HOW DOES DROUGHT AFFECT BMP PERFORMANCE?
How do antecedent conditions affect pollutant loadings?

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ABSTRACT

The year 2007 brought a severe drought to most of Georgia, as the normal 50.20 inches of rainfall (the 30 year average) was replaced with a mere 31.85 inches. The shortfall of over 18 inches dropped reservoirs to record low levels, forced extreme water usage restrictions, and gave new life to the "water wars" between Georgia, Alabama, and Florida over the water in the Chattahoochee/Flint River system. Public awareness of the importance of our water supply, and the need to use this resource responsibility was greatly enhanced, as everyone turned their eyes to the skies hoping for relief. In the middle of the drought, the research group at CrystalStream realized that we were sitting on a field laboratory in the form of 400 structural BMPs (Best Management Practices) in the drought area, most with historical data concerning the amount of materials they collected. While the new devices would offer little in the way of comparative data, many of the older devices had up to eight years of historical cleaning records. This data was studied to determine the effects of a drought on pollutant wash-off rates.

When this paper was conceived and the original abstract submitted, we were still in the middle of the drought. It was hoped that winter and spring rains would break the drought and provide new insights of how antecedent conditions affect wash-off rates. In general, this was the case, as rainfall was near normal for the first four months of 2008, only being a few inches below normal. A summary of rainfall data for Atlanta is included, with the data source being the National Weather Service, Peachtree City Georgia.[1]

The data show there is a relationship between antecedent rainfall amounts in many cases, but the variability of the relationship indicates that some other aspect of rainfall may be more important. In general, overall loading remained the same over time, indicating that materials simply build up in anticipation of an event that will move them off of the surface and into the runoff flows. Based on historical patterns, it appears that higher intensity (rate of rainfall) of summer storms is a more important mobilization factor than the volume (depth) of rainfall. If this generalization is true, it would indicate that simply treating a certain volume of rainfall (like a 24-hour one inch storm) might not be effective. This pattern of loadings may be critically important in semi-arid climates, where long dry periods allow surface buildup, and where smaller, low intensity storms may not mobilize the material. When larger intensive events eventually wash the material off the surface and into the run-off, volume based or low flow BMPs may not be operating.

THE RAINFALL DATA

Rainfall data has been accurately recorded in Atlanta for well over 50 years. Unfortunately, the historical use of this data has been to assess the statistical probability of certain events to occur within a specific time interval. This works well for sizing pipes, culverts and other conveyances (in most cases), but this characterization of rainfall is practically useless for water quality applications. Rainfall patterns during an individual storm, and the overall frequency of storms, are essentially chaotic. The classic rational hydrograph or 24-hour storm distribution curves are useful tools for site planning, but the nicely ordered rainfall patterns depicted by these methods do not exist in nature. The entire world of water quality is almost always defined as a certain depth of rainfall falling within a 24 hour period. The “One Inch First Flush” or something similar, is the definition of the storm requiring treatment. This definition meshes nicely with the historical data available, which was recorded as a 24 hour total once each day. For the purposes of modeling the wash-off rate of pollutants, this data is useless, and says little about the conditions during the storm event. A one inch 24-hour total may have occurred when the entire total fell in 10 minutes, which is a rainfall rate of 6 inches per hour. On the other extreme, it may have fallen steadily at a rate of 0.04 inches per hour for the entire 24 hours. The first event would be an epic thunderstorm, while the second would be a fine mist. The conditions on the surface, in pipes and other conveyances during these two events would be radically different.

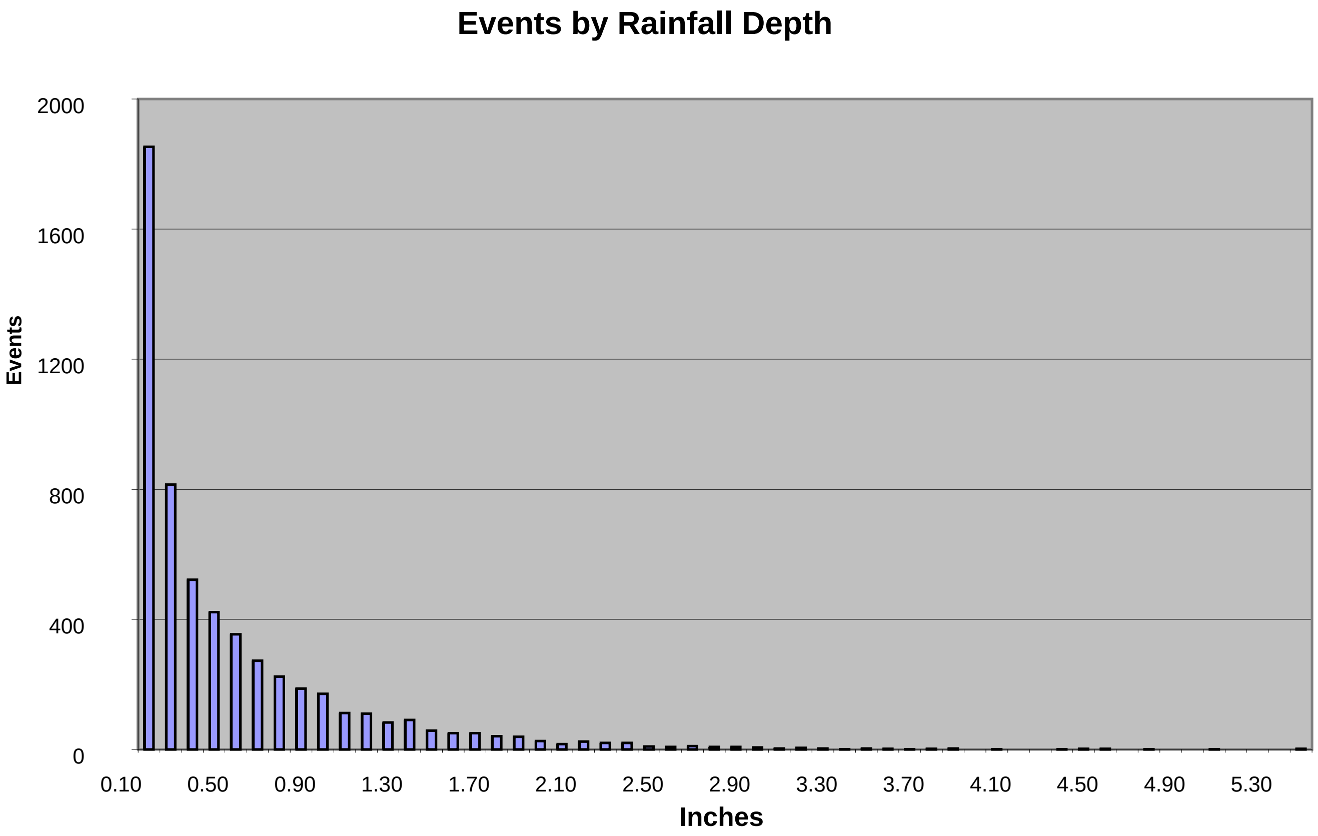

Figure 1

The lack of understanding about rainfall patterns can lead to obvious mistakes in setting water quality rules and requirements. A simple study of the Atlanta rainfall data over the last 50 years shows that 2,442 inches of rain had fallen in 5,642 events over that time period, for an average of just over 48 inches annually. These 5,642 events are depicted in Figure 1 with the number of events plotted versus the storm depth. The Georgia “water quality” storm definition is a depth of 1.2 inches within 24 hours. There were 5,125 events of 1.2 inch depth and under, or 91% of all the events. If the regulation writers were after 90% of the storm events, they did well. Unfortunately, only 62% of the annual rainfall volume occurs in these events. Figure 2 shows the total volume of rainfall versus the rainfall depth that fell during these events. Unless one assumes that nothing washes off in large storms, the prospect of intercepting 80% of the annual pollutant load by treating 62% of the annual rainfall is a weak one. Increasing the water quality storm depth to 1.8 inches would capture 81% of the annual rainfall volume. This shows a much different pattern of distribution. A system that captures 100% of the pollutants during this group of storms would have a better chance to meet pollutant removal goals. While the annual volume from the group of storms at 1.2 inch depth and under is only 62% of the annual total, there is an additional 1.2 inches of rainfall included in all storms over this depth. A 1.6 inch storm would still contribute 1.2 inches to the annual total with an additional 0.4 inches of excess that would overflow a volumetric structure with storage for the first 1.2 inches. If you add the base 1.2 inches of larger storms to the total for all storms at or below the 1.2 inch standard, the total volume goes up to 87% of the annual rainfall volume. This is a more reasonable amount to treat for an 80% removal goal. With the bias toward smaller storms, which make up the bulk of this group of storms, making an assumption that the majority of the wash-off occurs during these events is dangerous.

The assumption that the movement of materials off of the surface only occurs at low flows, or that no significant pollutants move at higher flows goes against basic physical laws. Similarly, assuming that a small depth storm does not produce high flows is also erroneous. A 0.5 inch rainfall depth in 24 hours may have actually fallen in 5 minutes, which is a rainfall rate of 3 inches per hour. That rate of rainfall is very high, and would produce very high flows on the surface and in pipes. In summary, using a depth of rainfall is misleading as far as the amount of annual rainfall treated, and says very little about the rainfall rates during those storms.

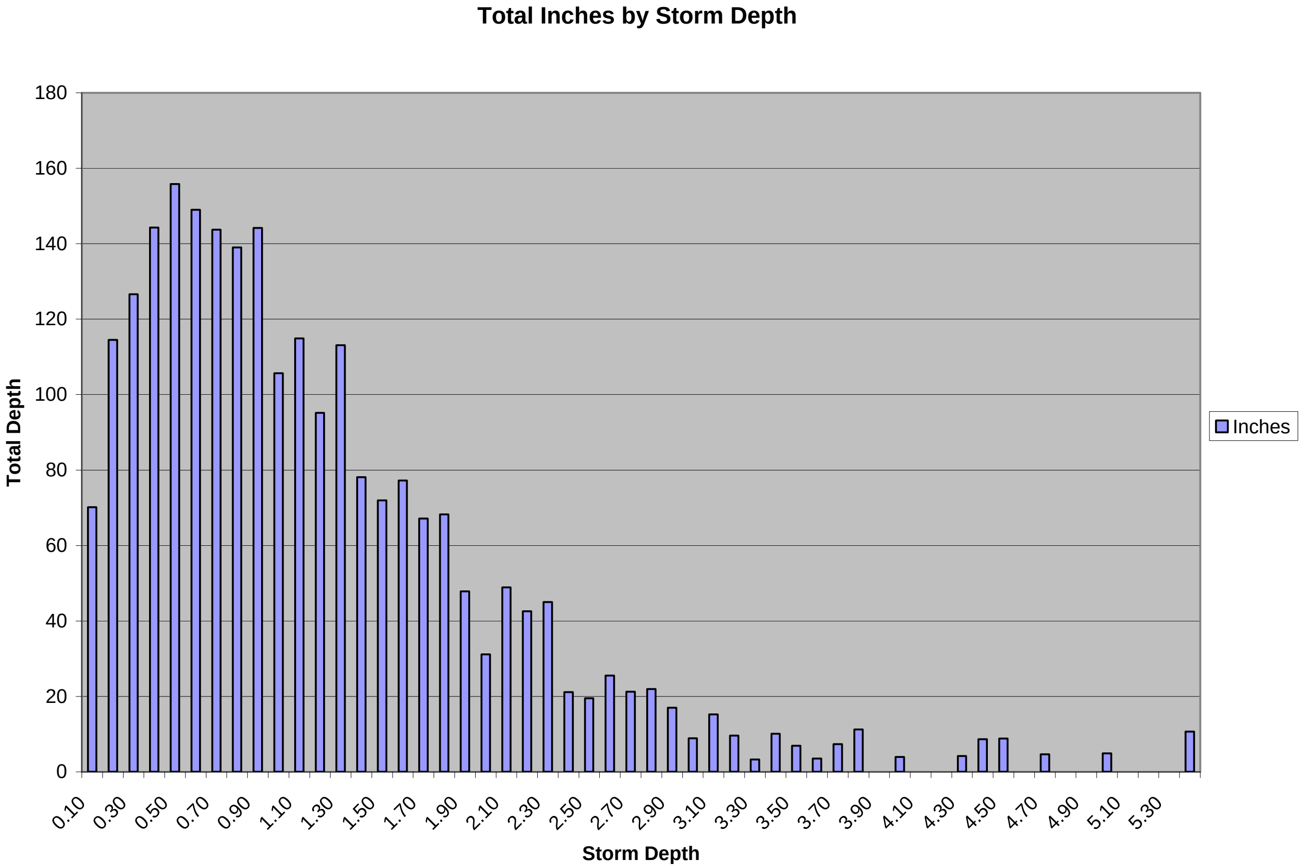

Figure 2

This paper has had to rely on rainfall records that are based simply on depth. Unfortunately, no systematic recording of rainfall rates was available and if available, such data would have been only marginally useful. The rainfall rate, or intensity, varies moment to moment at any given point on the ground, and a high intensity at a recording station might not be present just a few yards away. Common sense and personal observation tells us how variable storms can be, with one side of a street receiving rain while the other stays dry. Some storms are very steady and predictable over wide areas, so that various recording stations show similar depths and rainfall rates, but many are not. For the purposes of this study, however, using generalized depth data may be appropriate. The concept is to take several years of "normal" rainfall, and compare overall sediment loadings for a large group of vaults in the Atlanta area. In the broad view, the goal is to attempt to tie rainfall patterns to pollutant delivery. An important aspect of the way the rainfall data was used is that the data is "lagged" six months. The devices in the study were cleaned out every six months, on average. That means that a January 1 cleaning would represent material washed into the device by the rainfall over the prior six months. The actual rainfall amounts for the previous six months were simply summed to produce a six month total.

Figure 3 shows the annual rainfall in Atlanta from 2001 through 2007, with the 30 year average of 50.20 inches being shown for comparison. It should be noted that in the year 2001 there also was a severe drought. The years 2003, 2004 and 2005 were years with a surplus of rainfall.

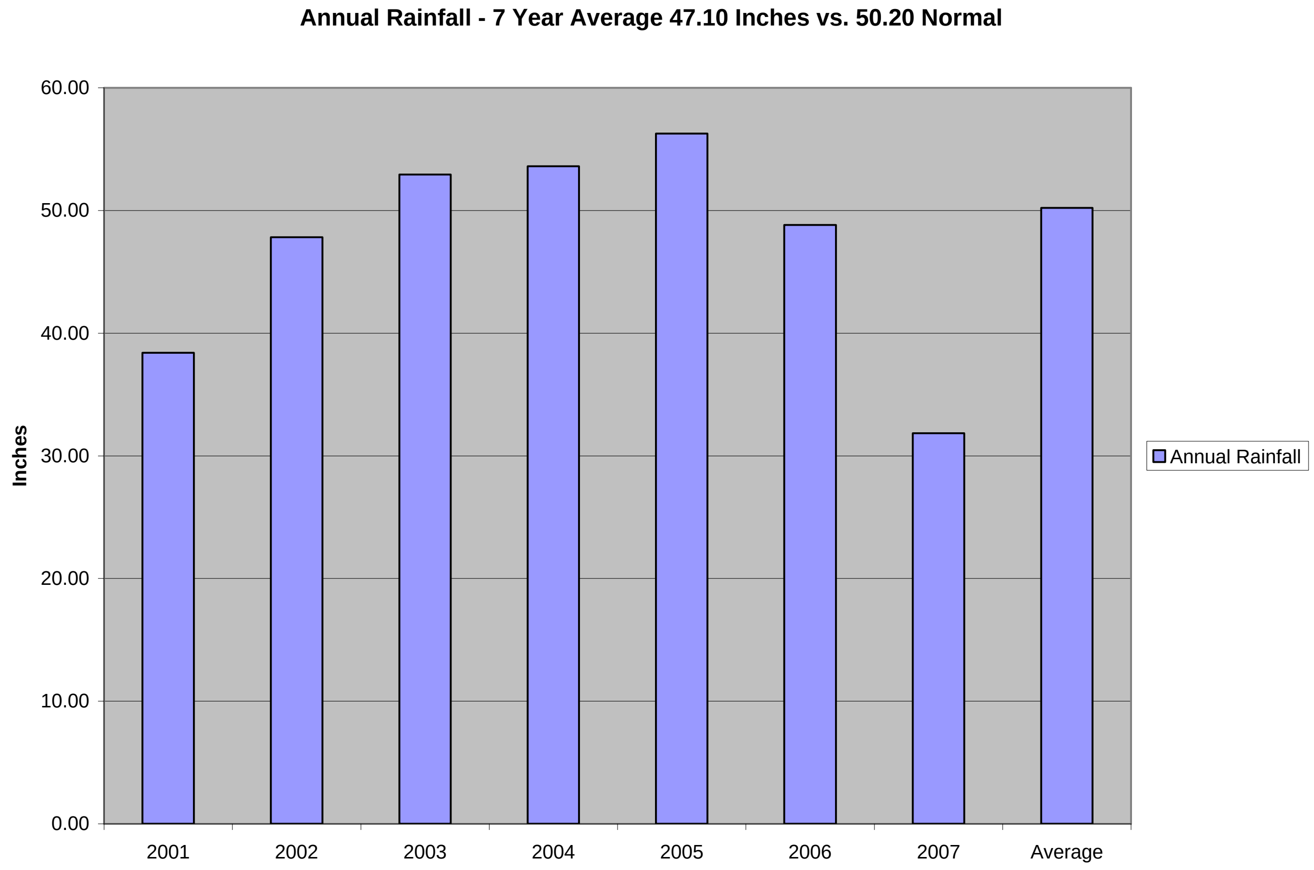

Figure 3

THE LOADING DATA

Previous studies have shown that the wash-off rates for pollutants are highly variable from site to site. The major factor that affects the amount of material washing off is the site usage. High traffic sites tend to have higher amounts of all types of pollutants. Other causes of high wash-off rates are a high percentage of impervious, a low total acreage, and steep slopes adjacent to and flowing onto a site. Because the raw quantities vary greatly on the studied sites, from over 20,000 pounds per acre per year down to 800 pounds per acre per year, comparing the weights directly would not provide an accurate picture. Instead, we summed up the total weight of the material collected over the life of the device through the end of 2007, and divided it by the years in service to get a yearly average. This average was assigned a loading factor of one for that site. An individual cleaning that produced a weight 20% higher than the average would receive a load factor of 1.20, and a cleaning that produced a weight 10% lower than the average would receive a load factor of 0.90. In this way, the individual site variability was removed as a factor in the ratings, as the site usage and physical parameters did not change over the time of the study.

The first look at the loading data was a grouping of all the cleanings by month. The January cleanings from each year were averaged, as were the cleanings from every other individual month to look for seasonal variations. Figure 4 shows the seasonal variation of the loadings represented by the blue line. The loadings for July, September, and October are above average, with August being almost exactly average. The loadings are plotted at 20 times their value to bring them into scale with the rainfall data.

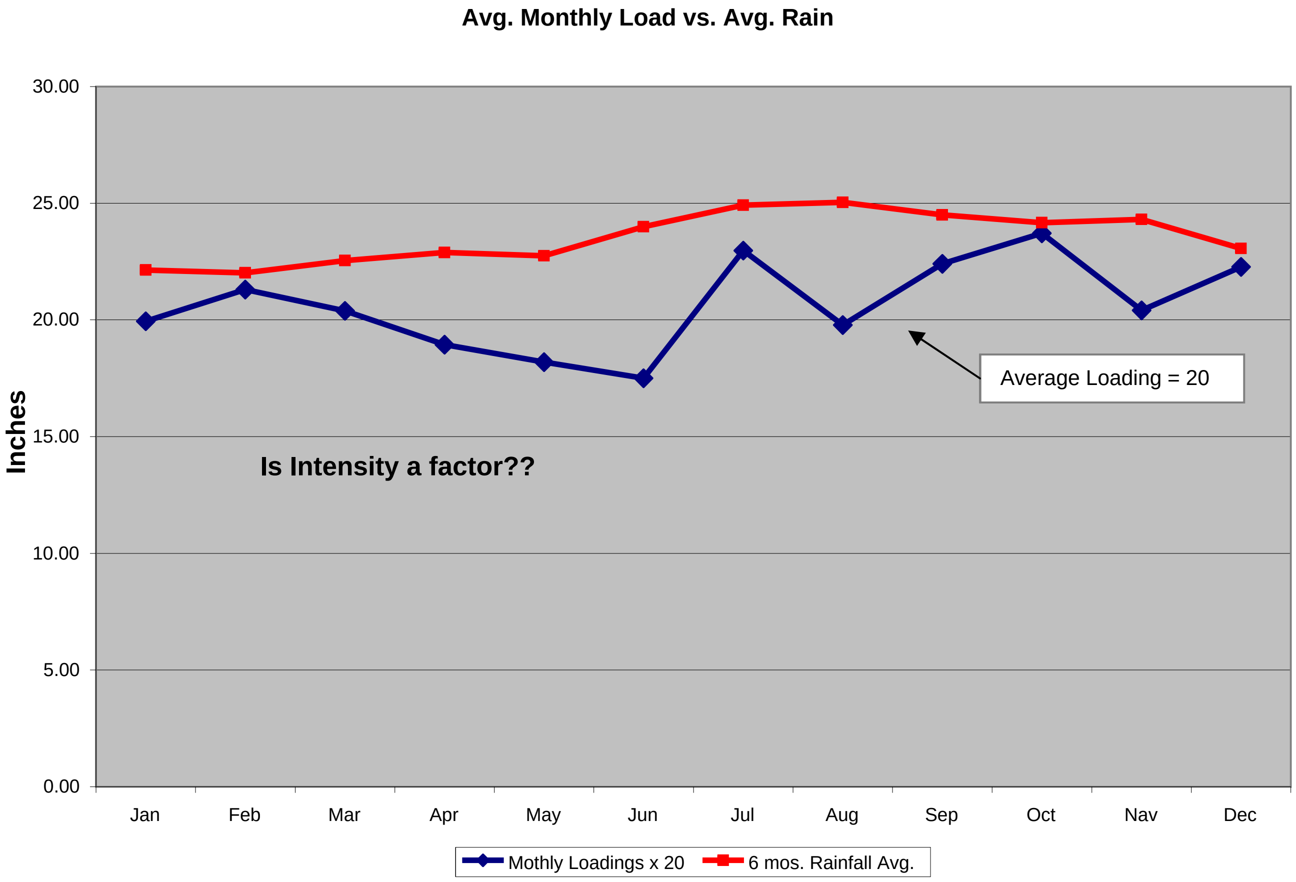

Figure 4

The red line is the rainfall data showing the actual depth of rainfall for the six month period prior to each month. While there is some correlation with the highest antecedent rainfall totals corresponding to the highest loadings in the late summer and fall, there is also a divergent pattern in the February through June comparison, where slightly increasing rainfall totals have resulted in a steady decrease of the loads. This appears to be the result of the lower intensity of the more gentle winter and spring rains. Once the higher intensities of the summer storms begin to influence loadings, we see a rather large jump in loadings for July. This explanation of the trends shown is speculative by the author, in that no intensity data exists to support any conclusion. An alternate explanation that may apply to at least some sites is that previous high intensity events moved material into a device that was then cleaned out, and subsequent high intensity events had little or no material available to wash off, regardless of the high energy produced on the surface by the storm. What is clear is that a high volume of rainfall does not necessarily produce high loadings.

The overall annual patterns of loading do not seem to hold up in the data shown in Figure 5, where each year is divided into quarters, and the average loads are plotted against the six months antecedent rainfall. Looking at the first quarter (Q1) of each year, we see a variable pattern. In 2003, Q1 was just above average. In 2004 and 2005, Q1 was below average, while 2006 and 2007 were above average. This variability is true of each quarter, when viewed year over year.

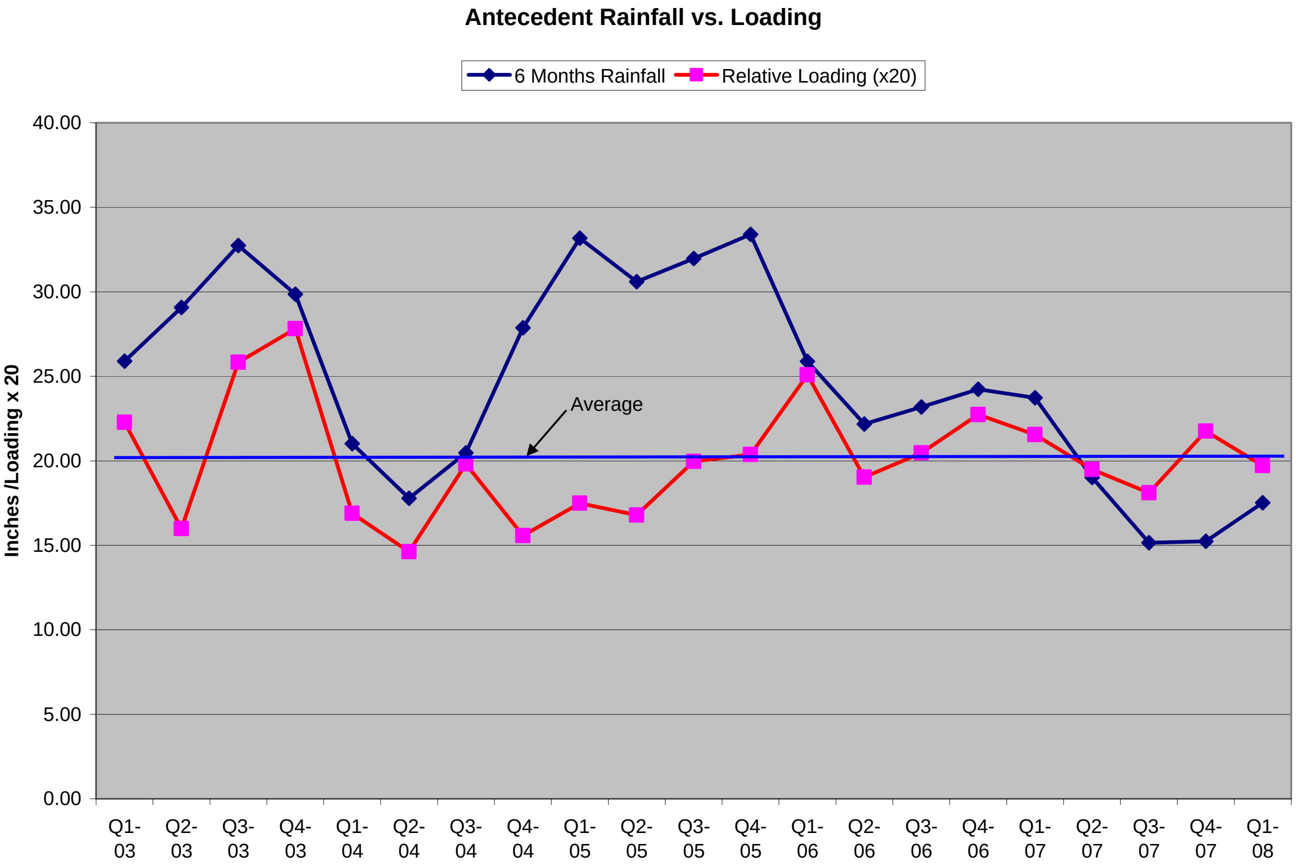

Figure 5

The more important trend to notice is that from Q1 2003 through Q3 2004, the loadings essentially followed the rainfall patterns, with Q2 of 2003 being an obvious exception. The same is true for Q1 2006 through Q3 2007, where rainfall and loadings showed relatively similar patterns of change. The period starting in Q3 of 2004 and extending to Q1 of 2006 show divergent patterns, where loadings decreased as rainfall increased. A study of the rainfall during this period that included intensities might show that low intensities allowed surface buildup, which resulted in a large wash-off during Q1 of 2006, when antecedent rainfall was low compared to the past quarter, but loadings spiked to their highest level in three years. Following this spike, the loading versus rainfall pattern returned to a “normal” relationship until the drought of 2007 began to show up in the six month antecedent rainfall amounts.

Over the period of the drought (Q2 2007 through Q1 2008), the loadings were just slightly under average overall, with one minor upward spike in Q4 2007, and one small dip in Q3 of 2007, but neither data point was remarkable in view of the variability in loadings over the history of the study. Looking at the overall quarterly pattern it is evident that high antecedent rainfall does not necessarily deliver high loadings, and during the drought, loadings have remained steady. If further examination of the rainfall characteristics were made, it is possible that other relationships would become evident. The prospect of using actual rainfall depth data from each site, and recording intensities for each site is somewhat daunting, but that level of data is what would be required to determine empirical relationships. For this study, the broad look at quarterly averages and six month antecedent rainfalls does at least provide us with some insights about rainfall to loading relationships. It also points out that simplistic loading models probably have no relevance to real world conditions.

Figure 6 shows the same data as Figure 5, but broken out by month. This chart also includes 2002 data, which did not have as many data points to relate, and was omitted from the quarterly based statistical relevance. What the 2002 data might indicate is that it was a wash-off loading recovery from the 2001 drought. All of the available data showed loadings disproportionately high when compared to the six months antecedent rainfall depths.

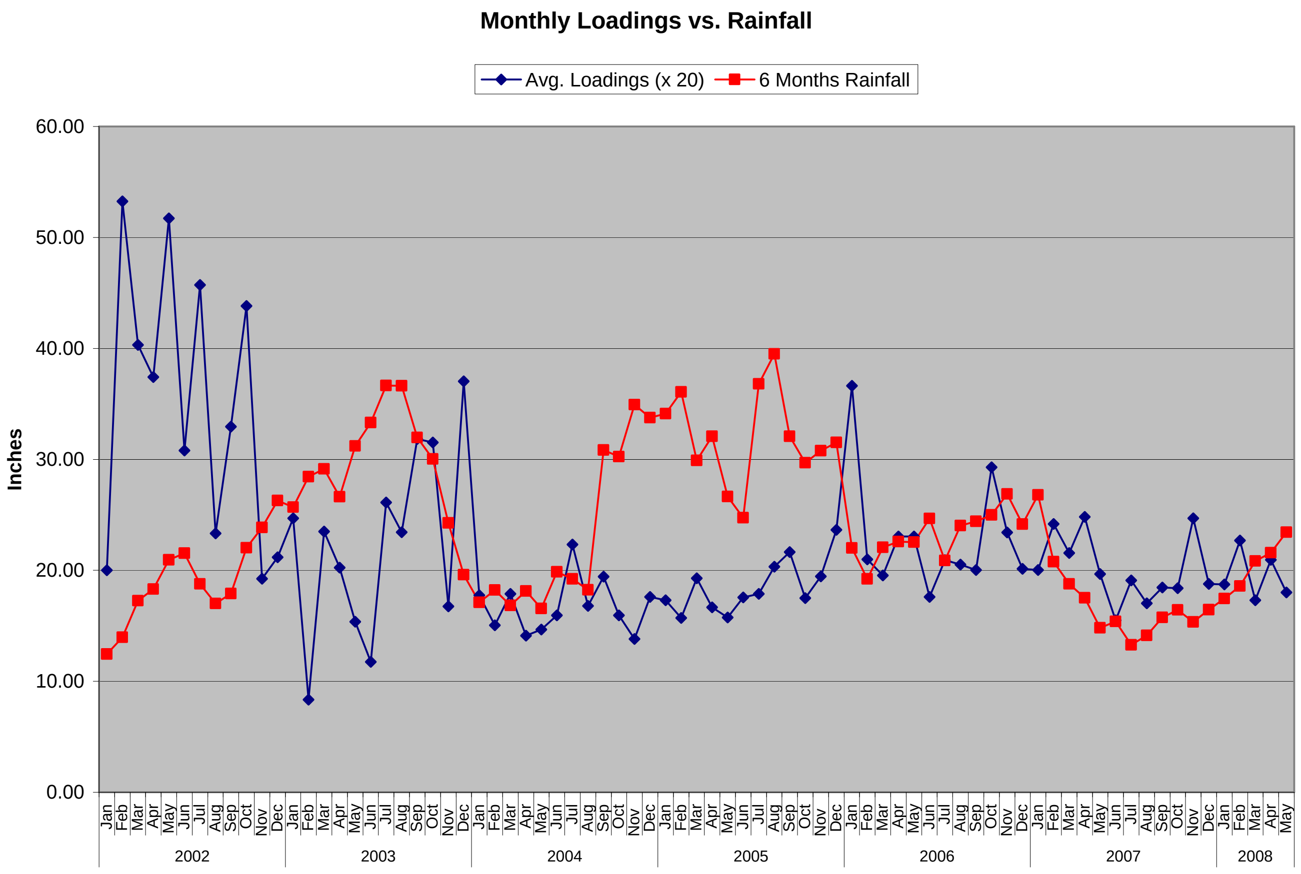

Figure 6

In looking at the overall patterns, the monthly data as a whole tends to agree with the quarterly patterns. In 2002 there was a smaller sample of data, but it is included here to show how the 2001 drought might have led to more material washing off in 2002. The overall trend reversed in 2003 where rainfall is up, but loadings are down, with the exception of December. In 2004, loading and rainfall tracked together for much of the year, followed by about 15 months of high rainfall accompanied by slightly lower than average loadings. At the beginning of 2007, rainfall totals began to fall off as the drought deepened, but the loadings were slightly low for most months. Four months show higher than average loadings, which brought average loadings during the year to near normal. In October of 2007, rainfall began to increase steadily through May of 2008, but loadings remained about average.

SUMMARY

As of May 2008, the rising level of rainfall had not produced higher loadings in the devices studied. While there does seem to be some correlation between antecedent rainfall depths and loadings, there are significant differences over long periods of time that seem to go counter to a direct relationship between depth of rainfall and material loading.

There are two obvious factors outside of rainfall depth that can affect the loading rate. The rate of rainfall, or intensity, is not related to the depth of rainfall. In many cases, short, intense thunder storms will exhibit the opposite relationship between overall rainfall depth, as opposed to a long, gentle soaking rain. The short intense event will have a low overall depth, and a high intensity, where the long gentle event will have a high overall depth, and a low intensity. The intensity of rainfall is what creates the wash-off and transportation energy to produce high loadings. A few of these short, intense events could produce months of “reversed” data.

The availability of material to wash-off is a second factor that can cause loadings to be low, even with good rainfall depths. A high intensity event may move material that has built up for months or years into a device in a single event. Subsequent rainfall might have all of the characteristics needed to transport high loadings, but may simply lack material to transport. The opposite effect may come into play, as well. If there is a long period without a high energy event, material may build up in large amounts, and an average event may transport more material than normal.

Further study is required to establish the actual relationship between rainfall and loadings. Rainfall data must include intensity data, with a tipping gauge to measure rainfall rates at the least. The geometry of the sites studied here is available, and would need to be included to show the effect of slopes, types of conveyances, and other physical factors that would affect loading rates. The particle size distribution of the materials captured would also be needed to better understand what is transported, and when.

In the end it makes good common sense that the overall loading rates would be steady during a drought. Unless some mechanism were in place to remove material that otherwise would have washed off, the material will reach the device downstream over time. The detail of the rainfall data available does not provide sufficient evidence to link a drought or excess rainfall depths to wash-off levels at this time.

REFERENCES

1. Rainfall Resources, National Weather Service Forecast Office, Peachtree City, Georgia