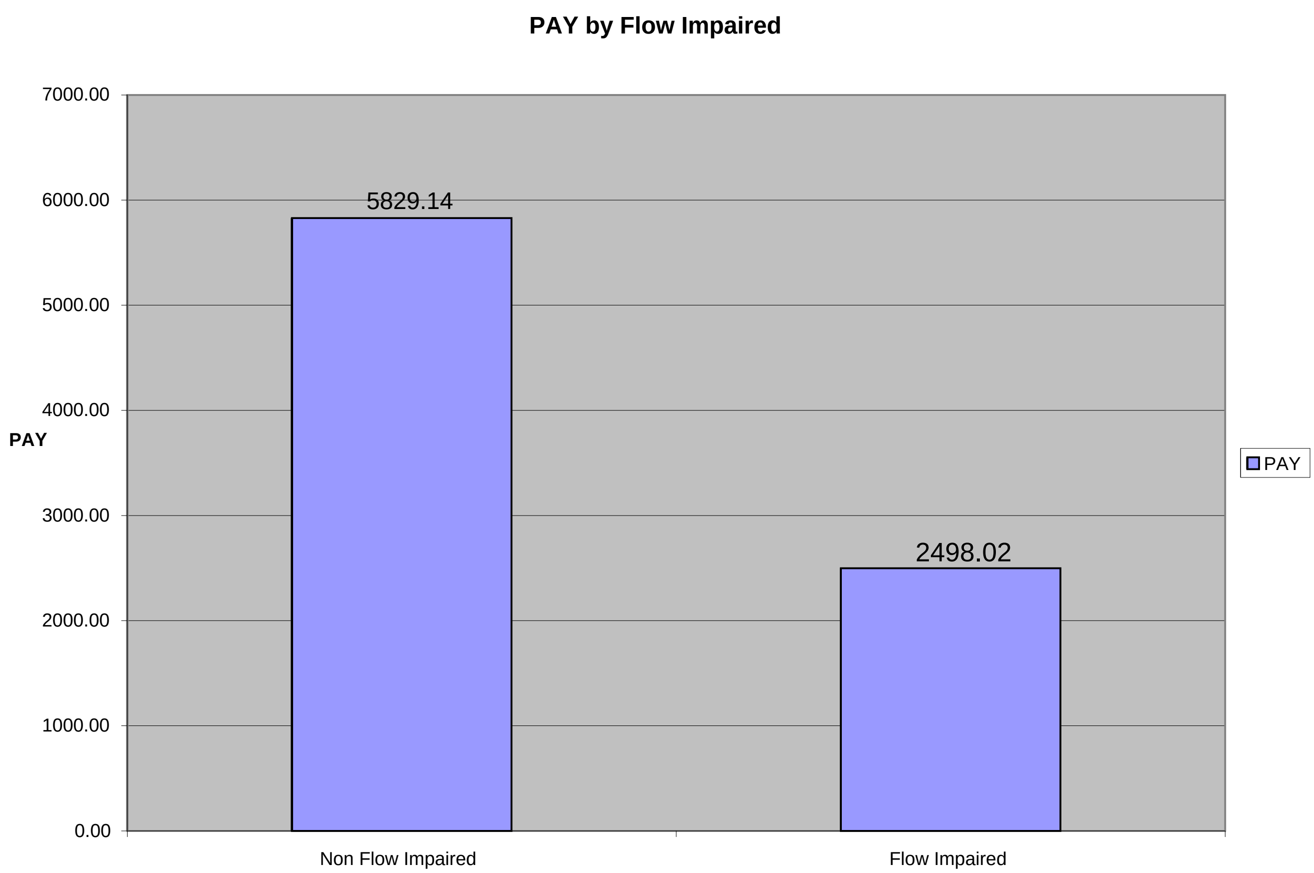

Figure 11

Figure 11 shows the data grouped by flow impairment. In this grouping, any device or structure above the vault that acts to impair the flow, such as a weir, fore bay, bypass, or pond is classified as a flow restriction. This is a wider group than simply ponds or bypasses, and generally shows that restricting flow to a vault effectively cuts the performance in half. This is counterintuitive in that a lower flow would give a vault a better HLR, but follows the logic of "low flow equals low delivery" quite well. It appears that the low delivery effect is stronger than the enhanced capture effect.

It should be remembered that all these effects are interrelated. The studies done here are intended to isolate the effects as much as possible, but in the field, complex relationships exist between ponding, flow restrictions, bypasses and other performance impacts.

IMPAIRMENT SUMMARY

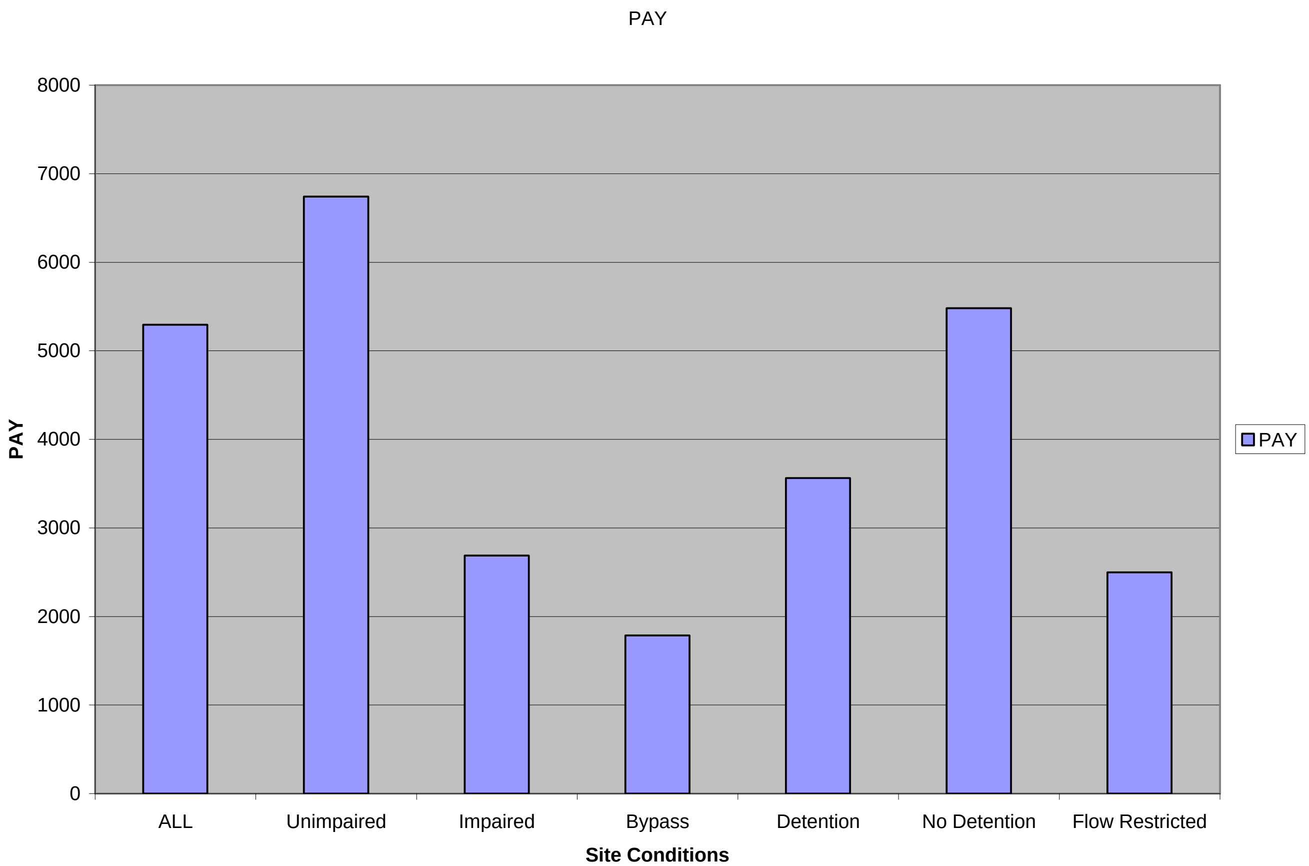

Figure 12

The bar chart in Figure 12 shows the data for all sites and various groups side by side. The results for all sites that are unimpaired show that the average potential for removal performance is almost 7,000 PAY. This is the standard against which bypass, detention, and flow restricted sites should be examined. It is clear that the worst possible thing to impose on a gravity vault is some type of flow bypass. A close second is any type of flow restriction upstream. It also shows that while a detention facility upstream cuts performance about in half, the vault downstream is valuable for collecting sediment that washes through the pond for whatever reason. A system designer needs to take into account these effects when adding a vault to a system to help achieve good water quality. The physical aspects of vault placement are important, but there are other factors that impact the decision making process in a more profound way.

SITE USAGE AS A PERFORMANCE FACTOR

Our field experience has demonstrated that some vaults have been designed with an excellent HLR, completely unimpaired, and with proper attention to particle size distribution and other physical factors, but still perform very poorly when compared to the average device. Over time, it has become apparent that some site usages simply do not produce a high pollutant load. If you consider two one-acre sites that are 90% impervious and located side by side, with identical building footprints and identical paving surfaces, you might see where one site could have a very different pollutant profile from the other. Make one site a dentist's office with 20 trips onto the site daily by patients, and make the other site a gasoline/convenience store with 1,200 trips a day by the general public. From a hydrology and flow standpoint, they could be identical, but from a pollutant standpoint, they are two different worlds. This data set has been studied by site usage, to help identify patterns in the loading rates for each usage.

Broad general categories have been developed that each site was placed into, and sub-categories were developed to further refine the data. Figure 13 shows the PAY for the broad categories.

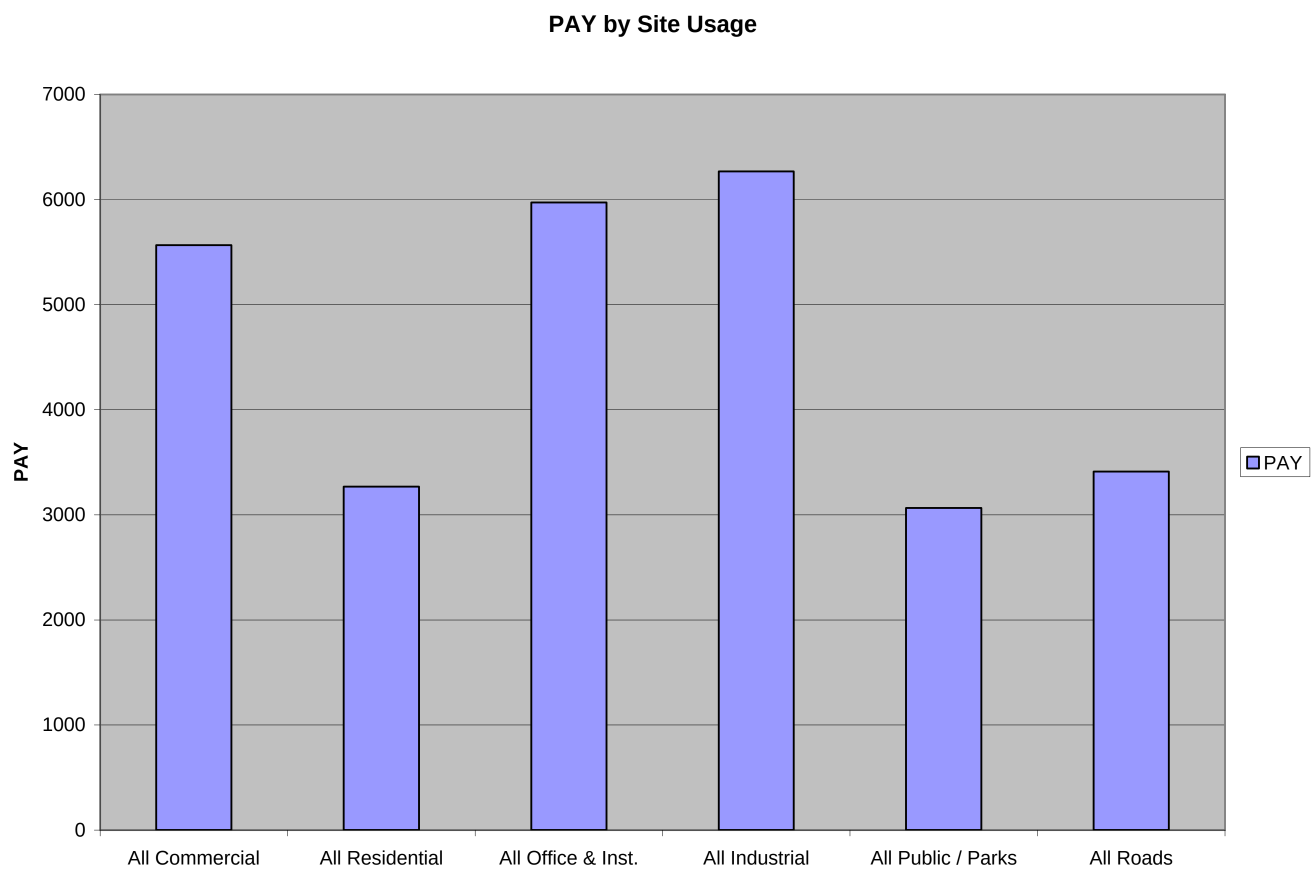

Figure 13

Although NURP characterized residential loading (101 mg/L) as higher than commercial loading (69 mg/L), our data does not show that to be the case. In general, the high traffic sites, such as office and commercial sites, and industrial sites show very similar loading rates. The office sites were somewhat of a surprise, but further study showed that office developments tend to be multi-story, with a high parking to building roof ratio, combined with high traffic turnover. The retail commercial sites tend to be one story, and many have excess parking that is unused much of the time. The relatively lower use of residential and public park land tends to produce lower loadings. Roads were somewhat of a surprise, but make better sense when the relatively low impervious coverage of the entire "basin" is considered, along with the filtration effect of grassed shoulders and medians is taken into account. There were over 40 sub-categories that these broad areas were divided into, and which help to explain these overall trends when broken out separately.

Figure 14 shows the breakdown of the PAY for all sites based on a more detailed site usage. The variability of the data is impressive, and suggests that great care is needed in making any pre-development assumptions for pollutant loading. It should also be noted that even the lowest PAY numbers recorded exceed current wash off models. Using low loading models to predict the life expectancy of structures such as infiltration basins, wetlands and retention facilities can lead to much higher maintenance costs than predicted at the least, and premature failure at the worst.

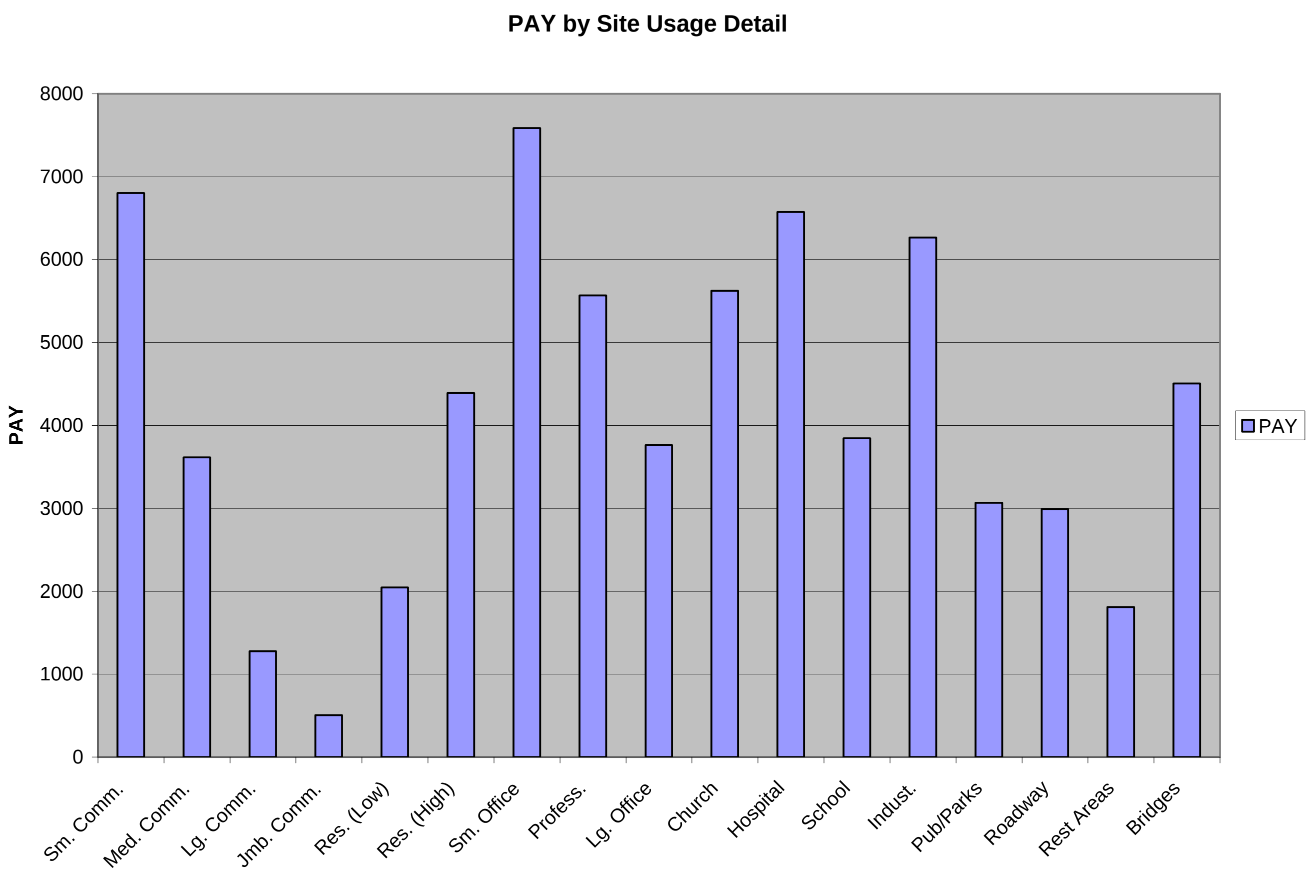

Figure 14

The first four bars are the commercial sites in the data set, with "Small" sites being generally under one acre, "Medium" sites being 1 to 5 acres, "Large" sites being 5 to 15 acres, and "Jumbo" sites being over 15 acres. There is an obvious trend in the data where the PAY goes down as the size of the site increases. There are several possible explanations for this. One factor is that the larger sites have a large roof area, and many unused parking spaces. There are generally less "trips per square foot" for these sites, as well. Very often, the larger "big box" stores and centers have an aggressive street sweeping program to enhance their public image. The implications of this data on commercial sites are obvious. Sediment sensitive BMPs might be fine for large commercial sites, but would be stressed on smaller sites. Maintenance would be more of an issue on smaller sites.

The next two bars are the residential sites, with a division at about 50% impervious coverage. Under 50% coverage is termed low density here, with high density being over 50% coverage. There is more than one category in each of these groups, but grouping them in this manner shows that low density residential exhibits much lower loading than higher density residential. High density residential seems to behave more like “Medium” commercial or “Large” office. This is probably indicative of the ratio of impervious acreage to total acreage, and the likelihood of professional site and landscape maintenance for the higher density residential. These sites tend to be apartments, condominiums, or high-rise developments.

The next six bars are the office and institutional sites. “Small Office,” designated here as less than 2 acres, and “Hospital” have the highest PAY, with both over 6,000 PAY. “Professional” and “Church” loadings fall in the middle, with “Large Office” and “Schools” both falling below 4,000 PAY. The data does not follow specific factors, such as high traffic usage. You would expect that large offices will have more traffic than Churches, but the PAY for those offices is lower. It is probable that high impervious and high traffic act to put the PAY for “Small Office” over 7,000, but the trends are not as obvious for this overall category. This may be due the fact that office and institutional layouts are highly variable, while commercial sites generally fit into patterns, such as big box retail, and gas/convenience stores.

The “Industrial” sites are the most varied of all, and are lumped into a single bar on this chart. The highest sustained PAY for any vault in this data set is over 45,000 for an industrial mining site. Other mining sites exhibit similar loadings. Without the extremely high (over 30,000 PAY) industrial sites, this category would have a PAY of just under 3,500.

The next four bars are public lands in one form or another. Most of the data from parks is related directly to the parking areas for those parks, and the PAY is similar to medium sized commercial sites. The roadway data is typically small catchments along roads that would empty directly into streams or waterways without a vault in place to help remove pollutants. As mentioned above, the grassed shoulders of many roadways mitigate the loads coming to the vault. The data from rest areas show relatively low loadings. This is probably related to good site maintenance and good supervision of the usage. Most of these vaults are in place to protect receiving waters from accidental or intentional hydrocarbon spills. The final bar, showing bridges at the highest PAY of all public lands, reflects the fact that a bridge deck is 100% impervious, and is a highly sloped connected surface.

While further study and examination of the sites themselves can lend better insights as to the causes for the high variability of the PAY seen over all these sites, there is no denying the fact that there are large differences in the data set. Much can be learned by going into greater detail and breaking down the categories into subsets based on physical factors. This breakdown, however, will have to wait until there is a larger data set. The subcategory, “Small Commercial, under 60% design percentage, above detention, non-flow restricted and less than 80% impervious surface ratio” only has one member at this point in time. For now, just a few observations are possible to expand this analysis.

COMBINED SITE USAGE AND PHYSICAL IMPAIRMENTS

Figure 15 takes two subcategories, “Small Commercial” and “Medium Commercial,” that have a significant number of members in the data set, and compares the PAY for both impaired and unimpaired sites. It also shows the average PAY for non-bypass, bypass, no detention and detention to put the results of the two categories into perspective.

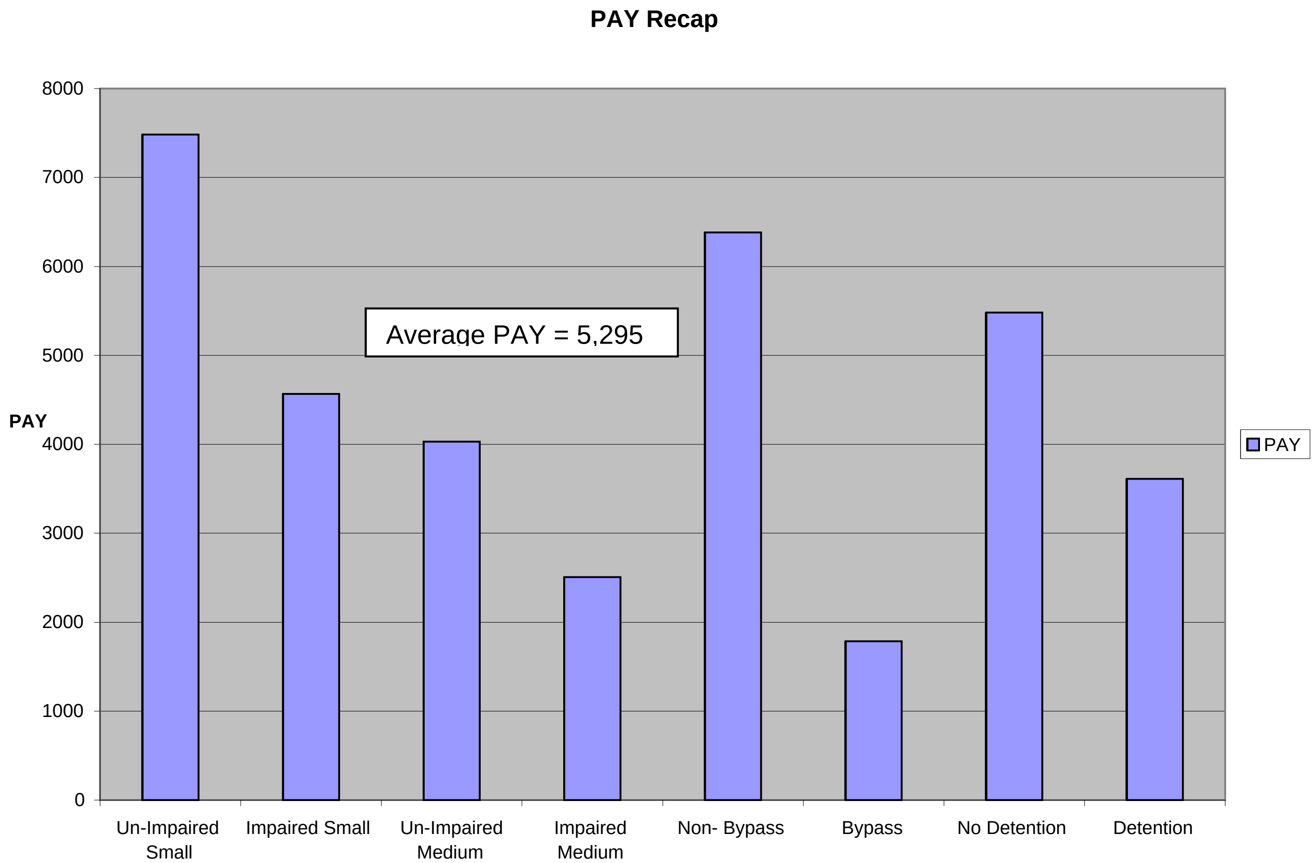

Figure 15

Here it can be seen that an average 7,500 PAY can be expected on unimpaired small commercial sites, and that almost 3,000 PAY is lost when these vaults are impaired. For medium commercial sites, 4,000 PAY is the norm, with about 1,500 PAY lost to impairments. These are significant impacts when the fact that a model based on the NURP 69 mg/L loadings for commercial sites only predicts total annual loadings of 750 PAY. Small commercial sites are loading one order of magnitude higher than such a model would predict. If the model loadings were raised to 200 mg/L as some suggest, the predicted PAY would be about 2,175. Looking back at the chart, where bypass sites are shown at just under 2,000 PAY, the models begin to make sense. NURP was based on evaluating "first flush" as the only important portion of a storm. NURP data was largely gathered from automated samplers and analyzed using poor laboratory methods that could not detect larger particles. A bypass site is making the same assumptions, and the average PAY shown on the chart correlates pretty well with the models showing higher loadings. The serious error made in these cases is that the additional 3,000 to 5,000 PAY that is easily removed from these sites is not important.

TRENDS OVER TIME

One possible pitfall in looking at this type of data is the fact that most of the sites are new development. This means that even though the vaults are cleaned just after the construction phase when the property is occupied, there still may be influences of higher loading in the early days of site usage, based on areas that are not completely stabilized, etc. Earlier analysis of this data, when the oldest sites were only four years old seemed to indicate that this might be a trend. Figure 16 shows the PAY for the sites in the data set based on the number of years they are been in service.

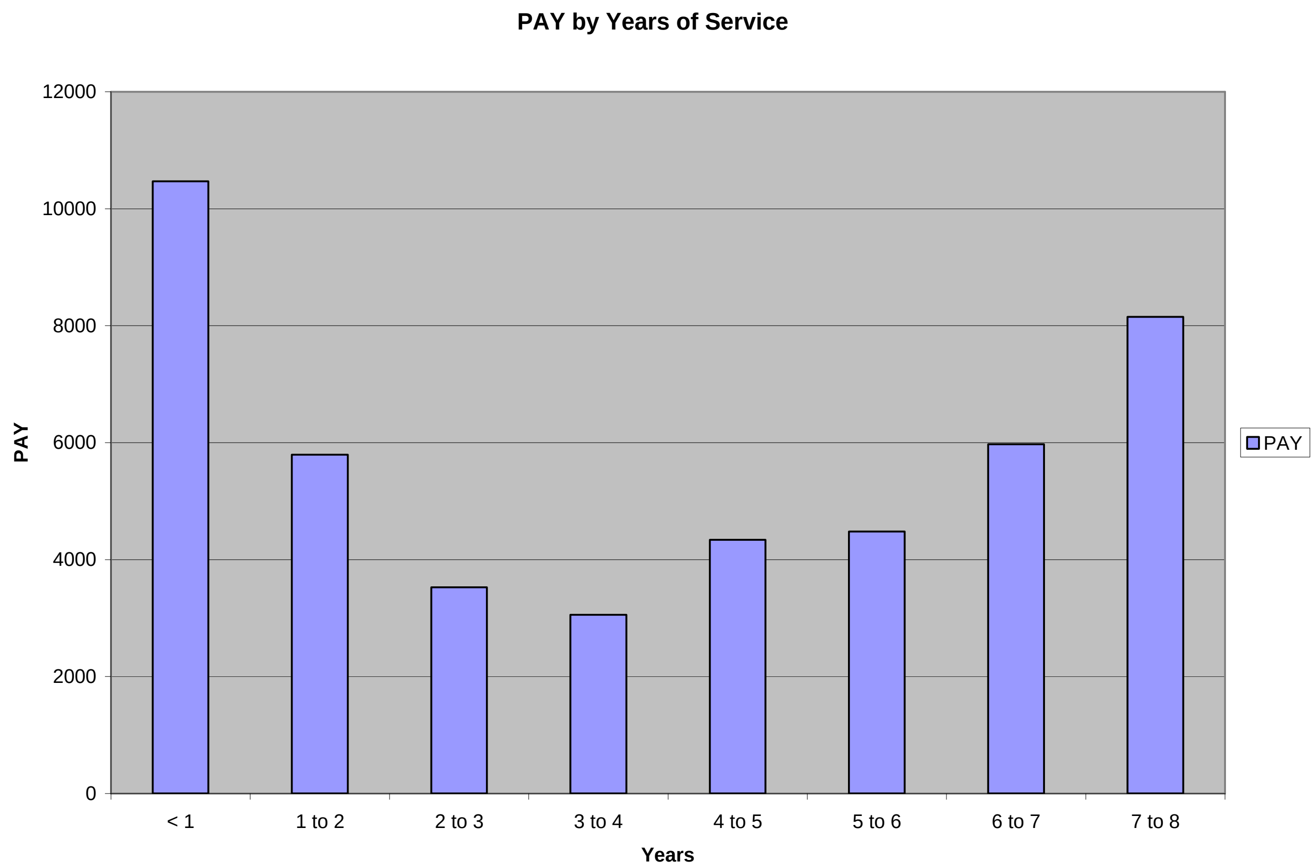

Figure 16

The chart above shows that there is some drop off of loading over the first three years, but that the loading picks back up over time. This may be a function of early wash off in the beginning, and higher surface wear later on. More data will be needed to confirm this over time. Residential sites that build out slowly are difficult to classify as to a "start date." One poor contractor can literally pour tons of sediment into the street five years into a subdivision's life. Nevertheless, looking at the data over time seems to have value, and can aid planners in BMP design. Maintaining a sediment fore bay or a vault ahead of all other practices until all building is completed might be one strategy indicated by this trend in the data.

SUMMARY

It appears that the actual average potential for removal is near 6,000 PAY (see Unimpaired Vaults under 60 percent design in Figure 8). This makes no statement about how much material has been missed by these vaults, but a rough guess can be made that the lower performance (about 2,000 PAY less) of the over 60 percent design unimpaired groups is material that is not captured, or subsequently lost. For this set of vaults, with a design percentage average of 64 percent, it appears that the process of making design decisions guided by an intimate knowledge of the site conditions has been the correct approach.

It would seem that no BMP, including land based BMPs, should be “flat rated” for removal percentages or a particular flow with no consideration for site conditions; yet this is the common practice. The variability shown is this study indicated the need for site specific design, but most proprietary BMP vaults and standardized land based BMPs never take this into account. They are simply flow or acreage based, with a removal percentage assumed, regardless of site characteristics. The “laundry lists” of acceptable BMPs for a jurisdiction should be evaluated in light of the trends shown above, with the local removal data dictating how and when each type is used, and a range of effectiveness determined. This means that local cleaning and maintenance procedures must first be done, and then records kept, so that they can be studied. A logical next step to analyze the pollutant characteristics for various sites would be the addition of particle size distribution data. The data set that this paper is based upon is expanding daily, and the performance parameters will continue to be developed and published to assist design professionals and regulators.

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