STORMWATER TREATMENT NORTHWEST©

This newsletter and the next one to follow in July present some new stormwater modeling concepts that we believe are needed to link BMP performance to receiving water protection and improve BMP selection and design. It's time to move in a new direction. It's time to invest in the development of physically based models that provide a much better understanding of the stormwater quality data we already have and the additional data we should obtain. Physically based models are mathematical programs designed to simulate physical processes that are directly related to the desired output of the model itself. For example, let's assume that the desired output of a stormwater quality model is the storm-by-storm event mean concentration (EMC) of TSS in the runoff from an urban site of interest. A physically based model would attempt to simulate the accumulation of particulate material on the site and the washoff of this material by the site's estimated stormwater runoff. Both the accumulation component and the washoff component would be physical processes included in the model.

The concepts presented herein were developed by your editors, Roger Sutherland and Gary Minton, along with Dave Felstul of Herrera Environmental Consultants. Please contact Roger if you would like to learn more about these ideas. Most of these ideas presented were included in a proposal to the Water Environment Research Foundation (WERF) last year in response to its request for Project No. 06-SW-1. Although our proposal was not selected, we know that several members of the selection committee saw a considerable amount of merit in what was proposed so we have decided to share it with our readers. Some of the ideas presented were also discussed previously in our August 2006 newsletter under the heading "Characterizing Stormwater Quality – A Proposed Focus."

Because of its length, the presentation of our concepts and proposed actions will occur in this and the next issue, which will be sent out in July. This issue will discuss the model's intended purpose and users. It will provide a big picture view of the modeling approach needed and its technical basis. It will also describe some of the ancillary benefits of having a model such as the one envisioned. The next issue will outline the specific steps needed to create the model or stormwater management tool that has been envisioned.

The overall goal of the WERF research project 06-SW-1 was stated as:

> This research will help link stormwater BMP control effectiveness for specific pollutants and flow to receiving water loadings, impacts and water quality objectives in order to help stormwater managers in the selection of design of BMP systems.

The RFP stated that stormwater program managers need appropriate methods and tools that can explicitly address the inherent uncertainty of BMP performance and receiving water quality. With scientifically-based, easy-to-use tools, stormwater program managers should be able to identify appropriate BMP selection and design characteristics having the highest likelihood of solving specific water quality problems. The RFP also stated that research should focus on the development-level scale (say 5-300 acres) but another desired outcome will be in defining how site-level methods and tools may be scaled up to a watershed (say 10-100 square miles or more).

WHO WOULD USE THE TOOL AND FOR WHAT PURPOSE?

At the watershed scale, the end user is most likely the NPDES Coordinator or Stormwater Manager for a local jurisdiction along with support staff for various community or environmental groups. We believe the stormwater management tool we envision could be used in an urban or urbanizing stream basin to consider the level of pollutant load reduction needed to achieve specific water quality goals, either at the receiving waters or at intermediate points further upstream in the basin. This analysis would produce basin-specific specifications and standards for structural BMPs and/or level-of-effort required for non-structural BMPs. The model could also be used by jurisdictional engineers for design of regional water quality facilities for subbasins of a few hundred to a few thousand acres. The engineer will wish to evaluate how to maximize pollutant reduction at minimal cost within local site constraints of hydraulic head and available space.

At the site development scale, the end user is most likely the development or redevelopment engineer responsible for managing stormwater quality and quantity leaving a site. This tool could be used to model and implement design standards specified by the community for structural BMPs including on-site detention and low impact development (LID) techniques, which are likely to be required. At this scale, the development engineer wants to maximize the cost effectiveness of several LIDs (e.g. amended soils, porous pavements, rain gardens or green roofs) as a way to reduce detention volume and improve water quality. As a result, this tool must be able to explicitly simulate the integrated performance of these LID techniques on a storm-to-storm basis over a long time period so the hydrologic response of the site under the user defined LID design conditions are specifically known.

Therefore to be effective, the desired stormwater management tool must consider long-term continuous hydrographs rather than single event peaks or just small storms. At the site scale, the tool should appropriately consider shallow subsurface water or interflow. At the watershed scale, the tool should simulate interflow and baseflow at the receiving water on a continuous basis.

A NEW MODELING APPROACH IS NEEDED

Typical pollutant loading models are based on various land use types: single and multi-family residential, commercial, industrial, freeways, and open space. Unfortunately, this format is not particularly useful, as it is not tied directly to the specific BMPs under consideration and likely to be implemented. We suggest an alternative format based on pollutant source areas like streets, parking lots, roofs, landscaped areas of various descriptions, and other activity types that relate directly to certain pollutant sources like construction sites or gas stations. Such a format allows a direct tie to BMPs and various LID treatments as noted below:

- **Streets:** *BMPs include pavement cleaning, sump cleaning, catch basin filters or screens. LIDs include porous pavements and rain gardens.* Loadings differ by street type such as highway or freeway, arterial, commercial (whether CBD or shopping center), residential collectors; pavement type; and pavement age and slope.
- **Parking lots:** *BMPs and LIDs similar to streets.* Loadings vary by parking lot type or activity, e.g. high volume retail to light commercial employee lot.
- **Landscaped areas**: *BMPs include education programs on fertilizer and pesticide use. LIDs include amended soils, swales and rain gardens.*
- **Roofs:** *BMPs include downspout disconnect or treatment. LIDs include green roofs and cisterns.* Loadings differ by type and age of roof materials, atmospheric deposition, etc.
- **Construction sites:** *Erosion control BMPs.* Loadings vary by soil type and land slope.
- **Other:** Activities that generate special loadings such as gas stations, hobby farms, and particular industries with outside activities.

Using this source area approach, the user identifies total area within a defined watershed that relate to the same sources. For large watersheds (e.g. tens of thousands of acres), the location of the source areas within the watershed is important and it may need to be subdivided into smaller subbasins. The primary value of this approach is that it recognizes most watersheds contain already developed areas. In many situations, the watershed is completely developed, therefore the focus should be and will be on the nonstructural BMPs, along with some LID and treatment devices implemented through redevelopment.

TECHNICAL BASIS FOR PROPOSED APPROACH

Maestre and Pitt (2007) recently combined nationwide stormwater quality data from four major stormwater databases: NURP, USGS, International BMP Database, and NSQD. The combined database contained approximately 10,000 individual stormwater events from 594 sampling locations representing 16 different land use categories spread throughout all nine of USEPA's defined rain zones. Their analysis found that, within a given rain zone, **the variability between sampling locations for any land use category is greater than the variability between land uses themselves**. According to their results, it is expected that around 5 to 20% of the sites located in the same USEPA rain zone and land use category will have *median* concentrations that are significantly different than the remaining sites in the group. In other words, **traditional land use classifications are very poor indicators of actual stormwater quality**.

Based on Maestre's and Pitt's conclusions, it is obvious that using the "simple method" to estimate stormwater pollutant loadings will likely result in poor predictions at both the individual and watershed scales. For those not familiar, "The Simple Method" involves assigning an invariant constant concentration for a specified pollutant of interest and for a particular land use type. Many of the most popular pollutant load generation models currently used today like PLOAD and almost all spreadsheet type models use this "simple method" approach. The selected median or mean concentrations are typically based on local or regional data such as those made available by Maestre and Pitt (2007). At the watershed scale, these estimated pollutant loads for each contributing land use type, are usually obtained by assigning invariant runoff coefficients to each land use type, and then combining the pollutant loads using GIS techniques to provide estimates at some downstream point in the watershed.

There are several more advanced "simple method" approaches that assign a statistical distribution of pollutant concentrations to each land use type. This distribution is usually based on a single-variant statistical analysis of observed data, which unfortunately could be flawed for various solids concentrations (see next section for further discussion on that point). Although this more advanced technique does add the realism of uncertainty in the generation of land use based stormwater pollutant loads and concentrations, it still possesses one major flaw. There is no direct explicit relationship between the specific physical characteristics and anthropogentic activities occurring on the source areas within the land use of interest and the resulting pollutant load and concentration response. In other words, if you change any of these underlying causes of pollution, there will be no change in the pollutant load or concentration distribution assumed by the simple method for that land use type. So there is no explicit linkage between actual underlying site characteristics and activities and its actual stormwater quality response when using a land use based simple method approach, no matter how advanced the method appears to be.

Maestre's and Pitt's conclusions were not unexpected for those who have developed and used physically based deterministic models over the years (Sutherland and Jelen, 1996; Pitt, 1997). The important things that affect stormwater quality are: (1) the physical characteristics of the site or watershed, and (2) the anthropogentic activities that occur on each of the source areas within the site or watershed. Source areas will provide varying amounts and qualities of stormwater runoff dependent upon these things (Waschbusch, Selbig and Bannerman, 1999; Pitt, Bannerman, Clark and Williamson, 2005).

Studies have shown for decades that urban impervious surfaces constructed to transport or store vehicles seem to generate the greatest pollutant mass loadings (i.e. highways, streets, driveways and parking lots) compared to those with no automotive activities. Thomas R. Schueler, Executive Director of the Center of Watershed Protection refers to these source areas as "habitat for cars." We have also known for over

30 years that the magnitude of accumulated pollutants found on these "habitats for cars" is directly related to the daily volume of cars using a specific roadway or parking lot (Shaheen, 1975; Sutherland, Minton, and Marinov, 2006). If WERF's research goal is to develop a real understanding between the urban built environment and the resulting quality of stormwater runoff impacting downstream receiving waters, we cannot afford to ignore these basic relationships between our activities on urban source areas and the accumulated pollutants that are available for transport by stormwater.

Unfortunately, the focus cannot simply be just streets, parking lots, and highways. Other impervious surfaces like roofs, sidewalks and pathways, and pervious areas like lawns, landscaping and vacant lots can also affect both receiving water quantity and quality. Sutherland and Jelen (1996) showed that pervious source areas adjacent to directly connected streets and parking lots can contribute significant amounts of sediments and associated pollutants to observed street dirt accumulations. We call this behavior "wet weather accumulation." Others referred to it as wet weather washon. We also showed that once these behaviors are adequately accounted for using a continuous accumulation function, then sediment and pollutant washoff can be accurately modeled storm by storm, one season to another, year after year (Sutherland and Jelen, 1996).

In other words, only a pollutant load generation technique that is based on the physical characteristics and the anthropogentic activities occurring on a site area along with an understanding of the complex source area interactions like wet weather washon can produce a total population of accurate pollutant load and concentration responses driven by area specific rainfall characteristics. And these responses can then be linked to actual changes in any of the underlying factors like physical characteristics, anthropogentic activities and rainfall itself.

IS THE EXISTING DATA SET FLAWED?

A large body of stormwater quality data has been collected over the past 40 years. It is not possible, given the large amount of data and several hundred publications, to summarize what these data are "telling us" regarding physical, chemical and bacterial constituents of stormwater. Chapter 2 of Gary Minton's book *Stormwater Treatment: Biological, Chemical and Engineering Principles* (Minton, 2002) provides an introduction and overview of the subject. One might conclude that today there is little need to collect "end-of-pipe" stormwater data, inasmuch as we already have so much. Certainly, it means we need to be selective. Some would argue we should essentially begin anew in collecting data. Why? Two reasons.

First, there is evidence that all of our past monitoring is biased and should be "tossed out". Why biased? Because the withdrawal water velocities of older automatic samplers limited pickup capabilities with regard to particle size: perhaps 100 to 200 microns and somewhat larger for sands, but larger sizes for organic particles and clays having lower specific gravities. Hence, we may have been understating the concentrations of sediments and some attached pollutants. Most metals, phosphorus, petroleum and related hydrocarbons, and pesticides, are fairly hydrophobic and, therefore, sorb to these larger particles.

The view for over two decades is that at least half the sediment in stormwater is silts and clay, the rest sand size. Recent data, collected in a manner that avoids automatic sampler limitations, suggests sand is the dominant size. Others argue that we have had bias in the opposite direction. Concentrations, and therefore loadings, may be overstated to the extent that we have tended to sample larger storms (e.g. 0.5 inches or more in depth). Most runoff occurs from much smaller storms. In Portland, Oregon, for example, approximately 70% of the cumulative annual runoff volume occurs from rainfall events of less than 0.5 inches. Smaller storms have lower rainfall intensities, resulting in lower overland and street gutter flow velocities and, consequently, lower pollutant washoff concentrations. Particle sizes are likely smaller in these storms because of low gutter velocities. Hence, the bias of older automatic samplers may have been counterbalanced by the failure to recognize the dominance of the smaller storms.

The second possible reason for bias in current stormwater quality data is laboratory procedures. Samples collected in the field must be split into aliquots for analysis. Rapid hand mixing and pouring fails to properly move larger material that may have been captured. And, lab test sub-sampling procedures failed to pick up these particles. Newer procedures (e.g. churn splitters, separate analysis of larger material by prescreening, full sample rather than sub-sample analysis, etc.), have likely reduced these laboratory procedures biases.

IT'S TIME TO MOVE IN A NEW DIRECTION

It's time to invest in the development of physically based explicit models that provide a better understanding of the stormwater quality data we already have. Much work has already been completed towards this goal but more is needed. The next issue will focus on the completed work and that which is needed. Once this model is assembled, future data collection efforts could then focus on developing a better understanding of the physical processes that have been assumed to occur in the urban environment that help to produce contaminated stormwater. New data collection efforts could focus on:

1. Sampling the street or parking lot directly, rather than (or in addition to) stormwater runoff. Measure the street dirt on the pavement before and after storms. The difference is what was removed with stormwater, assuming washon from adjacent areas has been excluded by proper site selection. The procedure is safer and less costly than sampling stormwater. Such sampling provides a rapid cost-effective characterization for correlating levels of parking lot and streets use and eventual stormwater quality.
2. Sample precipitation quality (i.e. wet deposition) for pollutants of interest at significant concentrations and not washed from impervious surfaces. This provides better information regarding the effectiveness of some BMPs, and the origin of some pollutants.
3. Consider the significance of air emissions from industries. Deposition occurs on water bodies and impervious surfaces, both directly and indirectly. Items #1, 2 and 3 allow better decisions regarding the benefits of air pollution controls and pavement cleaning.
4. Studies over the past 40 years have shown that fecal coliform is a meaningless indicator of the presence or absence of disease organisms. Enterococci and E. Coli have been shown to be better indicators. Consider using these indicators and sampling swimming beaches and surveying gastrointestinal illnesses, rather then general bacti characterizations.
5. Characterize stormwater quality by toxicity, rather than "laundry lists" of pollutants. Where toxicity is observed, specialized studies then focus on causes. Dissolved pollutants are not necessarily bioavailable due to the complexities of stormwater chemistry. Inferring potential or presumed toxicity by comparing concentrations of metals, PAH, and/or pesticides, to esoteric receiving-water standards is likely misleading.

As more data in each of these interest areas is collected, further model refinements can be made. It is through this continuing iterative process that we will improve our understanding of stormwater quality and our ability to effectively change the stormwater quality response through our BMP selection and design.

FUTURE VALUE OF PROPOSED RESEARCH

Due to the controversy surrounding the measurement of solids in transport discussed earlier, there are concerns regarding the validity and value of the national stormwater quality datasets. Abandoning this data would be foolish considering the effort and money spent gathering the information. We need to maximize its use by developing physically based explicit stormwater quality models with proven and accepted sediment transport algorithms that can help us explain and adjust the data we have already collected. Many of these critical algorithms or model pieces have already been created and tested on a limited basis.

After this physically based explicit model is created (which is the focus of research we propose), it can then be used to further understand and potentially adjust the flawed TSS data on a site-by-site basis. This will be done by comparing historic measured TSS concentrations to those computed TSS concentrations obtained from only the finer fraction (i.e. less than 100 to 200 microns) of the model's simulated washoff. This is why the model needs to be able to provide particulate washoff estimates and TSS concentrations for various size ranges of transported particulates. Model parameters will then be adjusted to more closely match these comparisons. The resulting "calibrated" model will then simulate pollutant washoff from long traces of historic rainfall. These simulations will then include reasonable estimates from the model of all sediment sizes transported by the stormwater, including those finer fractions being observed by existing collection techniques. The comparison of the statistics from the simulated washoff data to that from the original flawed dataset will help us understand the significance of the solids transport issues at each site of interest on a case-by-case basis. These additional case studies (i.e. objectives of future research) would allow us to enhance and expand the historic dataset and gain valuable insights into the potential effectiveness of various BMPs, also on a case-by-case basis.

Of course, we proposed to conduct a few of these case studies as part of our research efforts. Case studies will be useful in developing the tool we envision. Such studies will also demonstrate for stormwater managers how this tool can improve their understanding of BMP pollutant removal effectiveness and the impacts on downstream receiving waters.

STAY TUNED FOR NEXT MONTH'S ISSUE

Next month's issue will focus on the technical details of the stormwater management tool that we envision.

REFERENCES

Maestre, A. and R. Pitt (2007). "Stormwater Databases: NURP, USGS, International BMP Database and NSQD," *Contemporary Modeling of Urban Waters Systems, Monograph 15*, CHI Publications.

Minton, G.R. (2002). *Stormwater Treatment: Biological, Chemical, and Engineering Principles,* Resource Planning Associates, Seattle, WA. (http://www.stormwaterbook.com)

Pitt, R. (1997). "Unique Features of the Source Loading and Management Model (SLAMM)," in *Advances in Modeling the Management of Stormwater Impacts, Volume 6,* CHI Publications.

Pitt, R., R. Bannerman, S. Clark, and D. Williamson (2005). "Sources of Pollutants in Urban Areas," in *Urban Water Systems – Monograph 13,* CHI Publications.

Shaheen, D.G. (1975). "Contributions of Urban Roadway Usage to Water Pollution," *U.S. Environmental Protection Agency,* EPA-600/2-75-004.

Sutherland, R.C., and S.L. Jelen (1996). "Sophisticated Stormwater Quality Modeling is Worth the Effort," in *Advances in Modeling the Management of Stormwater Impacts, Volume 4*, CHI Publications.

Waschbusch, R.J., W.R. Selbig, and R.T. Bannerman (1999). "Sources of Phosphorus in Stormwater and Street Dirt from Two Urban Residential Basins in Madison, Wisconsin, 1994-1995," *U.S. Geological Survey, Middleton, Wisconsin, Water Resource Investigations Report 99-4021.*