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Stormwater Quality Monitoring: Correcting Current Deficiencies

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Abstract

Typical stormwater "quality" monitoring programs consist of measuring a suite of conventional pollutants in the runoff during selected storms where those concentrations are often compared to numeric water quality criteria and state standards. While such a strategy may conform to current minimum monitoring regulations, it provides essentially no useful data regarding water quality impacts of urban stormwater runoff. Stormwater monitoring programs need to properly evaluate the water quality impacts of the presence of chemical contaminants in concentrations above federal water quality criteria and state water quality standards. Site-specific water quality studies that properly incorporate aquatic chemistry and aquatic toxicology into the study design and data interpretation can provide the needed information to properly evaluate whether elevated concentrations of stormwater-associated contaminants which would lead to violations of water quality standards are, in fact, impairing the designated beneficial uses of the waterbodies receiving the stormwater runoff.

Introduction

A participant in a recent state of California Stormwater Quality Task Force meeting commented that he had been involved in monitoring stormwater runoff for the past few years but could find no useful way to use the data generated from the monitoring program. That finding would be expected based on the nature of typical stormwater runoff monitoring programs; it was predicted more than a decade ago (Lee and Jones, 1981), and key technical issues pointing to it were revisited more recently by Lee and Jones (1991a) and Lee (1992).

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Typical stormwater "quality" monitoring programs consist of measuring a suite of conventional pollutants in the runoff during selected storms. While such a strategy may conform to current minimum monitoring regulations, it provides essentially no useful data regarding water quality impacts of urban stormwater runoff beyond that which has been well-known since the work of Weibel *et al.* (1964). They found that urban stormwater runoff contains elevated concentrations of a variety of chemical contaminants and sanitary quality indicator organisms. The work of the senior author's graduate students in the 1960's and 1970's confirmed that finding and also showed that substantial portions of the chemical contaminants in urban stormwater runoff are in unavailable, non-toxic forms and thus would not adversely impact water quality as assessed by impairment of designated beneficial uses of the waterbody receiving the runoff.

The function of stormwater quality monitoring programs is to contribute to meeting the goal of urban stormwater quality management programs, which is to protect the quality of the receiving waters from degradation by stormwater-associated contaminants. In order to serve that function, monitoring programs must be designed and executed to provide meaningful information on water quality impacts of contaminants associated with stormwater runoff. It is therefore important to understand the technical deficiencies in the current stormwater quality monitoring approaches and effect appropriate modifications so that technically valid, cost-effective evaluation and management programs can be instituted.

Inadequacies of Current Stormwater Quality Monitoring Programs

Current stormwater quality monitoring programs focus on measuring total concentrations of a selected group of chemical contaminants in stormwater runoff where the concentrations found are often compared to the US EPA numeric water quality criteria and state water quality standards. Not properly considered in this approach are the nature/availability of chemical contaminants in urban stormwater runoff; the environmental chemistry, fate, and toxicity/availability of the chemical contaminants in the receiving water; and the foundations and assumptions of the water quality criteria and standards relative to the characteristics of urban stormwater runoff to receiving waters.

The tone for the current stormwater monitoring and management programs was set by the US EPA National Urban Runoff Program (NURP) conducted in the 1980's. NURP confirmed on a national basis that urban stormwater runoff contains high concentrations of a wide variety of contaminants. Table 1 presents median concentrations of chemical contaminants from the NURP stormwater runoff studies reported by Pitt and Field (1990). It shows that the concentrations of a number of commonly measured constituents in urban stormwater runoff (such as chromium, copper, cyanide, lead, zinc, and chlordane) typically exceed the US EPA freshwater water quality criteria. However, the NURP studies provided no information upon which to evaluate the water quality significance of those elevated

Table 1. "Estimated Contaminant Concentrations in US Municipal Stormwater Outfalls"*

	Median (ug/L)	US EPA Water Quality Criteria** (Fresh Water) (ug/L)	Drinking Water MCL (ug/L)
Arsenic	7	190. (As III)	50. ***
Chromium	30	11. (Cr VI)	50
Copper	35	6.5	1,000
Cyanide	40	5.2	200
Lead	150	1.3	15
Zinc	150	59	5,000
Bis(2-ethylhexyl)phthalate	6	15,000	---
Chlordane	1.5	0.0043	0.00046
Chrysene	1.5	---	---
Fluoranthene	3	3,980	42
Pentachlorophenol	15	13	0.28
Phenanthrene	1.5	---	---
Pyrene	2	---	---

* Table Information and Table Title from Pitt and Field (1990)

** From US EPA *Quality Criteria for Water* (1987); 4-day average values for a hardness of 50 mg/L as $CaCO_3$.

***In the process of being decreased.

---Means no values available.

concentrations of contaminants in urban stormwater runoff.

As discussed by Lee and Jones (1991b) and Lee and Jones-Lee (1994b), for numerous reasons, a mechanical comparison of concentrations of chemical contaminants in urban stormwater runoff with US EPA numeric water quality criteria and state standards does not provide a reliable assessment of the impact of stormwater-associated contaminants on water quality/beneficial uses of receiving waters. First, the US EPA criteria and state standards equivalent were generally developed for available forms of contaminants; many contaminants in urban stormwater runoff are present in unavailable/non-toxic forms. Second, it would indeed be rare that fish and aquatic life would be expected to reproduce and live in 100% stormwater runoff. The finding of even toxic levels of available forms of contaminants in urban stormwater runoff does not indicate that there would be toxicity or adverse impacts in the receiving waters. Typically there is appreciable dilution of urban stormwater runoff with the receiving waters at the point of mixing. If adequate dilution were not available, it would be likely that the aquatic life habitat associated with stormwater runoff would be severely limited by other factors, such as available water.

Third, the duration of exposure that aquatic organisms can receive from a runoff event should be considered in the interpretation of stormwater quality data and in the application of existing water quality criteria. The impact of a chemical contaminant on an aquatic organism depends on the duration of the organism's exposure to the given level of available forms of the contaminant. The US EPA water quality criteria were developed for protection of highly sensitive species under worst-case exposure conditions. The aquatic life criteria values listed in Table 1 to which the concentrations of contaminants in urban runoff were compared are what the US EPA considers to be chronic exposure criteria values, specified as 4-day average concentrations. The 4-day average was somewhat arbitrarily selected by the US EPA to represent a worst-case exposure situation so the criteria would be protective under chronic exposure conditions (lifetime or critical lifestage exposure). With few exceptions, many types of aquatic organisms could be exposed to the criterion concentrations of available forms of many types of contaminants for somewhat longer than 4 days without adverse impact. Urban stormwater runoff events are typically short-term and episodic in nature; receiving water organisms would not be expected to be exposed to the available forms of contaminants in urban stormwater runoff for critical chronic exposure durations. Thus, the chronic exposure criteria are over-protective for most urban stormwater runoff situations and for most contaminants.

The US EPA also lists 1-hr criteria values to represent worst-case shorter-term exposure situations and the associated concern for acute toxicity to aquatic life. Application of such criteria values to urban stormwater runoff would also be over-protective for most contaminants in urban stormwater runoff and most aquatic life forms. Many forms of aquatic life can readily survive exposure to available forms of chemical contaminants at the acute criterion concentration for several-day periods without adverse impacts. Generally, the concentration of a toxic contaminant that would kill 50% of test organisms in a 4-day exposure period is 50 to 100 times the chronic safe (no impact) concentration of that contaminant. Even a much larger factor would be expected to apply to typical stormwater runoff situations where the exposure of receiving water organisms would be expected to be on the order of a few hours to a day or so. There are no reliable chemical criteria by which to evaluate the potential adverse impacts on aquatic life-related beneficial uses of receiving waters that could be caused by the short-duration exposures to contaminants in the vicinity of a stormwater runoff discharge.

In addition to the over-protective aspects of the criteria discussed above, the US EPA water quality criteria specify that the 1-hr criteria values not be exceeded more than once in three years, to allow for "recovery" of the perturbed system. It is well-known that even considering toxic forms of contaminants, exceedance of a 1-hr criterion value more than once in three years does not necessarily adversely affect the aquatic ecosystem - the designated beneficial uses of the waterbodies. To specify that any exceedance, independent of magnitude of the water quality criterion or standard, can occur no more than once in three years is grossly over-protective of the beneficial uses of waterbodies.

The US EPA recognizes the highly over-protective nature of its current water quality criteria and the associated implementation approach; it is, under the current administration, working toward correcting this problem. While the chronic exposure criteria have been in effect for many years, they were not being enforced by many states because of their highly over-protective nature. With its beginning to focus on chronic toxicity to aquatic life, the US EPA is increasing its efforts to require that states enforce chronic exposure aquatic life criteria. This, in turn, necessitates that the Agency adopt more appropriate approaches for development and implementation of its water quality criteria into state standards and NPDES discharge limits. This is especially important for regulating stormwater runoff in order to avoid spending billions of dollars of public funds in the unjustified over-regulation of stormwater-associated contaminants.

The data being generated by current stormwater quality monitoring programs and the approaches used for their interpretation are providing misleading information regarding the impacts of urban stormwater runoff on receiving water quality. These technically unreliable approaches are being used by "environmental" groups and other interest-activists to claim that "the data" show that urban stormwater runoff discharges are having a significant adverse impact on water quality. It is likely that citizens' suits arising out of the implementation of the provisions of the Clean Water Act will become common in the future. In order to defend itself against inappropriate claims, dischargers need reliable data describing the real impacts of urban stormwater runoff based on evaluation of the water quality characteristics of the waters receiving the stormwater discharge. In order to do this and protect the interests of the public, stormwater dischargers will need to do considerably more than the minimum required monitoring of their discharges (e.g., only measuring total concentrations of selected chemical contaminants in stormwater discharges).

Factors to Consider in Establishing a Stormwater Quality Monitoring Program

A report entitled, *"Guidance for Conducting Water Quality Studies for Developing Control Programs for Toxic Contaminants in Wastewaters and Stormwater Runoff,"* was developed by the authors to discuss major issues in the development of technically reliable, cost-effective evaluation and control programs for chemical contaminants in discharges (Lee and Jones-Lee, 1992). Key factors that need to be considered in establishing monitoring programs for urban stormwater runoff-associated contaminants are synopsized below.

- Clearly establish the objectives of the monitoring program.
- Understand the nature and assessment of "water quality," the beneficial uses of the

receiving water, and water quality concerns.

- Select the parameters to be measured, justify the selection of each, and understand appropriate approaches for the interpretation of data for each parameter selected.
- Examine the results of previous studies to gain information on the expected concentration ranges and the expected variability (spacial and temporal) of the concentrations of contaminants in stormwater runoff and in the waterbody that is receiving the runoff.
- If no reliable data are available from previous studies, or if existing data are inadequate to define the variability of contaminant concentrations and other characteristics needed to establish a reliable monitoring program, conduct a pilot study for similar types of land use to make these determinations.
- List factors that can influence results of the study and how they may influence the results. For those factors that cannot be controlled, develop a plan to incorporate that information in the interpretation of the study results.
- Determine the statistical level of confidence at which the objective of the monitoring program is to be achieved and understand its relevance to assessing "water quality significance."
- If the purpose of the monitoring program is to determine changes in water quality characteristics that could be influenced by the stormwater runoff, select the magnitude of change that is to be detected and design the monitoring program for the runoff and receiving waters accordingly.
- Determine what factors control or influence the designated beneficial uses of the waterbody of concern, e.g., habitat, hydrodynamics, pollutants, etc.
- For each stormwater discharge point, determine the number and location of discharge/runoff and receiving-water samples to be collected in order to achieve the desired statistical confidence level and to determine water quality significance of the parameters of concern.
- Select sampling techniques and methods of analysis to meet the study objectives and level of confidence desired, being careful to avoid the "standard methods syndrome."
- Verify that sample collection and analytical methods are appropriate for each discharge and for the waterbody receiving the discharge for various seasons of the year.
- Conduct studies to evaluate the precision of sampling and analytical procedures and technique, the reliability of sample preservation, and the spacial and temporal variability of the system under investigation.
- Critically examine the relationship between the results of present and past studies.
- Review data for reliability and sufficiency as they are collected.
- Analyze and interpret data as sufficient information is collected. Consider modifications in the program that may be indicated by the data as they are collected.

The guidance provided by Lee and Jones-Lee (1992) for establishing a monitoring program for assessing the impacts of stormwater-associated contaminants on receiving water quality is significantly different from the approaches typically followed in establishing stormwater quality monitoring programs. The recommended approach requires a fairly sophisticated understanding of aquatic chemistry and aquatic toxicology as they are pertinent to evaluating impacts on "water quality," i.e., impacts on the designated beneficial uses of a specific waterbody receiving a particular stormwater runoff. For aquatic life-related beneficial uses it is the changes in numbers, types, and characteristics of the desirable aquatic organisms in the waterbody receiving the stormwater discharge of concern to the public that define water quality impact.

Assessing Impacts of Stormwater Runoff on Receiving Waters

Impacts of stormwater runoff-associated contaminants must be assessed on water quality in the vicinity of the discharge (near-field) and in the waterbody overall. For assessing the near-field impacts, the primary points of focus are the concentrations of available forms of contaminants and the duration of exposure that aquatic organisms in the near field can receive during the runoff event, as well as zones of passage by which organisms can traverse the area without exposure. The points of focus are fundamentally the same for assessing the water quality impacts on the waterbody overall, but consider the longer-term dilution and transformations that affect the concentrations and contaminant availability, as well as the aquatic life or other designated beneficial uses of the waterbody overall as they may be impacted by factors other than stormwater discharge.

As discussed above it is technically unreliable to presume that water quality impact is evidenced by the presence of chemical contaminants in runoff or receiving water in total concentrations in excess of US EPA water quality criteria or state water quality standards. The US EPA water quality criteria and state standards equivalent to them were not designed to regulate stormwater-associated contaminants. Because of the episodic nature of stormwater runoff events and the diminished availability/toxicity of many stormwater-associated chemical contaminants, a mechanical comparison between concentrations of total chemical contaminants in stormwater runoff with water quality criteria and standards typically greatly overestimates the potential water quality impacts of the stormwater-associated contaminants.

A reliable stormwater quality monitoring program includes appropriate consideration of the water quality/beneficial-use characteristics of waters receiving the stormwater runoff and how those characteristics may be affected by the discharged contaminants. Water quality impact studies must be highly directed toward addressing the key issues of concern. For example, if the concentration of a contaminant that is regulated because of its potential to bioaccumulate in fish tissue and render the tissue to be judged unsuitable for human consumption (e.g., mercury) exceeds water quality criteria-standards designed to prevent excessive bioaccumulation, the studies of the impacts of that runoff on receiving water quality should include measurement of the mercury concentration in the edible tissue of appropriately selected fish types or other edible aquatic life. If the concentration of mercury in the edible tissue is less than the FDA Action Limit or other appropriate standard, it may be concluded that whatever the past discharges of mercury have been from all sources, and despite the measured concentrations in runoff, those discharges are not resulting in excessive mercury in fish tissue, i.e., are not adversely affecting that aspect of the beneficial use. The finding of what are determined to be "excessive" concentrations of mercury in water without a concomitant finding of "excessive" concentration of mercury in fish tissue (the reason for concern about mercury) is not uncommon. This is because the US EPA criterion for mercury does not consider the fact that mercury exists in a wide variety of chemical forms, only some of which are available to be taken up by fish tissue. If, however, excessive levels of mercury were found in the edible tissue of fish in the waters receiving the stormwater discharge, additional studies would need to be conducted to determine whether the stormwater runoff-associated mercury was the cause or a significant contributor to the excessive mercury in the fish tissue. Such an assessment would require the conduct of specific studies designed to address that issue by qualified individuals.

For many contaminants in stormwater runoff that occur at elevated concentrations, the concern is the potential for toxicity to aquatic life. Since such assessments cannot generally be made on the basis of measured concentrations of contaminants in runoff or receiving water, it is important that the stormwater quality monitoring program include direct assessment of aquatic life toxicity of the discharge at carefully selected locations in the receiving waters. Some urban stormwater discharges will cause toxicity to test organisms in the commonly run standard toxicity tests. However, such toxicity tests tend to greatly overestimate the toxicity that would be expected in the waters receiving the discharges. That is because the duration of exposure and the exposure conditions in the test system are far worse (adverse) than those normally received by aquatic organisms in the receiving waters. Therefore, finding toxicity in toxicity tests of a stormwater runoff sample or of a sample of receiving water containing the discharge should not be interpreted to mean that the stormwater is having a significant adverse impact on the designated beneficial uses of the receiving waters. The toxicity tests conducted should be site-specific studies of the type described by Lee and Jones (1991b) which properly mimic the exposure conditions that organisms would likely encounter in the receiving waters for the stormwater discharge.

Before entering into comprehensive site-specific studies of the impacts of stormwater runoff-associated potentially toxic contaminants in receiving waters, however, it is important to determine whether the receiving waters are, in fact, causing toxicity to sensitive forms of aquatic life in the receiving water. If the receiving water watercolumn waters are not causing toxicity, it is obvious that neither stormwater-associated contaminants nor contaminants contributed from other sources are causing toxicity-related impairment of designated beneficial uses of the waterbody. The importance of making this fundamental assessment, and potential ramifications of overlooking the obvious were illustrated by recent regulatory actions for San Francisco Bay. Studies have shown that even though domestic wastewater discharges and stormwater runoff to San Francisco Bay contain copper and several other contaminants in concentrations above US EPA water quality criteria and state water quality objectives (standards) and the concentrations of copper in the waters of the Bay exceed the US EPA criterion at times by two- to three-fold, the Bay water containing that copper (and for that matter all other contaminants) was non-toxic to several forms of copper-sensitive aquatic organisms. As a result, there is no justification to require that the managers of stormwater discharges to San Francisco Bay spend public funds to treat the stormwater runoff to control contaminants that were of concern because of their potential to cause toxicity to aquatic life in the San Francisco Bay watercolumn.

Another area of expressed concern about the chemical contaminants in stormwater runoff is the potential for particulate contaminant forms in the runoff to accumulate in receiving water sediments where they could cause toxicity to aquatic life living in or on the sediments. While it is conceivable that this might occur, the potential for it to occur cannot be assessed based on the total concentrations of contaminants in the runoff or in the receiving water sediments. Lee and Jones (1992) and Lee and Jones-Lee (1993, 1994a) have reviewed approaches for assessing the significance of chemical contaminants in aquatic sediments that have evolved over the past two decades. As they discussed, biological effects-based evaluations are recommended for that purpose; chemical concentration-based evaluations have proven to be highly unreliable for making such assessments.

It is also important to consider in this regard that many aquatic sediments cause toxicity to aquatic life due to natural or other conditions that have nothing to do with stormwater runoff-associated contaminants. The finding of aquatic life toxicity in tests of sediments from downstream of a stormwater discharge cannot be presumed to indict stormwater runoff even if the runoff contained high concentrations of the same type of total contaminant. Many of the contaminants in stormwater runoff are in particulate forms that do not equilibrate with other forms of the same contaminants in the receiving waters or sediments.

Contrary to the statements made by Paulson and Amy (1993), it is not possible to reliably predict potentially toxic forms of stormwater-associated contaminants that will be present in the receiving waters from equilibrium-based chemical models. The use of those models requires that thermodynamic equilibrium be quickly achieved in the receiving waters. This will rarely be the case. Further, those models require information on complexation and sorption reactions that may occur in receiving waters but for which there are no reliable thermodynamic data available. Chemical measurements, *per se*, of the stormwater runoff or of the receiving waters will not provide reliable information on the potential biological effects of chemical contaminants in the stormwater runoff. Direct measurements of biological effects such as toxicity and bioaccumulation must be made.

Lee and Jones-Lee (1994c) have recently discussed a very significant problem associated with the approach being used by the US EPA in regulating chemical contaminants in aquatic systems that will become of particular significance in regulating stormwater-associated contaminants. This problem evolves out of the Agency's Independent Applicability Policy in which chemical-specific water quality criteria and state standards are presumed to be independently applicable to contaminants in point and non-point source discharge-runoff. This Policy means that in those situations where excessive concentrations of chemical contaminants above the US EPA water quality criteria are found where the exceedance is of concern because of potential aquatic life toxicity, yet measurements of the receiving waters for the discharge show no aquatic life toxicity to several sensitive forms of aquatic life, still requires the control of chemical contaminants causing the exceedance. This is the situation that has developed for copper in San Francisco Bay. The US EPA's Independent Applicability Policy is obviously technically invalid and should be abandoned. Biological effects-based criteria should take precedence over chemical-specific criteria in regulating chemical contaminants.

Monitoring of Performance of BMP's

Jones-Lee and Lee (1994) and Lee and Jones-Lee (1994b) discussed approaches to evaluate the efficacy of structural BMP's for the control of stormwater runoff-associated contaminants. They emphasized the importance of not following the conventional approach of judging the efficacy based on changes in the total concentrations of contaminants across the BMP (upstream vs. downstream). If the purpose of constructing a BMP for an existing discharge is to improve the designated water quality/beneficial uses of waters receiving the stormwater discharge, it is important to select, judge and monitor the performance of the BMP based on changes in the receiving water quality. This will necessitate the conduct of site-specific studies of the receiving water as discussed above.

Conclusions

The stormwater quality monitoring programs typically conducted today are significantly deficient in providing information to properly assess the impact of stormwater runoff-associated chemical contaminants on the designated beneficial uses of the waters receiving the runoff. The data generated by these stormwater monitoring programs provide an exaggerated impression of the potential water quality impacts that can readily be used by environmental activists and others against stormwater dischargers in an attempt to force compliance with measures that have nothing to do with protection of the water quality/designated beneficial uses of waters receiving stormwater runoff. Stormwater dischargers need to expand the scope of their monitoring programs to properly evaluate the water quality impacts of the presence of chemical contaminants in concentrations above federal water quality criteria and state water quality standards. Site-specific water quality studies that properly incorporate aquatic chemistry and aquatic toxicology into the study design and data interpretation can provide the needed information to properly evaluate whether elevated concentrations of stormwater-associated contaminants which lead to violations of water quality standards are, in fact, impairing the designated beneficial uses of the waterbodies receiving the stormwater runoff.

Appendix

Jones-Lee, A., and Lee, G. F., "Achieving Adequate BMP's for Stormwater Quality Management," IN: Critical Issues in Water and Wastewater, Proc. ASCE National Conference on Environmental Engineering, New York, NY, pp. 524-531, July (1994).

Lee, G. F., "Comments on 'Staff Proposal for Modification to Water Quality Order No. 91-13 DWQ Waste Discharge Requirements for Dischargers of Storm Water Associated with Industrial Activities,'" Submitted to the State Water Resources Control Board, Sacramento, CA, 6pp, September (1992).

Lee, G. F., and Jones, R. A., "Will EPA's Nationwide Urban Runoff Study Achieve Useful Results?" Civil Engineering 51:86-87 (1981).

Lee, G. F., and Jones, R. A., "Comments on General Industrial Stormwater Permit adopted by the California Sate Water Resources Control Board," Submitted to the State Water Resources Control Board, Sacramento, CA, 7pp (1991a).

Lee, G. F., and Jones, R. A., "Suggested Approach for Assessing Water Quality Impacts of Urban Stormwater Drainage," IN: Symposium Proceedings on Urban Hydrology, American Water Resources Association Symposium, November 1990, AWRA TPS-91-4, AWRA, Bethesda, MD, pp. 139-151 (1991b).

Lee, G. F., and Jones, R. A., "Water Quality Aspects of Dredging and Dredged Sediment Disposal," IN: Handbook of Dredging Engineering, McGraw Hill, pp. 9-23 to 9-59 (1992).

Lee, G. F., and Jones-Lee, A., "Guidance for Conducting Water Quality Studies for Developing Control Programs for Toxic Contaminants in Wastewaters and Stormwater Runoff," Report of G. Fred Lee & Associates, El Macero, CA, July (1992).

Lee, G. F., and Jones-Lee, A., "Sediment Quality Criteria: Numeric Chemical- vs. Biological Effects-Based Approaches," Proc. Water Environ. Fed. National Conf., Surface Water Quality & Ecology, Anaheim, CA, pp. 389-400 (1993).

Lee, G. F., and Jones-Lee, A., "Summary of Key Issues: Sediment Quality Evaluation and Sediment Quality Criteria," Prepared for the Southern California Toxicity Assessment Group's Sediment Quality Criteria Workshop, Fountain Valley, CA, March (1994a).

Lee, G. F., and Jones-Lee, A., "Stormwater Quality Management: Are Real Water Quality Problems Being Addressed by Current Structural BMPs?" Submitted for publication, Public Works, July (1994b).

Lee, G. F., and Jones-Lee, A., "Independent Applicability of Chemical and Biological Criteria/Standards and Effluent Toxicity Testing," Accepted for publication in The National Environmental Journal, July (1994c).

Paulson, C., and Amy, G., "Regulating Metal Toxicity in Stormwater," Water Environment and Technology, July (1993).

Pitt, R., and Field, R., "Hazardous and Toxic Wastes Associated with Urban Stormwater Runoff," Proc. of Sixteenth Annual RREL Hazardous Waste Research Symposium, US EPA Office of Research and Development, EPA/600/9-90 037, pp. 274-289 (1990)

Weibel, S. R., Anderson, R. J., and Woodland, R. A., "Urban Land Runoff as a Factor in Stream Pollution," Journ. Water Pollut. Control Fed. 36:914-924 (1964).

US EPA, "Quality Criteria For Water 1986," EPA 440/5-86-001, US EPA Office of Water, Washington, D.C. (1987).

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