Assessing and Managing Water Quality Impacts of Urban Stormwater Runoff[1]

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ABSTRACT

Considerable controversy exists on the real, significant water quality/beneficial use impacts of urban area and highway stormwater runoff-associated constituents. While this runoff contains a variety of potentially toxic constituents, such as heavy metals and certain organics, at concentrations that could be adverse to aquatic life in the receiving waters for the runoff, a number of studies, including those of the authors, have found that the heavy metals in residential street and highway stormwater runoff are in nontoxic forms. Further, it has been found that while stormwater runoff from many urban areas is toxic to aquatic life, that toxicity is due to pesticides used on residential properties.

This paper reviews the work of the authors, and the literature pertinent to the reliable assessment of the water quality significance of heavy metals and other constituents in urban area stormwater runoff that occur at total concentrations that potentially could be adverse to aquatic life and other beneficial uses of the receiving waters. Guidance is provided on an Evaluation Monitoring approach that focuses stormwater runoff monitoring on assessing the real impacts of chemical constituents and pathogen-indicator organisms in runoff waters as they may impact the aquatic life-related beneficial uses of the receiving waters. Also, guidance is provided on the approach that should be used to develop technically valid, cost-effective best management practices (BMPs) to manage real, significant water quality impacts of stormwater runoff-associated constituents.

INTRODUCTION

Water quality regulatory agencies in various parts of the world are beginning to develop programs for managing the water quality impacts of urban area and highway stormwater runoff-associated constituents. In the USA these programs are evolving out of the finding that urban area and highway stormwater runoff contains elevated concentrations of a variety of constituents that exceed US Environmental Protection Agency (US EPA) worst-case-based water quality criteria/standards. Of particular concern are certain heavy metals, such as copper, lead, zinc and sometimes cadmium; certain organics, such as the PAHs; oil and grease; nutrients (nitrogen and phosphorus compounds); and pathogen-indicator organisms, such as fecal coliforms.

The US EPA (1987) water quality criteria are designed to be protective of the receiving waters' beneficial uses, such as propagation of fish and aquatic life, domestic water supply, etc., under

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essentially all conditions from all types of constituent sources for potential sources. Typically, the criteria assume that the regulated constituents for which there are criteria are in 100 percent toxic/available forms and that the duration of exposure to aquatic life is for an extended period of time. It has been known, however, since the 1960s that many of the constituents, such as heavy metals, in urban area street and highway stormwater runoff are in nontoxic, non-available forms and, therefore, an exceedance of a worst-case-based water quality criterion/standard represents an "administrative" exceedance that relates to the fact that the application of these criteria and standards to urban area street and highway stormwater runoff significantly overestimates the impact of this runoff on aquatic life and other beneficial uses of the receiving waters for the runoff. This situation raises questions about how regulated stormwater runoff water quality managers, regulatory agencies, and others should evaluate the real, significant water quality/ beneficial use impairments associated with the runoff that are due to the chemical constituents in the runoff, to protect the beneficial uses of the receiving waters for the runoff without significant unnecessary expenditures of public funds for chemical constituent and pathogen-indicator organism control.

Unfortunately, it is not possible to rely on professional organization stormwater management guidance manuals, such as the WEF/ASCE (1998) and the FHWA (1996) manuals to provide reliable information that stormwater managers and others can use to develop technically valid, cost-effective stormwater runoff water quality management programs. These and other manuals of this type fail to properly incorporate well-known information on how chemical constituents and pathogen-indicator organisms impact the beneficial uses of waterbodies. This paper provides guidance on a recommended approach to address these issues.

Many of the issues summarized herein have been discussed in more detail in papers and reports developed by the authors that are available from their website, www.gfredlee.com, as well as their *Stormwater Runoff Water Quality Science/Engineering Newsletter*, past issues of which are also available from the website.

POTENTIAL IMPACTS OF URBAN AREA AND HIGHWAY STORMWATER RUNOFF-ASSOCIATED CONSTITUENTS ON RECEIVING WATER BENEFICIAL USES

Impact of Constituents

Urban area and highway stormwater runoff typically contains a variety of chemical constituents and pathogen-indicator organisms at concentrations that are a threat to the beneficial uses of the receiving waters for the runoff. Lee (1998a), as part of a review of the literature and, in particular, State of California urban stormwater runoff characteristics, discussed the current information on the potential impacts of urban area and highway stormwater runoff on receiving water quality. Table 1 presents a summary of these findings. For a discussion of Table 1, see Lee (1998a).

This table is based on the typical concentrations that are found in urban area and highway stormwater runoff and the concentrations of constituents that, under worst-case (i.e., most toxic and extended exposure) conditions, can be adverse to aquatic life and other beneficial uses of waterbodies. With respect to the pathogen-indicator organisms, such as fecal coliforms, the issue is the occurrence of concentrations of these organisms in a waterbody and, in particular, on a bathing beach where contact recreation occurs, at concentrations that are judged to be a threat to cause illness to those who use these waters for contact recreation.

Table 1

Potential Urban-Area & Highway Stormwater Runoff Water Quality Standards Compliance Problems*

Frequency/Condition	Constituents
Frequently	Copper, Lead, Zinc Bis (2-ethyl) phthalate Fecal Coliforms Aquatic Life Toxicity
In Some Locations	Cadmium, Mercury, PAHs Individual & Total

If on a List of US EPA "Impaired" Waterbodies for

Toxicity – *Ceriodaphnia*	OP Pesticide, Unknown Causes
Nutrients	N & P Compounds
Contact Recreation/Shellfish	Total Coliforms
Sediment-Associated Constituents	Heavy Metals, PAHs, NH_3, H_2S
Bioaccumulation of Hazardous Chemicals	Hg, DDT, PCBs, Chlordane, Dioxins, etc.

New Water Quality Criteria/Standards

Nutrients N & P
New Fecal Indicator Organisms
E. coli, Enterococci
Cryptosporidium, Enteroviruses
Organics - To Be Determined

Revised Water Quality Criteria/Standards

Hg, Se, As

* Does not necessarily mean a real, significant beneficial use impairment

Impact of Flow

In addition to the constituents listed in Table 1, one of the most significant impacts to aquatic life-related beneficial uses of waterbodies is the altered flow regime associated with urban area and highway stormwater runoff. The development of an area, which includes paving for driveways, sidewalks, roads, etc., generally greatly increases the amount of runoff from the area, due to the significantly reduced infiltration that occurs. It is becoming widely recognized that the increased flow associated with urbanization can significantly alter aquatic life habitat, through erosion of streambed and banks and the deposition of eroded materials in critical habitat areas. These issues are summarized in the WEF/ASCE (1998).

Maxted and Shaver (1997 and 1999) studied the impact of new development on aquatic organisms in streams receiving runoff from new residential developments. They concluded that the primary effect of the development was due to increased flow in the stream associated with stormwater runoff events which altered aquatic organism habitat. They also concluded that the construction of a conventional BMP such as detention basin to remove constituents from the residential area runoff did not alter the impact of the residential development on the aquatic organisms in the stream receiving the runoff.

The US Environmental Protection Agency (US EPA, 1999b) is proposing to regulate the impacts of urban area and highway stormwater runoff flow through the use of biological assessments in the receiving waters potentially impacted by the flow. These assessments would compare the numbers and types of organisms that should be present in a particular waterbody in the absence of elevated flows due to urbanization of an area, to those found in the region where elevated flows could be adverse to the aquatic life-related beneficial uses.

TECHNICALLY INVALID APPROACHES FOR MANAGING URBAN AREA AND HIGHWAY STORMWATER RUNOFF WATER QUALITY IMPACTS

A review of traditional approaches for managing the water quality impacts of urban area and highway stormwater runoff shows that, normally, a detention basin, grassy swale or infiltration system is developed as a so-called "BMP," where the stormwater runoff is "treated" to reduce the concentrations of constituents in the runoff waters. The WEF/ASCE (1998) manual provides detailed guidance on the development of conventional, traditional BMPs; however, as discussed by Jones-Lee and Lee (1998a), conventional, traditional BMPs such as detention basins were not developed to control constituents in urban area and highway stormwater runoff that are likely to cause adverse impacts to the beneficial uses of the receiving waters for the runoff. They have been and are traditionally today based on hydraulic design, largely without regard to the removal of constituents in the runoff waters that are potentially significant threats to the beneficial uses of receiving waters.

There are numerous examples of inappropriate approaches for developing guidance on managing the impacts of stormwater runoff-associated constituents to receiving water quality. For example, detention basins, grassy swales, etc., are often advocated as being effective BMPs for urban area and highway stormwater runoff for the control of the concentrations of heavy metals in the runoff. A review of how detention basins function with respect to removal of heavy metals and their demonstrated across-the-detention-basin removal shows that detention basins typically remove from 30 to 50 percent of particulate forms of heavy metals (Browne, 1999; Barrett, *et al.*, 1998).

It has been known, however, since the late 1960s that particulate forms of heavy metals are typically nontoxic to aquatic life. Further, their accumulation in receiving water aquatic sediments would not be expected to lead to toxic conditions within the receiving water sediments. The US EPA (1995) has determined that heavy metal toxicity to aquatic life should be regulated based on dissolved forms of heavy metals, rather than particulate forms. Therefore, the removal of heavy metals in a detention basin or grassy swale, which largely removes some of the particulate forms of heavy metals from urban area street and highway runoff, is not a water quality management technique, but a facade that allows those who advocate the use of detention basins or some other type of conventional BMP to say that something was done to "treat" the stormwater runoff, irrespective of whether that "treatment" was of value to improving, or in the case of new construction, protecting the beneficial uses of the receiving waters for the runoff.

A similar situation occurs with the control of phosphorus in urban area and highway stormwater runoff as part of an excessive fertilization (eutrohication) management program. The WEF/ASCE (1998) manual presents a discussion of the scope of the manual, where it is stated,

> *"Water quality parameters addressed most in this manual are total suspended solids (TSS) and nutrients (nitrogen and phosphorus); this reflects current common practice in BMP design. In fact, TSS and nutrients are the primary constituents of stormwater runoff that can be controlled by the passive BMPs considered in this manual. It is noted that focus on these parameters is not a complete oversight of other parameters, because most other constituents of concern (for example, metals, hydrophobic organics) are reduced by the processes used to remove TSS, and remove nutrients. Moreover, the two most widely documented effects of urban runoff on receiving waters are associated with sediment and nutrient enrichment.*

However, those familiar with the elements of nutrient impacts and control know that the focus of nutrient control programs should be on available forms of nutrients, not total forms. It is also well known through extensive research (Lee *et al.* 1980) that the forms of nitrogen and phosphorus that are removed as particulates in conventional BMPs are largely in non-available forms. For the WEF/ASCE manual to state that the guidance provided in this manual is appropriate for developing BMPs for nutrient issues is a significant deficiency in providing reliable information on BMP selection and evaluation for stormwater runoff nutrient-related problems.

Jones-Lee and Lee (1998a), in their review, "Snake-Oil BMPs..." have discussed the significant amount of unreliable information that has been foisted on the stormwater runoff water quality management field regarding the efficacy of conventional BMPs, such as detention basins, grassy swales, etc., in treating urban area and highway stormwater runoff so that it does not cause adverse impacts on the beneficial uses of the receiving waters for the runoff. While the lack of efficacy has been well-understood for many years, there are still professional groups, such as the Water Environment Federation and the American Society of Civil Engineers, who produce a stormwater management manual of practice which fails to discuss the issues concerning the expected performance of various BMPs. This situation makes these manuals largely unreliable in providing information that is urgently needed to insure that when funds are spent in the name of water pollution control associated with urban area and highway stormwater runoff, these funds are used in a technically valid, cost-effective manner.

Reliable Evaluation of BMP Efficacy

The typical approach used to evaluate the efficacy of a so-called "BMP" for urban area and highway stormwater runoff is to measure the concentration reduction of total constituents across the BMP unit, usually under low-flow conditions, where the maximum removal of the particulate forms can be expected. This approach for BMP evaluation is fundamentally flawed and unreliable. BMPs are developed for the purpose of protecting/enhancing the beneficial uses of the receiving waters for urban area and highway stormwater runoff. **THE ONLY WAY TO EVALUATE THE EFFICACY OF A BMP FOR URBAN AREA AND HIGHWAY STORMWATER RUNOFF WATER QUALITY MANAGEMENT IS TO ASSESS HOW ITS INSTALLATION AND OPERATION IMPACT THE BENEFICIAL USES OF THE RECEIVING WATERS THAT IT IS DESIGNED TO PROTECT/ENHANCE.** Across-the-unit BMP measurements of constituent removal can, and usually provide highly unreliable information on the potential benefits of the installation and operation of a particular BMP, such as a detention basin, for removal of heavy metals, nutrients, and many other constituents in urban area and highway stormwater runoff that can be detrimental to the beneficial uses of the receiving waters for the runoff.

The reliable way to assess the benefits of a particular BMP is to conduct a site-specific evaluation of how the removal of constituents by a particular BMP impacts or, in the case of a proposed BMP installation, potentially impacts the beneficial uses of the receiving waters for the runoff. Typically, those responsible for developing BMPs do not have the academic background and professional expertise to reliably develop BMPs that are designed to manage water quality in a technically valid, cost-effective manner. This approach requires that appropriate aquatic chemistry, toxicology/biology, as well as hydraulics/hydrodynamics be incorporated into the BMP evaluation. .

There is increasing information being published on the lack of efficacy of traditional BMPs in addressing real water quality problems and the inappropriateness of using across the BMP unit removals to evaluate the BMPs' efficacy. The USA Great Lakes states and Ontario. Canada have been active in implementing phosphorus control programs in the Great Lakes Basin for over 20 years. The International Joint Commission for the Great Lakes (IJC 2000) developed a summary report covering the Great Lakes Basin experience in control of nonpoint source nutrients. Of particular interest are the conclusions by Schueler, Center for Watershed Protection, Washington, DC (IJC 2000),

> "***BMPs that Have Not Worked***
> *Several BMPs have not been successful, either because they do not have the capability to remove pollutants, or because they are impractical from a maintenance standpoint. Still, other practices have very little evidence to demonstrate their effectiveness. The BMPs that have shown poor performance include:*
> • *conventional detention*
> • *dry extended detention*
> • *infiltration basins*
> • *porous pavement*
> • *oil/grit separators*
> • *drainage ditches*

- *straw bales (for erosion and sediment control)*
- *public education (may work but we have very little evidence)."*

The US EPA, through the American Society of Civil Engineers, is developing a National Stormwater Best Management Practices (BMP) Database (ASCE 2000). Great caution must be used in relying on this database as a source of adequate information on what can be expected in the way of water quality/beneficial use improvement through the use of one or more of the BMPs included in this database. This database consists of information on the amount of removal of constituents across BMP units. It therefore does not provide the information that is needed to determine whether the across-the-unit removal by the BMP has had any impact on the beneficial uses of the receiving waters for which the BMP is being developed. Without this information, there is no reliable assessment of the BMP's efficacy. In most cases, a critical review of this so-called "efficacy" will show that the removal has had little or no impact on the water quality/beneficial uses of the receiving waters. Further, because of the altered flow regime associated with some of the BMPs, the development of the BMP may have done more harm to the aquatic life-related beneficial uses of the receiving waters than f the BMP had not been developed.

One of the BMPs that is being advocated as a highly effective BMP for managing urban area and highway stormwater runoff is the infiltration of the runoff waters into a groundwater system. Frequently stormwater infiltration is advocated as a BMP without regard to whether the constituents in the infiltrated stormwater can cause groundwater pollution. The WEF/ASCE (1998) manual provides detailed guidance on how to construct stormwater infiltration BMPs, but, although well-known in the literature, it does not provide guidance on how to evaluate whether stormwater infiltration can cause groundwater pollution. Lee, *et al.* (1998) and Taylor and Lee (1998) have reviewed the potential problems associated with the use of infiltration as a stormwater runoff water quality BMP. Their review includes a discussion of the monitoring and evaluation programs that should be conducted as part of using an infiltration BMP to manage the impacts of urban area and highway stormwater runoff.

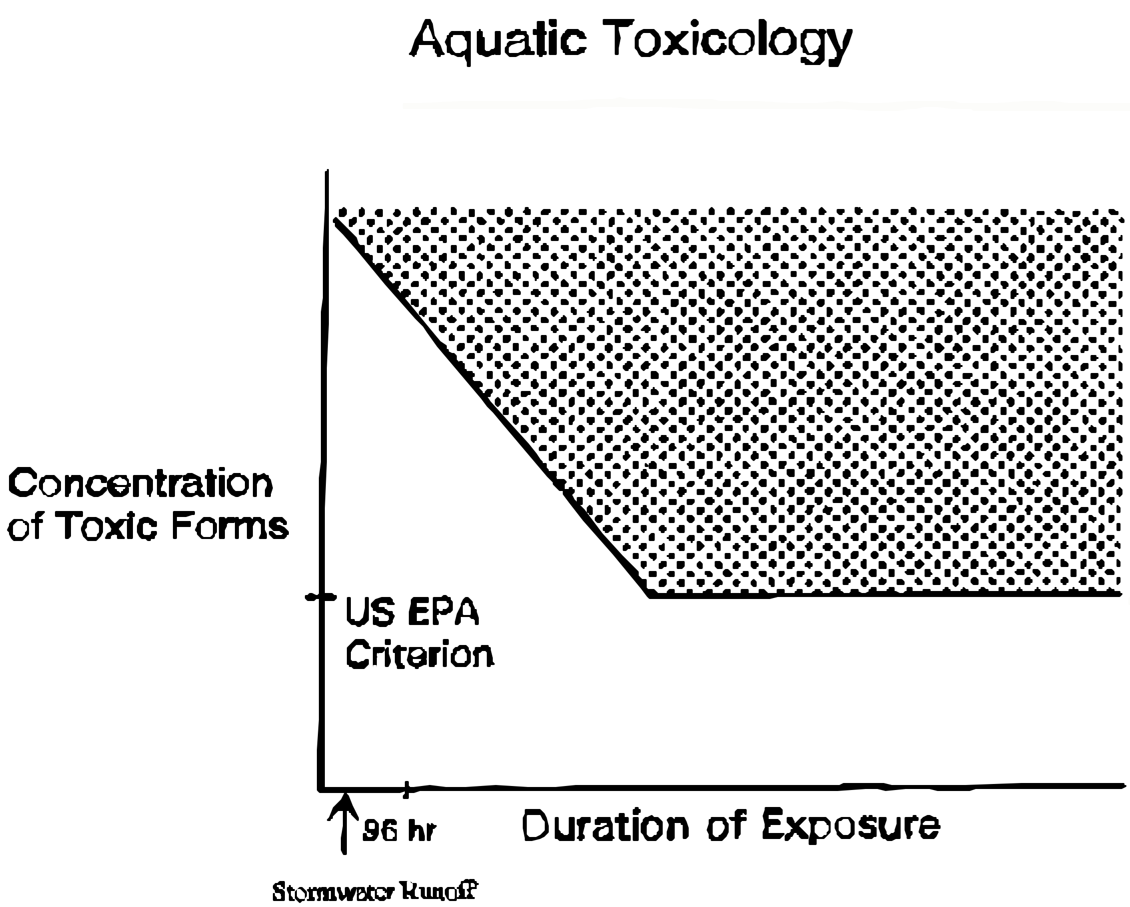
REGULATORY REQUIREMENTS

In 1987 as part of reauthorization of the Clean Water Act, the US Congress established that the US EPA develop a regulatory approach that mandates that urban and highway stormwater management agencies develop pollution control programs. The US EPA (1990) established that National Pollutant Discharge Elimination System (NPDES) permitted stormwater management systems shall control **pollution** of the receiving waters to the maximum extent practicable (MEP) using best management practices (BMPs). One of the most significant problems that exits in the stormwater runoff water quality management field is the sloppy use of the term pollution and pollutant. Far to often the terms pollution and pollutant are used when chemical constituent should be used.

Pollution is defined in the Clean Water Act as an impairment of the beneficial uses of a waterbody. For aquatic life impacts, this translates to the alteration of the numbers, types and characteristics of desirable forms of aquatic life in the receiving waters for stormwater runoff that is due to runoff-associated constituents, either alone or in combination with the same or other constituents in the receiving waters for the runoff. It is extremely important that those working in the stormwater runoff water quality management field use the terms pollution and pollutant for those situations where there is clear evidence that an use impairment of the waterbody has occurred or is occurring.

Typically, individuals not knowledgeable in the topic area attempt to use exceedance of US EPA worst-case-based water quality criteria and state standards based on these criteria as defining "pollution." However, this approach ignores the fact that chemical constituents in aquatic systems exist in a variety of forms, only some of which are toxic/available, and that the concentration of available form/duration of exposure relationship governs adverse impacts to aquatic life, not just concentrations. This relationship is shown in Figure C-1. As indicated, in Figure C-1, high concentrations of toxic/available forms can be present for short periods of time, such as in stormwater runoff near the point of discharge, without being toxic under the conditions of the runoff event. While constituents such as heavy metals under extended

Figure C-1



exposure can be toxic to aquatic life if they are in a toxic chemical form, short-term exposures of laboratory-based toxic forms do not necessarily lead to ambient water toxicity.

Figure C-2 shows the aquatic chemistry that must be considered in evaluating pollution associated the introduction of constituent. Typically, the analytical methods used to measure constituents in urban area and highway stormwater runoff, as well as ambient waters, measure the total concentrations of constituents, as represented by those that are present at the hub of the aquatic chemistry wheel shown in Figure C-2. However, there are eight different types of chemical/biochemical reactions that can occur, which influence the actual chemical species present in a particular system. It is the chemical species, as represented by the products of these reactions at the end of the spokes on the rim of the wheel, that determine impacts. Only some of those chemical species that exist at the rim are in toxic/available forms. A reliable evaluation of the water quality impacts of chemical constituents to cause pollution requires incorporation of highly sophisticated aquatic chemistry, hydraulics and hydrodynamics and toxicity/biology. This degree of technology has thus far been largely absent from urban area and highway stormwater runoff water quality management.

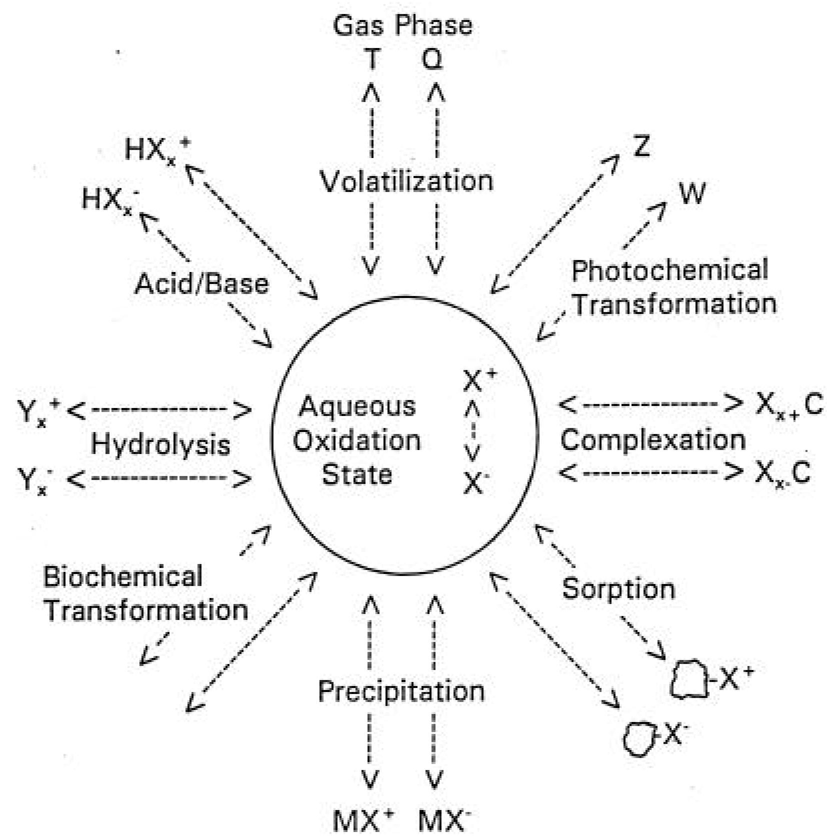
Traditionally, event mean concentration (EMC) is used in stormwater runoff water quality data workup. EMC is contrived parameter that is often used to "examine" the water quality impact of stormwater runoff associated constituents. However, a critical review of how potentially toxic chemical constituents impact aquatic life shows that EMC is not a valid water quality parameter. Chemical constituents do not impact aquatic life based on the average concentration during a runoff event. As shown in Figures C-1 and C-2, it is the concentration of toxic form-duration exposure relationship that controls whether a toxic constituent is adverse to aquatic life related beneficial uses of a waterbody.

Another significant problem with stormwater runoff "water quality" evaluations is the emphasis on first flush issues. There is the often mistaken belief that the initial (first flush) runoff is most adverse to aquatic life related beneficial uses of waterbodies. This error arises from the failure to properly consider how chemical constituents impact aquatic life. The sometimes higher concentration of some constituents in urban area and highway runoff that occurs for a short period of time associated with the "first flush" may not be adverse to aquatic life. Lower concentrations of toxic available forms over longer periods of time may be more adverse to water quality/beneficial uses than the first flush associated constituents. It is important to not assume that high total concentrations of potential pollutants cause adverse impacts on the beneficial uses of the receiving waters for stormwater runoff.

Regulating Pathogen Indicator Organisms in Urban Area and Highway Stormwater Runoff

One of the most significant real impacts of urban area and highway stormwater runoff is caused by the high concentrations of fecal indicator organisms in the runoff waters. These organisms are a threat to the use of the receiving waters for domestic water supply and for contact recreation, such as swimming, wading, etc. The US EPA (1999a), as part of its "beaches" program, is devoting considerable attention to managing the sanitary quality of beaches and other contact recreation waters. One of the areas of particular concern in managing the sanitary quality

Figure C-2
Aquatic Chemistry of Chemical Constituents



Distribution Depends on Kinetics & Thermodynamics of Reactions in a Particular Aquatic System

Each Chemical Species Has Its Own Toxicity Characteristics

Many Forms Are Non-Toxic

leak into stormwater management systems. The typical municipal sewerage system often has significant leaks, due to broken or inadequately sealed pipes, failure of pump stations, blockage of the sewerage system, etc., which results in the discharge of domestic wastewaters to the nearby water courses, which are, typically, stormwater conveyance systems.

This situation can cause dry weather flow in stormwater management systems to have very high concentrations of human fecal organisms. There can also be high concentrations of human fecal organisms in stormwater runoff due to leakage of the domestic sewerage system. Since animal-derived fecal indicator organisms are not necessarily associated with human pathogens, there is need for all stormwater management agencies to ensure that the domestic wastewater management agencies maintain their sewerage system in such as way as to prevent, with a high

POLITICS OF STORMWATER RUNOFF WATER QUALITY MANAGEMENT

Some environmental activist groups have selected urban area and highway stormwater runoff as a target area for their group activities. Some are supporting their activities through litigation against stormwater management agencies, where they achieve a settlement of a lawsuit which requires that the stormwater management agency do something, such as install conventional BMPs, without regard to whether they will impact the receiving water quality. The authors have encountered several situations where public works directors, stormwater management agency managers and others capitulate to the environmental activist group's positions on issues of installing conventional BMPs, even though they know that the BMPs will have little or no impact on the beneficial uses of the receiving waters for the stormwater runoff.

This situation is at the root of one of the most significant problems that exists in the environmental field today, where significant amounts of public funds are being spent in the name of environmental pollution control that are largely misdirected to controlling non-problems or problems which are of limited significance. Further, because of the approach that is used today in regulating chemical constituents in aquatic systems which focuses on chemical concentration control as opposed to chemical impact control, substantial amounts of money are being spent in public works projects to achieve worst-case-based water quality criteria/standards. Because of the nature of the source and/or the receiving waters, the exceedance of the criterion/standard represents an "administrative" exceedance associated with the highly overly-protective nature of the US EPA water quality criteria and state standards based on these criteria. Rather than conducting the studies to evaluate, on a site-specific basis, whether the constituents that exceed water quality standards, as well as the unregulated constituents in urban area and stormwater runoff for which there are no standards, are adversely impacting the beneficial uses of the receiving waters, some stormwater management agencies install conventional BMPs.

One of the most significant problems in proper management of urban area and highway stormwater runoff is an attitude among some stormwater management agency managers that they do not want to become involved in controversial issues, especially with environmental activist groups, on appropriate regulation of stormwater runoff water quality impacts. The authors have repeatedly encountered situations where stormwater management agencies responsible to the public comply with what is obviously over-regulation of stormwater runoff, rather than convincing their superiors, the city council, and others that it is in the public's best interest to insure that when public funds are spent, they are used wisely to address real, significant water quality problems, and not those that arise out of inappropriately developed/implemented regulatory approaches. Rather than conducting the studies that are needed to properly determine the real, significant impacts of chemical constituents and pathogen-indicator organisms in urban area and highway stormwater runoff, the complacent stormwater management agencies accept inappropriate regulatory approaches, which can cost the public large amounts of funds in unnecessary expenditures for constituent control, compared to those that are needed to protect beneficial uses in a technically valid, economical manner.

An example of this type of situation occurs where environmental activist groups are supporting their legal staff through litigation against public agencies, based on worst-case-based approaches for compliance with water quality standards in the stormwater runoff. Situations have occurred where stormwater management agencies have been "blackmailed" into conducting best management practice studies, in which the management agency was prevented by the environmental activist groups from doing the studies needed to evaluate the potential benefits of implementing conventional BMPs, such as detention basins, grassy swales, etc., on the beneficial uses of the receiving waters for the stormwater that is "treated" by such practices.

Basically, the environmental activist groups only wanted data presented from these studies that would show the removal of a constituent across the BMP, and did not want data produced which could show that this removal had no impact on the beneficial uses of the receiving waters. Those familiar with conventional stormwater runoff so-called "water quality" BMPs' efficacy know, as discussed above, that in most cases conventional BMPs are largely ineffective in removing constituents that are significantly adverse to the beneficial uses of the receiving waters for the runoff. While they may show significant removal of total heavy metals, suspended sediment, etc., they rarely are effective in removing the toxic (dissolved) forms of heavy metals or other constituents that potentially could cause real impacts on receiving water beneficial uses.

The Santa Monica Bay Restoration Program is a prime example of how environmental activist groups, working with regulatory agencies, can trap the public into inappropriately spending large amounts of funds in the name of stormwater runoff water quality management, where there are significant questions about the expenditures impacting the beneficial uses of receiving waters for the runoff. The Santa Monica Bay Restoration Program management, through the Los Angeles Regional Water Quality Control Board, the State Water Resources Control Board, and the US EPA, adopted a Santa Monica Bay Restoration Program that required that the public in the Santa Monica Bay watershed spend $42 million over 5 years "treating," through conventional BMPs, urban area and highway stormwater runoff.

As discussed by Lee (1995,1998b), this management approach was not based on a finding that the heavy metals and other constituents in the stormwater runoff that were to be "treated" by the conventional BMPs were having a significant adverse impact on the beneficial uses of the Santa Monica Bay. It ignored the aqueous environmental chemistry/toxicology of the heavy metals and other constituents in the Santa Monica Bay watershed stormwater runoff as these constituents may impact the beneficial uses of Santa Monica Bay.

The lack of technical validity in this program was -of the Santa Monica Bay watershed cities; however, they did not oppose the development of this "restoration program," since it would cause them and their city to be considered "anti-environment." While this program was adopted several years ago, it has not been implemented by the cities. There is still need to determine what real, significant water quality problems that are impairing the beneficial uses of Santa Monica Bay are being caused by heavy metals and other constituents in Santa Monica Bay urban area street and highway stormwater runoff.

It is extremely important to the wise use of public funds that the stormwater management agencies not succumb to the environmental activist groups' "blackmail," but require that properly funded studies be conducted on what can be achieved through various BMPs to treat/manage urban area and highway stormwater runoff-associated constituents. Not all environmental activist groups are practicing deceptive approaches toward meaningfully addressing urban area and highway stormwater runoff water quality impacts. Responsible environmental groups support working with stormwater management agencies, regulatory agencies, and others to determine the real water quality impacts associated with urban area and highway stormwater runoff, and then work toward finding support for controlling these impacts in a technically valid, cost-effective manner. This is a far more valid and appropriate approach than the approach that is used by some environmental activist groups of claiming that any attempt to adjust the US EPA national water quality criteria for site-specific conditions represents a weakening of the Clean Water Act.

One of the causes of the current situation is that many, if not essentially all, environmental groups face the problem of not having the technical expertise and resources to participate in the complex process of applying today's aquatic chemistry, toxicology and biology in regulating urban area and highway stormwater runoff to protect beneficial uses without significant unnecessary expenditures for constituent control. It is important for those who manage public and private funds to provide financial support for environmental groups so that they can actively participate in developing and implementing appropriate policy for urban area and highway stormwater runoff water quality management.

RECOMMENDED APPROACH

Presented below is a summary of the recommended approach for developing technically valid, cost-effective stormwater runoff water quality management programs.

Reliable Monitoring of Stormwater Runoff-Associated Constituents/Impacts

The first step in developing a credible stormwater runoff water quality management program is the reliable monitoring of the runoff to determine its characteristics and its impacts. The conventional stormwater runoff water quality monitoring program, which involves sampling the runoff from a couple of storms each year, in which a suite of heavy metals and other constituents is determined, generates data that cannot be used to determine whether the runoff is having a significant adverse impact on the beneficial uses of the receiving waters for the runoff. This approach generates data that show that there are exceedances of worst-case-based water quality criteria/standards, but provide no information on the impact of the constituents responsible for the exceedances, as well as the unregulated constituents in the stormwater runoff which are not measured because of a lack of a water quality criterion/standard.

Jones-Lee and Lee (1998b) have summarized an alternative monitoring approach (Evaluation Monitoring) that shifts the monitoring resources from measuring chemical concentrations in the runoff waters to assessing the water quality impacts of the constituents in the runoff on the beneficial uses of the receiving waters for the runoff. Rather than measuring copper in street and highway runoff and finding that most of the time the copper is present at concentrations above a worst-case-based water quality standard for protection of aquatic life, the evaluation monitoring approach measures toxicity in the runoff waters using appropriately sensitive forms of aquatic life. If toxicity is found, its cause and the source of the constituents responsible are determined through toxicity identification evaluations (TIEs) and forensic TIEs. A properly implemented Evaluation Monitoring program involves a stakeholder watershed-based process in which all interested parties are active participants in determining the water quality significance of a potential adverse impact, such as a laboratory-based measured aquatic life toxicity. Further information on the Evaluation Monitoring approach is provided by Jones-Lee and Lee (1998b).

Lee and Taylor (1999), through the application of Evaluation Monitoring to stormwater runoff in the Upper Newport Bay, Orange County, California watershed, showed that the exceedances of the copper, lead, and zinc water quality criteria in the runoff waters did not represent an adverse impact on the beneficial uses of the Upper Newport Bay. These metals were in nontoxic forms; however, the stormwater runoff was found to be toxic to *Ceriodaphnia* and *Mysidopsis,* freshwater and marine zooplankters, respectively. This toxicity was determined through TIEs to be due to the organophosphate (OP) pesticides diazinon and chlorpyrifos that are used on residential properties for termite, ant and lawn and garden pest control. The OP pesticides are not regulated by water quality criteria and standards, and therefore their presence in the stormwater runoff was unknown.

Review Existing Water Quality Characteristic Data for the Stormwater Runoff and the Receiving Waters

Presented below is a recommended approach for evaluation of the water quality significance of stormwater runoff-associated constituents on the water quality -beneficial uses of the receiving waters. This section is adapted from Lee and Jones-Lee (1999).

Determine if there is an exceedance of a receiving water water quality standard that is caused or contributed to by the stormwater runoff. Also determine if a real water quality use impairment (pollution) of the receiving water is occurring in the receiving waters for the stormwater runoff discharge that is due to constituents in the stormwater runoff. The purpose of this effort is to determine if the stormwater runoff is causing or significantly contributing to real pollution-use impairment of the receiving waters for the stormwater runoff. This will assess whether the exceedance of the water quality standard is an administrative exceedance relative to the highly protective nature of worst-case-based water quality criteria/standards when applied to many constituents in most waterbodies.

If an inadequate database exists to determine if a violation of a water quality standard or a receiving water use impairment is occurring, then initiate a water quality monitoring/evaluation program designed to evaluate whether a real significant water quality use impairment is occurring in the stormwater runoff's receiving waters. Use the Evaluation Monitoring approach in evaluating whether a real significant water quality problem exists in the receiving waters for the runoff. This effort will enable stormwater runoff discharge water quality managers and others to reveal and appropriately address the over-regulation that arises from the US EPA's Independent Applicability Policy and the use of worst-case-based water quality criteria/standards.

Addressing Administrative Exceedances of Water Quality Standards

As discussed by Lee and Jones-Lee (1995c) the worst case based water quality criteria should be used as a trigger to indicate the need for further evaluation. If a water quality standard violation occurs without a significant use impairment of the receiving waters, then petition the regulatory agencies for a variance from having to meet water quality standards in the runoff receiving waters based on there being no use impairment occurring in the receiving waters due to the stormwater runoff-associated constituents. This variance should include the opportunity to adjust the receiving water standards/stormwater discharge limits and/or the designated uses of the receiving waters to protect the designated beneficial uses of receiving waters for the stormwater runoff without significant unnecessary expenditures for chemical constituent control. These adjustments should be based on appropriately conducted receiving water studies that focus on assessing chemical impacts, rather than the traditional approach of measuring chemical concentrations and loads.

The US EPA (1994), in their Water Quality Standards Handbook, provides guidance on how the worst-case-based water quality criteria can be adjusted for site-specific conditions. It is important to understand, however, that the Agency's approach for developing site-specific criteria/standards can still lead to over-regulation, since it does not fully account for the aqueous environmental chemistry of constituents as they may impact the beneficial uses of a waterbody.

Determining the Cause of Pollution and the Source of the Pollutant

If a water quality use impairment is found in the receiving waters for the stormwater runoff, determine the specific causes of the use impairment and, through forensic studies, whether the toxic/available form of the specific constituent(s) responsible for the use impairment is derived from the stormwater runoff of concern. Also determine the relative significance of the stormwater runoff versus other sources of the specific constituents responsible for the use impairment as a cause of the use impairment. The relative contribution information is needed to evaluate the potential improvement in the receiving water water quality as a result of implementation of the proposed BMP.

Selection and Economic Evaluation of BMPs

Select a BMP(s)/treatment processes to control the specific constituents responsible for the use impairment. The BMP/treatment process selection should be based on the specific chemical species that cause a water quality use impairment in the receiving waters, rather than the total concentrations of the constituent. For example, focus the BMP on removing those forms of dissolved copper that are significantly adverse to beneficial uses of the receiving waters for the runoff, rather than on total copper, much of which is in a non-toxic form. Jones-Lee and Lee (1998) and Taylor (1998) have indicated that the cost of retrofitting an urban area with conventional BMPs such as detention basins is on the order of $1 to $3/person/day over 20 years for the population served by the stormwater runoff management system. The conventional BMPs such as detention basins will not "treat" the stormwater runoff to achieve water quality standards in the "treat: water and will bypass the constituents that are the greatest threat to cause water quality impacts.

In order to achieve water quality standards in the BMP treated stormwater runoff the cost is increased to about $8 to $10/person /day in order to acquire the land for the collection and advanced wastewater treatment system and its operations. Typically, because of the very high cost of treating urban area and highway stormwater runoff, associated with collecting and treating the high flows that can occur, the primary BMP that will need to be used will frequently be source control, where the constituents specifically responsible for the use impairment are controlled at the source.

Evaluate Cost-Effectiveness of a BMP(s) in Controlling Significant Pollution

If the development and operation of the proposed stormwater runoff BMP treatment process appears to be economically feasible, then estimate the potential improvement in the designated beneficial uses that will occur in the receiving waters relative to the unregulated or under-regulated sources of the same pollutant(s) responsible for the use impairment. If the potential improvements in the receiving water's designated beneficial uses is limited compared to projected costs to eliminate the use impairment, then the community leaders, regulatory agencies, environmental groups and public groups that are interested in appropriate use of funds should work together to evaluate if the expenditures for stormwater runoff chemical constituent control is the best use of the funds potentially available to meet societal needs.

Evaluate the Efficacy of the BMP/Treatment Processes

BMP/treatment process efficacy evaluations must be based on evaluating the improvements that the BMP/treatment process causes or, for new developments, is expected to cause in the receiving water beneficial uses. This will require site-specific studies of the impact of the development and operation of the BMP on the receiving waters' beneficial uses for the treated discharge. Do not assume that an across the BMP unit removal of a constituent (s) can be translated into a receiving water beneficial use improvement.

Detection of Future Stormwater Runoff Water Quality Problems

Develop an ongoing monitoring/evaluation program to search for subtle and new water quality use impairments. An important component of a properly developed and implemented stormwater runoff water quality management program is the funding of a stakeholder consensus-based monitoring/ evaluation program to detect subtle water quality problems that were not detected in the initial search for real, significant water quality use impairments. This program should be designed to detect new water quality use impairments that arise from the use of new or expanded-use chemicals that become part of stormwater runoff. The search for undetected and new problems should be repeated every five years to coincide with the NPDES permit cycle.

Watershed-Based Approach
The stormwater runoff BMP selection should be formulated/implemented on a watershed-based water quality management program in which the stakeholders for the management of the stormwater runoff water quality and the beneficial uses of the receiving waters and downstream waters for the stormwater runoff that could be impacted by the runoff, work together in a consensus-based approach to formulate, implement, and evaluate the stormwater runoff water quality management program. Provide funds to all major stakeholders to enable them to participate in the process.

Managing Contaminated Sediment Quality Issues
Increasing regulatory attention is being given at the federal and state level to managing the water quality impacts of chemical constituents in aquatic sediments. The aquatic sediments near stormwater runoff locations often contain elevated and sometimes greatly elevated concentrations of a variety of chemical constituents that are potential pollutants that have been derived, at least in part, from stormwater runoff. This situation is leading to the development of aquatic "Superfund"- "aquafund"-like programs in which responsible parties (PRP) are being designated to pay for contaminated sediment remediation. Stormwater management agencies are especially vulnerable to be named as PRP because of their perceived "deep pockets" for funding sediment remediation.

Further, the NPDES stormwater discharge permits for suspected sources of the constituents that are present in the sediments at elevated concentrations are being modified to reduce the input of the associated constituents. The California Water Resources Control Board (WRCB 1998) has adopted the Bay Protection and Toxic Hot Spot Cleanup Program Policy that implements a California aquatic sediment aquafund. This Policy, as adopted, will lead to inappropriate designation of toxic hot spots and the naming of principal responsible parties (PRPs) for their remediation. Lee and Jones-Lee (1998a) and Lee (1998c) have discussed the significant technical problems with the BPTCP Toxic Hot Spot cleanup Policy.

As discussed by Lee and Jones-Lee (1998b), there are situations where the discharge of hazardous chemicals in stormwater runoff to waterbodies causes significant water quality use impairments associated with elevated concentrations of chemical constituents in aquatic sediments. There are also many situations where elevated concentrations of chemical constituents in aquatic sediments that are potential pollutants such as heavy metals do not cause an impairment of a waterbody's beneficial uses. Because of the great cost of "superfund" aquatic sediment remediation programs, it is important to properly evaluate whether an elevated concentration of a chemical constituent in aquatic sediments represents a real significant use impairment that would justify the remediation of the sediments to remove the constituents that are causing the elevated concentrations.

Reliable Evaluation of the Water Quality Significance of Chemical Constituents in Aquatic Sediments

There is considerable misinformation on how to reliably evaluate whether a chemical constituent or group of constituents present in an aquatic sediment is significantly impairing the beneficial uses of the waterbody in which the sediments are located. There are basically two approaches being advocated. One of these is a chemical concentration approach in which an elevated concentration of a chemical constituent that at some locations and under certain conditions is in a form that is adverse to the organism assemblages present within or on the sediments. The other is a biological effects-based approach which focuses on measuring chemical impacts such as toxicity and/or bioaccumulation rather than chemical concentrations.

There are situations where constituents in sediments that are of concern because of their potential to bioaccumulate to excessive levels in higher trophic-level edible organisms (fish and shellfish) serve as important sources of hazardous chemicals in fish that are used as food. There are also situations where the elevated concentrations of potentially toxic or bioaccumulatable chemicals in sediments are in non-toxic, non-bioavailable forms. It has been well established since the 1960's that there is no relationship between the concentrations of chemical constituents in sediments and their toxicity/availability for bioaccumulation. As discussed by Lee and Jones (1992), Lee and Jones-Lee (1993) and Lee and Jones-Lee (1996) the toxicity/availability of chemical constituents in aquatic sediments is determined by the concentration of many of the bulk parameters of the sediments such as TOC, sulfides, carbonates, clays, iron and aluminum oxides, etc. that interact with the potential pollutants to cause them to be non-toxic. Lee and Jones-Lee (1999) have discussed the approach that can be used to evaluate whether the constituents in urban area street and highway stormwater runoff, as well as wastewater discharges, that become associated with sediments, are causing significant water quality impacts in the receiving waters for the stormwater runoff.

Conclusions

Stormwater runoff water quality management agencies, regulatory agencies, and the public face significant challenges in developing and implementing urban area and highway stormwater runoff water quality management programs that will be appropriately protective of the beneficial uses of the receiving waters for the runoff without unnecessary expenditures for stormwater runoff-associated constituent control. The development of this approach will require a watershed-based, integrated, cooperative effort, which incorporates current levels of water quality science and engineering and, especially, aquatic chemistry and toxicology/biology into defining the real water quality impacts of stormwater runoff-associated constituents and managing them in a technically valid, cost-effective manner.

Additional Information

Additional information on these issues is available in the references listed below as well as in papers and reports developed by the authors that are available at the www.gfredlee.com. These publications contain references to the work of others that is pertinent to the topics discussed.

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