The Right BMPs?[1]

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An essential step in achieving effective local and national stormwater runoff water-quality management programs is developing technically valid approaches for assessing the water-quality significance of chemical constituents and pathogens in urban runoff. But are we measuring the right things? And are the BMPs we currently use actually protecting water quality? Beginning in the early 1980s with the US Environmental Protection Agency's (EPA) National Urban Runoff Program (NURP), I became concerned about the lack of technical validity in assessing the impact of runoff constituents. Although EPA established what was already known -- that urban area stormwater runoff contained elevated concentrations of a number of constituents that exceeded water-quality standards -- no information was provided through the NURP studies on whether these above-standard concentrations in stormwater runoff were adverse to fish and aquatic life or to many other beneficial uses of receiving waters.

A related question raised by current compliance monitoring is that it relies heavily on structural best management practices (BMPs), such as drain inlet inserts, vegetated swales, media filters and detention basins. Although numerous studies have been completed dealing with siting criteria and constituent removal efficiencies for BMPs, there are fewer works assessing BMP effectiveness on a watershed basis, specifically the relationship of a conventional BMP system to achieve compliance with water quality standards. There is even less research defining the relationship between structural BMPs and receiving water quality.

Because we still do not apply basic principles of aquatic chemistry, aquatic toxicology and water quality in managing urban area stormwater runoff, the public may soon be spending millions of dollars for stormwater runoff water quality management programs, even though it is not established that these expenditures address significant water quality-use impairments.

A recent case in California illustrates the issue. The Los Angeles Regional Water Quality Control Board has adopted a requirement that new residential developments "treat" the first 0.75 in. of runoff through such conventional BMPs as detention basins, grassy swales, and inlet filters. The constituents removed by these BMPs however, have repeatedly been found in a number of areas to be in nontoxic or unavailable forms. In addition, some of the potentially significant pollutants, such as organophosphate pesticides, in stormwater runoff are not impacted by conventional BMPs.

The process taking place today in California is expected to spread nationally. When a water quality standard violation is found in the National Pollutant Discharge Elimination system (NPDES)-permitted stormwater runoff, the permit holder will have to work with the regulatory agency in applying ever-more effective BMPs to eliminate the violation. The fundamental problem with this regulatory approach is that EPA water quality criteria -- which serve as the basis for state water quality

[1] Published in Stormwater 1:64-72 (2000).

standards -- tend to over regulate heavy metals and many other urban stormwater constituents and could fail to regulate harmful constituents present in urban stormwater for which there are no existing standards. Of the more than 75,000 chemicals presently used in United States commerce, only about 200 are regulated. As just one example, the chemicals known as benthiazoles are present in rubber vehicular tires and, because of tire wear, are present in urban area and highway stormwater runoff. These chemicals accumulate in receiving water sediment, such as the San Francisco Bay, to measurable concentrations. They are believed to be carcinogens. Yet they are not measured in pollution control or water quality evaluations. Even though they were reported in San Francisco Bay sediments in 1987, there is no information on their environmental impacts. The benzthiazoles are one of many groups of chemicals present in urban area and highway stormwater runoff that could pose threats to surface water and also -- as I will discuss in a future article -- to groundwater quality.

This article first examines five commonly used structural BMPs: their performance in removing some of the common constituents found in urban stormwater runoff as well as their relative costs to install and maintain. I then include some recommendations I provided to the Los Angeles Regional Board, which are equally relevant wherever similar stormwater plans are being considered. Finally, I propose as an alternative method, Evaluation Monitoring, for addressing the true impacts of urban stormwater runoff on receiving waters.

Characteristics, Performance, and Cost Effectiveness

Current structural BMPs are based largely on hydraulic considerations rather than true water quality issues. Scott Taylor, P.E., has provided a lucid examination of the characteristics and performance of conventional BMPs for stormwater runoff: drain inlet inserts, extended detention basins, biofilters, media filters and infiltration. He is vice president of water resources at RBF Consulting in Irvine, CA and also chairs the California Stormwater Quality Task Force Work Group on BMPs. He points out that most of the structural BMPs now in use do not effectively remove dissolved constituents which are potentially responsible for impairment of receiving waters, and therefore are not cost-effective solutions as they do not, by themselves, enable stormwater managers to achieve compliance with water quality standards. Taylor suggests that a comprehensive and effective program must include both structural and nonstructural BMPs in combinations designed to remove targeted constituents. Beyond merely monitoring and evaluating the quality of receiving waters, we must also bring about changes in urban planning and design to address peak flow and volume increases.

Table 1 shows the percentage reduction each BMP achieves for five types of constituents found in stormwater runoff: solids, nutrients, pesticides, metals and bacteria. Removals of commonly monitored constituents can be estimated with good accuracy with tools such as the American Society of Civil Engineers (ASCE) BMP database. Note that the values shown in Table 1 are generalized and total (particulate and dissolved) for nutrients, pesticides and metals.

Table 1. Percentage Reduction in Stormwater Load by BMP (Source: Barrett, 1999)

Runoff Control	Solids	Nutrients	Pesticides	Metals	Bacteria
Drain Inlet Insert	10	5	5	5	5
Extended Detention	75	25	25	50	40
Basin	70	30	30	50	0
Vegetated Swales	85	40	40	63	0
Filter Strips	85	40	40	70	55
Media Filters					

Table 2. Generalized Capital Cost for Conventional BMPs (Source: Barrett, 1999)

Runoff Control	New Construction Cost, $/acre	Retrofit Construction Cost, $/acre
Drain Inlet Insert	1,000	1,000
Extended Detention Basin	10,000	25,000
Vegetated Swales	10,000	30,000
Filter Strips	17,000	37,000
Infiltration Basin	20,000	38,000
Media Filters	27,000	55,000

Table 3. Generalized Maintenance Cost for Conventional BMPs

Runoff Control	Maintenance Cost per Year
Drain Inlet Insert	$500
Extended Detention Basin	3% construction cost
Vegetated Swales	$5/ft.
Filter Strips	$1/ft.
Infiltration Basin	3% construction cost
Media Filters	3% construction cost

Tables 2 and 3 show the generalized capital costs for construction (both new and retrofit) and maintenance of these five structural BMPs. The capital cost of conventional BMP installation varies widely depending on the site conditions. The primary factor is whether the BMP will be implemented as part of new construction or is a retrofit project. Table 2 provides costs on a dollar-per-tributary-acre basis, assuming a 1-inch capture from the contributing watershed. Construction cost data are site-specific and the values given in Table 2 should be considered valid for planning purposes only. Future versions of the ASCE BMP (2000) database will include cost data for various devices.

Operation and maintenance costs are also difficult to estimate on a general basis, because variables such as maintenance access and constituent load are site-specific. Table 3 gives general maintenance costs for conventional BMPs on an annual basis.

Infiltration. Infiltration of stormwater can be a zero-discharge solution infiltrating the entire design water quality volume to the surrounding soil. Infiltration is a popular BMP in areas that have relatively permeable soils. Significant questions remain as to the potential impacts on groundwater quality from the infiltration of stormwater. A 1983 EPA NURP study concluded that most pollutants of importance in urban runoff are intercepted during the process of infiltration and quite effectively prevented from reaching the groundwater aquifer underlying recharge basins. However, an EPA report developed in the early 1990s cited several examples of groundwater pollution by constituents in infiltrated urban stormwater. Consequently, stormwater infiltration devices should always include a groundwater monitoring element. Soils that are conductive to infiltration are also relatively poor in filtering and adsorbing contaminants that could otherwise enter an aquifer.

Infiltration devices have a poor performance record because of clogging. Current guidelines call for minimum soil permeability rates of about 0.52 in./hr. for infiltration to be considered feasible (Schueler and Clayton, 1998). Generous safety factors should be used by increasing surface area. The depth to the groundwater table, seasonally adjusted, must be well documented (10 ft. of separation to the invert of the infiltration device is recommended). If soil permeability does not allow the use of infiltration, retention and irrigation may be considered. The design water quality volume is stored and subsequently pumped through an irrigation system.

Media Filters. A variety of media filters are currently in use, including sand, compost, sand peat, and perlite/zeolite. Perlite/zeolite and compost filters are proprietary. The use of compost has declined because nutrients are released from this media. Sand filters enjoy the most widespread application. Slow sand filtration is a relatively old technology largely abandoned by the US water industry several decades ago in favor of rapid sand filtration. Sand filters are generally limited to low-turbidity waters and operate through a combination of straining and adsorption. Sand filters are among the most efficient conventional treatment devices, achieving good removal of particulates and modest removals of bacteria and dissolved metals.

Sand filters are designed with a sedimentation chamber to store all or part of the water-quality volume, followed by the sandbed. The purpose of the sedimentation chamber is to remove the settleable solids that could otherwise rapidly clog the filter. The sandbed is designed for a filtration rate of about 3.5 ft./day (Barrett, 1999) but generally operates at the rate limited by the release from the sedimentation chamber. Various configurations are available, including the Austin, Delaware, and Washington, DC designs. Sand filters require relatively high maintenance compared to other BMPs.

Drain Inlet Inserts. Three basic types of inlet inserts are available: tray, bag, and basket types. Each is installed in a drain inlet or catch basin to treat stormwater runoff. The tray type allows flow to pass through filter media contained in a tray located around the perimeter of the inlet. Runoff enters the tray and leaves via water flow under design conditions. High flows pass over the tray and into the inlet unimpacted. The bag-type insert is made of fabric and is placed in the drain inlet around the perimeter of the grate. Runoff passes through the bag before discharging into the drain outlet pipe. Overflow holes are usually provided to pass larger flows without causing backwater at the grate.

The basket-type insert consists of wire mesh placed around the perimeter of the inlet. The wire screens larger materials from the runoff. Some basket-type inserts contain filter media similar to the tray type.

Drain inlet inserts of all types have generally performed poorly in tests for several reasons. First, contact time between the runoff and the filter media is very short. Second, little storage area is available for material that is removed from the flow. The insert acts as a temporary storage location, retaining solids as flow decreases, but may allow resuspension when flow and velocity subsequently increase. Third, inserts require high maintenance and must be closely monitored during rain events to ensure that they are not clogged or bypassing flow. Such a level of maintenance is impractical for most installations.

Bag- and basket-type drain inlet inserts can be effective in removing gross pollutants (trash) if they are well maintained. For areas with a limited number of inlets where trash removal is the desired objective, these types of inserts can be a useful BMP. Tray-type inserts are generally not effective in trash or solids removal.

Biofilters. Biofilters consist of dense vegetation designed to filter runoff as it passes through the BMP. The detention or "residence" time is generally insufficient for a significant portion of the runoff volume to be infiltrated; however, for biofilters in soils with good infiltration characteristics, infiltration can be significant for storms smaller than the design storm. Biofilters can be effective in removing particulates from runoff.

Biofilters are an attractive BMP and can be incorporated into many projects with relatively little site modification. Conveyance structures that are normally paved can sometimes be replaced with vegetation. Buffer strips can be provided where sheet flow leaves paved areas. Biofilter swales are generally designed with a flow velocity of less than 1 ft./sec and are installed in a location with enough length to provide a residence time of at least five minutes (the length of the swale divided by the average flow velocity) (WEF/ASCE, 1998). Biofilter strips treat sheet flow, and their width is a function of the contributing drainage area, but the strips should be at least 12 ft. wide (Barrett, 1999).

Swales and strips must be designed to withstand flow rates that exceed the water quality design velocity to ensure that they are not damaged during high flows or cause upstream flooding. Certain types of well-established vegetation can be sustained in flow velocities of up to about 8 ft./sec., with a more typical value being 4-5 ft./sec. In the Southwest, vegetation that does not require irrigation may be prudent to reduce water consumption. Biofilters can serve as a pretreatment device prior to infiltration or in situations where extended detention is desirable but insufficient area is available. Biofilters require a moderate maintenance schedule as compared to other BMPs.

Extended Detention Basins. Relatively popular BMPs, extended detention basins have a design well documented from flood control engineering, and extended detention may be incorporated as an element into flood control detention basins. Extended detention employs a relatively longer drain time than conventional detention used for peak flow control. An average hydrograph detention time of 24 hours is desired and can be achieved by using a full basin drain time of at least 48 hours, with no more than

5% of the water quality volume draining in the first 24 hours (Barrett, 1999). Sedimentation in the basin is the primary removal mechanism.

Extended detention basins can be relatively effective in removing solids (including gross pollutants) but are relatively ineffective in removing dissolved constituents and bacteria. The application of extended detention must include a review of the downstream receiving channel to ensure that their use does not cause increased erosion of the channel.

Careful consideration should be given when installing extended detention basins upstream in an alluvial channel. The stability of an alluvial channel depends in large part on the quantity of bed material load transported by the stream, as well as the frequency and duration of the bank-full discharge. Extended detention basins are effective in removing the bed material load from natural channels. Channel stability problems and channel scour can result from the misapplication of this BMP. Extended detention is a useful BMP where particulate removal is a desired objective for the downstream receiving water. Extended detention requires moderate maintenance as compared to other BMPs.

Case Study: Los Angeles

In June, I submitted comments to the California State Water Resources Control Board regarding the Los Angeles Regional Water Quality Control Board stormwater regulations and its Standard Urban Storm Water Mitigation Plan. The plan called for treating the first 0.75 in. of stormwater runoff with conventional BMPs as discussed in this article to reduce pollutant loadings to water bodies.

It is important to note, however, that ***constituents*** are not necessarily ***pollutants***. According to the Clean Water Act, a pollutant is a constituent that impairs the beneficial uses of a waterbody. By using the term *pollutant* synonymously with chemical constituents in stormwater runoff and assuming that many constituents in stormwater runoff from developed areas are pollutants, the LA Regional Board is potentially chasing ghosts of problems. Techniques are readily available to determine whether a particular runoff constituent is in fact a pollutant in the receiving waters for that runoff.

Additionally, the BMPs listed in the plan are primarily directed at controlling particulate forms of constituents of concern, such as heavy metals which, in urban area street and highway stormwater runoff are well known to be nonpollutants. EPA has determined that many of the heavy metals of concern in urban stormwater runoff should be regulated based on dissolved forms present in ambient waters. The dissolved forms of heavy metals and many other constituents are not removed to any significant extent by conventional BMPs.

The irony of the plan -- and of many similar approaches around the country -- is that it calls for the removal of constituents from urban stormwater runoff that might not need to be removed at all and it proposes as a means of removal BMPs that are largely ineffective for this purpose.

My comments on the plan included the following recommendations for the LA Regional Board:

1. Define real, significant water quality-beneficial use impairment problems, caused by constituents in new developments as well as existing residential and commercial areas. This will require a substantial effort devoted to characterizing urban area stormwater runoff and, most importantly, to assessing the beneficial use impairment of the receiving waters by the runoff constituents.

2. Where significant receiving water beneficial use impairments are found, determine the cause of the impairment and the specific sources of the constituents responsible. This will require abandoning the "all chemicals in stormwater runoff are bad" approach. Instead it requires using appropriate forensic studies to determine the source of constituents responsible for the use impairment. Many constituents of concern in urban stormwater runoff exist in a variety of chemical forms, only some of which are toxic and available. Further, not all sources of a given constituent are equally significant in causing beneficial use impairment in the receiving water.

3. Once the source(s) of impairment-causing constituents are identified and quantified as to their significance, develop site-specific BMPs to control these constituents at their source. In most cases, because of the high cost of treating large volumes of stormwater runoff, these BMPs will not be runoff-based treatments but will require source control as the BMP. Based on the information available, it appears that there will be few instances where conventional BMPs of the type specified in the LA Regional Board's plan will be appropriate for controlling the beneficial use impairment.

4. Become the leader in organizing the stormwater runoff water quality management stakeholders in developing a watershed-based stormwater runoff water quality management program. It will be important to provide an opportunity for environmental groups to be provided with sufficient support so that they can be active participants in the technical aspects of water quality impact assessment and BMP selection and evaluation.

5. Become a leader in developing a watershed stakeholder-based water quality use evaluation program that is designed to determine the real, significant water quality-use impairments that are occurring in the waterbodies within the Board's jurisdiction. This should be an ongoing monitoring and evaluation program with stakeholders funding the program and participating in its organization, execution, and reporting of results.

Although the program outlined here is suggested as a more technically valid and economical alternative in an area of new developments, the approach can also be used in existing residential and commercial areas.

Evaluation Monitoring

My recommendation for the Los Angeles Regional Water Quality Control Board, as well as for other stormwater management programs, is to abandon the current mechanical approach of focusing on constituents in runoff waters and instead begin to define the real, significant water quality use impairment problems associated with urban runoff. Only then can appropriate BMPs be developed that will cost-effectively control the problem. One way to do this is through Evaluation Monitoring, an approach that Anne Jones-Lee and I developed associated with water quality studies in the Upper Newport Bay watershed in Orange County, CA (Jones-Lee and Lee, 1998).

Evaluation Monitoring requires a fundamental shift in the way we think of "water quality." It requires us to take a step back and look at what we -- and the public -- hope to achieve from monitoring water quality and how we should be spending public funds for monitoring and water pollution control.

The compliance monitoring adopted by EPA in the early 1980s and widely used today is a mechanical and relatively easy-to-administer method. It determines whether concentrations of constituents in an NPDES-permitted discharge exceed water quality standards or discharge limits, usually relying on samples taken at an arbitrarily established frequency for a year or so. If standards are exceeded more than once in three years, the waterbody is included in the state's 303(d) list of impaired waterbodies. The listing sets off a regulatory process that ultimately leads to the establishment of total maximum daily loads for the sources of the constituents responsible for the exceedance.

However, the EPA national water quality criteria were never intended to be implemented as not-to-be-exceeded values irrespective of the type of water being investigated. The EPA site-specific criterion adjustment approach, such as the Water Effects Ratio approach, only partially adjusts for the chemistry of constituents in aquatic systems that impact their toxicity/availability. This approach does not allow adequate time for chemical equilibrium to be reached and does not address the key issue of the impact and the form of the constituent of concern added to the waterbody on its toxicity/availability. The mechanical application of EPA national criteria as state ambient water quality standards will be, for many if not most waterbodies, overly protective; in some cases, much higher concentrations of constituents of concern than the water quality standard can be present without adversely impacting designated beneficial uses. With limited funds available for water quality management, it makes more sense to focus on solving real and significant water quality-use impairments that adversely impact beneficial uses of a waterbody.

In contrast to current compliance monitoring, Evaluation Monitoring focuses on assessing chemical impacts rather than chemical concentrations or loads. It defines water quality as the character of water relative to designated beneficial uses, rather than simply a list of concentrations of chemical constituents and biological data compared to numeric standards. Evaluation Monitoring looks, for example, at copper toxicity in a receiving waterbody rather than the copper concentration, at mercury and polychlorinated biphenyl (PCB) bioaccumulation rather than the concentrations of those constituents, and at excessive algae rather than nitrate and phosphate concentrations.

Evaluation Monitoring is a watershed-based technical stakeholder-driven water quality problem definition and control program. It serves as a basis not only for addressing the overly protective nature of EPA national water quality criteria and state standards based on these criteria, but also for regulating chemical constituents for which there are no water quality criteria or standards. Table 4 lists factors to be considered in evaluating how chemical constituents actually impact the designated beneficial uses of receiving waters. Table 5 lists typical water-quality-use impairments.

Table 4. Factors in Translating Runoff-Measured Concentrations of a Constituent to Potential Aquatic-Life Water-Quality Impacts

Stormwater Runoff	
	• Measured concentration of constituent during runoff event-concentration time profile • Discharge of the runoff water during runoff event-hydrograph • Analytical chemistry of the method used for analysis-what chemical species are measured
Receiving Waters	
Physical Factors	• Currents, tides-transport and advection, mixing and dispersion
Biological Factors	• Duration of organism exposure to toxicant • Organism movement or locomotion • Sensitivity to toxicants • Organism assemblages - resident populations relative to habitat characteristics
Chemical Factors	• Aquatic chemistry • Kinetics and thermodynamics of reactions • Additive, synergistic and antagonistic reactions and impacts • Toxic/available and nontoxic/nonavailable forms • Background concentrations of constituents of concern

Table 5. Water-Quality-Use Impairments

- Aquatic life toxicity - water column
- Sediment toxicity that impairs water quality - beneficial uses
- Excessive bioaccumulation of hazardous chemicals
- Dissolved oxygen depletion
- Domestic water supply water quality
- Groundwater recharge
- Eutrophication - excessive fertilization
- Sanitary quality impairment - contact recreation and/or shellfish harvesting
- Suspended sediment impacts
- Oil and grease accumulation
- Litter accumulation

Some of the basic questions that need to be addressed in evaluating whether stormwater runoff-associated constituents from a particular area are adversely impacting the beneficial uses of a waterbody include:

- Is there significant toxicity in the receiving water associated with stormwater runoff events that could be adverse to aquatic life populations in the receiving waters?
- Are there closed shellfish beds, swimming areas, etc., that could be impacted by stormwater runoff-associated pathogen-indicator organisms?
- Is there excessive algal/aquatic weed growth that could be stimulated by aquatic plant nutrients (nitrogen and phosphorus) in the stormwater runoff waters?
- Is there litter or debris derived from stormwater runoff?
- Do the fish or shellfish contain excessive concentrations of hazardous chemicals, such as mercury, PCBs, or dioxins that could be derived from stormwater runoff?
- Is the receiving water for the stormwater runoff excessively turbid during a runoff event?
- Is there shoaling, burial of spawning areas, shellfish beds, etc., occurring in the receiving waters as a result of the transport of suspended sediment in the stormwater runoff water?
- Is there an accumulation of oil and grease in the receiving waters that is aesthetically unpleasing and/or adverse to aquatic life?
- Are domestic or other water supplies experiencing treatment problems, excessive costs, etc., because of stormwater runoff-associated constituents?

For many impairments, such as excessive bioaccumulation, excessive suspended and deposited sediments, excessive pathogen-indicator organisms, and low dissolved oxygen, it is possible, through direct measurements of the receiving waters at the point of concern, to determine if there is a use impairment. For example, for excessive bioaccumulation, collecting edible organisms from the receiving waters and determining whether the tissue contains excessive concentrations of hazardous chemicals is straightforward and can be readily accomplished. Similarly, excessive concentrations of pathogen-indicator organisms on a particular beach or within a shellfish population are also readily discernible. True water quality studies of heavy metals and other potentially toxic chemical constituents should include aquatic life toxicity measurements. A water quality study of mercury that does not measure edible fish tissue concentrations of mercury is not a credible water quality study, although studies of this type are typically associated with compliance monitoring.

The first phase of the Evaluation Monitoring program should be devoted to a critical review of the existing database on the water quality characteristics of waterbodies and their tributaries. Based on this review, information gaps on current water quality-use impairments of the type listed in Table 5 should be defined and the monitoring program then focused on filling these gaps.

Once a comprehensive set of data from past studies, as well as from any current monitoring programs has been collected and a report prepared on this database, a stakeholder-developed consensus should be formulated on what real water quality-use impairments exist in the various parts of the watershed of concern. When these impairment problems have been defined and if the cause of these impairments has not been determined, site-specific studies should be undertaken to determine the cause or the specific chemical constituents responsible for the use impairments.

A use impairment should be a designated beneficial use impairment of the waterbody that is perceivable by the public, rather than simply an exceedance of a water quality standard or objective. The water quality significance of such exceedances should be addressed as a separate issue and specific studies should be conducted to determine the relationship between the exceedance and the impairment. Additionally, in defining the cause of the water quality problem, the emphasis should not be on the total constituent, such as total copper, cadmium, or lead, but on the specific forms of the constituent responsible for the toxicity, excessive bioaccumulation, or other use impairment, such as available forms of nutrients that impact excessive fertilization of a waterbody.

When the specific constituents responsible for the use impairment have been identified, through forensic studies the specific sources of the constituents responsible for the use impairment can be determined. Again, the focus should not be on all sources of total copper or other constituents, it should be on those sources of copper, mercury, and so on that are adverse to the beneficial uses of a particular part of the waterbodies of concern.

Once the true water quality problems have been defined and the source of the specific constituents responsible for the problem identified, then water quality-use impairment management plans can be formulated. Rather than relying on the mass load approach, based on total constituent loads, such plans must employ current science and engineering to determine the potential benefits of controlling the input of a constituent responsible for a water quality-use impairment to a particular degree on the beneficial uses of a particular part of a waterbody -- usually near the point of discharge/runoff (near field impacts) -- and on the overall beneficial uses of the waterbody (far field impacts).

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