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SUGGESTED APPROACH FOR ASSESSING WATER QUALITY IMPACTS OF URBAN STORMWATER DRAINAGE

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ABSTRACT: In November 1990 the US EPA issued regulations for the control of contaminants in urban and industrial stormwater runoff. Some municipalities have already developed NPDES permits that require that water quality standards (often equal to US EPA criteria) be met at the edge of the mixing zones for those discharges. However, US EPA water quality criteria were not designed to be applied to short-term, high-intensity exposures such as urban stormwater runoff. Further, many contaminants of concern in urban stormwater drainage, e.g., heavy metals, are in forms that are non-toxic. This paper suggests approaches that cities and industries should follow to determine the real impact of stormwater-associated contaminants on receiving water quality and to develop technically valid, cost-effective approaches to protect designated beneficial uses of receiving waters from those contaminants.
KEY TERMS: Stormwater; pollution; water quality standards; impact assessment.

INTRODUCTION

In November 1990 the US EPA established that approximately 100,000 industrial facilities, 173 cities, and 47 counties will be required to obtain NPDES permits for stormwater discharges (US EPA, 1990). A key part of such permits will be the development of management plans to reduce pollutants in runoff and to stop illegal connections and illicit dumping of contaminants in storm drains. These regulations are an outgrowth of the US EPA 1988 report "National Water Quality Inventory, 1988 Report to Congress" in which the US EPA reported that states cite diffuse pollutant sources as the leading cause of water quality impairment. The US EPA and the states specifically singled out urban stormwater runoff as a cause of water quality impairment. A critical review of the literature, however, shows that while it has been known for nearly 30 years that urban stormwater runoff contains elevated concentrations of a variety of chemical contaminants (e.g., Weibel et al., 1964), there are few, if any, documented cases where contaminants associated with urban stormwater (not influenced by illegal connections or illicit dumping from commercial or industrial sources or by combined sewer overflows) have had an adverse impact on designated beneficial uses of waters receiving such discharges.

Part of the confusion regarding the impacts of urban stormwater runoff on water quality lies in the fact that some urban storm drains receive illegally and/or illicitly disposed industrial and/or commercial wastes and/or combined sewer overflows. Such discharges could have adverse impacts on receiving water quality and should be controlled. However, part of the confusion also lies in the manner in which

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assessments of adverse impact are made. The US EPA's National Urban Runoff Program (NURP) is often cited as a source of information that shows that a variety of pollutants including heavy metals, pesticides, and nutrients are present in elevated concentrations in urban stormwater runoff. Pitt and Field (1990) published a summary of US EPA NURP and post-NURP activities that presents information that they claim supports the position that contaminants in urban stormwater drainage are causing significant adverse impacts on the quality of surface waters of the US. Part of that assessment was the summary of estimated contaminant concentrations in stormwater discharges (that included commercial contributions) from US cities having >100,000 people, based on 100 outfall samples; that summary is presented in Table 1. That is the type of information that has been presented to Congress and used to justify development of an NPDES permit system for municipal and industrial stormwater discharges. While Table 1 shows that chemical contaminants are discharged in urban/commercial runoff from a group of US municipalities, it does not address the issue of the impacts of urban stormwater-associated contaminants on designated beneficial uses of receiving water (water quality). It only indicates that there are chemical contaminants in urban stormwater drainage that, if present in available forms in sufficient concentrations in the receiving water, could have an adverse impact on receiving water quality depending on exposure durations, and other site-specific conditions.

The assumption that the presence of total concentrations of contaminants in receiving waters, much less an outfall, in excess of US EPA criteria represents adverse impacts, ignores the wealth of knowledge in aquatic chemistry and aquatic toxicology on how contaminants impact beneficial uses of water. It has been known for 25 years that chemical contaminants exist in aquatic systems in a variety of chemical forms, only some of which are available/toxic to aquatic life. It is also well-known that in addition to the availability of contaminants, the impact that they have on aquatic life and other beneficial uses of receiving waters depends on the duration of organism exposure. These relationships must be considered in evaluating the water quality impacts of a particular discharge (Lee et al., 1982).

Table 2 summarizes data presented by Pitt and Field (1990) on concentrations of total and "soluble" forms of heavy metals in runoff from various types of urban areas. That table shows that with few exceptions only a very small fraction of the total concentrations of heavy metals in samples from the named sources is in a soluble form. Since particulate (nonfilterable) forms of heavy metals are, in general, non-toxic, conclusions drawn about water quality impacts of heavy metals in urban stormwater drainage on the basis of their total concentrations can be highly misleading.

Lee and Jones (1981) expressed concern about the adequacy of the US EPA NURP for developing information and approaches for judging the potential impacts of chemical contaminants in urban stormwater drainage on the beneficial uses of receiving waters. Unfortunately, adequate attention has still not been given to this topic by the US EPA or state regulatory agencies. Unless great care is taken, this could result in the expenditure of massive amounts of public and private funds to achieve stormwater discharge permit limitations but with little or no impact on receiving water quality beyond that which could be achieved if more technically valid approaches were used for assessing the potential

Table 1. Estimated Contaminant Concentrations in US Municipal Stormwater Outfalls

	Median Conc. (ug/L)	Detection Frequency (%)	Discharges (tons/year)
Arsenic	7	50	80
Chromium	30	60	350
Copper	35	90	700
Cyanide	40	25	200
Lead	150	95	3000
Zinc	150	95	3000
Bis(2-ethylhexyl) phthalate	6	20	30
Chloradane	1.5	20	5
Crysene	1.5	10	3
Fluoroanthene	3	15	10
Pentachlorophenol	15	20	70
Phenanthrene	1.5	10	4
Pyrene	2	15	8

Table from: Pitt and Field (1990)

Table 2. Concentrations of Non-Filterable ("Particulate") and Filterable ("Soluble") Heavy Metals in Stormwater Runoff *(ug/L)*

	Cadmium		Chromium		Copper		Lead		Nickel		Zinc	
Source Area Runoff	non filt	filt	non filt	filt	non filt	filt	non filt	filt	non filt	filt	non filt	filt
Roofs												
median	0.8	0.23	7	<1	17	1.2	13	<1	5.1	<1	100	80
maximum	30	0.95	510	2.3	900	8.7	170	1.1	70	<1	1580	1550
Parking Areas												
median	0.7	<0.1	18	<1	20	1.8	30	<1	40	<1	30	23
maximum	70	1.0	310	2.4	770	9.2	130	2.5	130	1.6	150	88
Storage Areas												
median	2.4	0.3	60	1.1	30	1.0	30	1.6	30	<1	66	9
maximum	10	1.3	340	32	300	1.7	330	5.7	90	<1	290	103
Streets												
median	0.8	0.2	3.3	1.3	15	1.9	30	1.3	3	<1	58	23
maximum	220	0.6	30	2.7	1250	11.4	150	3.9	70	<1	130	76
Vehicle Svc Area												
median	8	<0.2	19	<1	8	2.1	75	<1	35	<1	67	18
maximum	30	0.3	320	<1	580	6.3	110	1.4	70	<1	130	83

Data from: Pitt and Field (1990)

impact of chemical contaminants.

Use of US EPA Criteria for Stormwater-Associated Contaminants

Critical to appropriate implementation of NPDES permits for urban and industrial stormwater drainage-associated contaminants is how the regulatory agencies will determine when a violation has occurred. Some cities such as Sacramento, CA have obtained early permits under the recently adopted regulations, that require that the total concentrations of the contaminants at the edge of a mixing zone in the receiving water be no greater than the state water quality standards (called "objectives" in California). Those are the same standards that are applied to municipal and industrial wastewater discharges and are typically numerically equal to the US EPA water quality criteria promulgated in July 1985. The US EPA recognized in the early to mid-1980's that those criteria concentrations were in general lower than needed to protect aquatic life because they were being applied to total concentrations of contaminants rather than to the available forms. While this situation was recognized within the agency and the technical community, it stood because the US EPA could not within its administrative framework develop testing procedures that would allow application of the criteria to available forms of contaminants. However, as discussed by Lee and Jones (1990a), several states have developed analytical testing procedures that enable them to focus their standards on forms of contaminants that are more likely to be available to affect aquatic life in receiving waters rather than on total contaminants. Further, as discussed by Lee and Jones (1990b), the US EPA will now allow states to base their water quality standards on available forms of contaminants. The US EPA is actively investigating the appropriateness of using its water quality criteria as a basis for limiting contaminants in urban and industrial stormwater discharges.

Even though it has been known for many years that total concentrations of contaminants are poor measures of potential water quality impacts of many wastewater discharges, it was not until the US EPA's 1985 policy document on the control of toxics began to be implemented that these deficiencies have come to be of significant importance in regulating contaminant discharges. Because of the controversy that exists across the country on the approach that should be used to judge violations of NPDES stormwater discharge limitations, there can be little doubt that technical deficiencies in the US EPA's criteria will be corrected. If they are not, many billions of dollars will be spent by cities and industries for stormwater runoff treatment works to remove unavailable forms of contaminants to meet standards at the edge of a mixing zone, that are not causing adverse impacts on beneficial uses of receiving waters. It is therefore essential that federal and state regulatory agencies develop appropriate water quality criteria and standards that can be used as a reliable basis for judging violations of stormwater discharge permits that cause impairment of beneficial uses of receiving water.

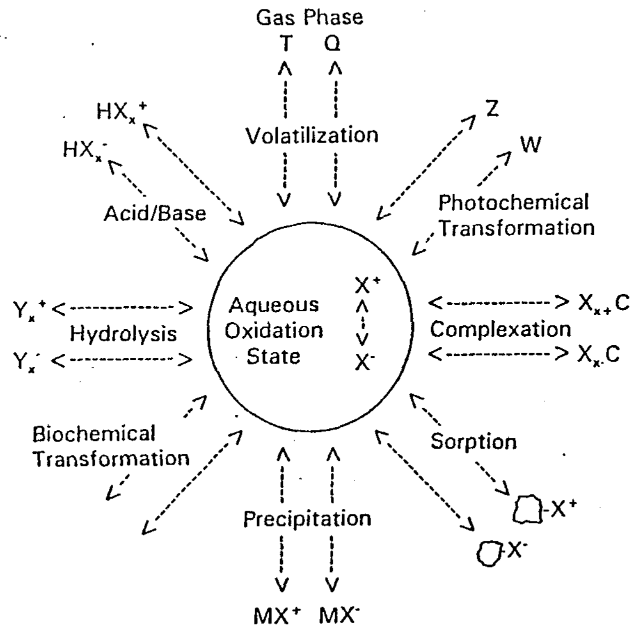
SUGGESTED APPROACHES FOR ASSESSING THE POTENTIAL IMPACTS OF URBAN STORMWATER DRAINAGE-ASSOCIATED CONTAMINANTS

There are several characteristics of stormwater discharges that significantly influence how contaminants in such discharges impact aquatic life and other beneficial uses of receiving waters. As discussed above, it has been known since the mid-1960's (e.g., see Lee, 1973) that some of the contaminants in urban stormwater drainage are in forms that are not available to affect aquatic life. Cowen and Lee (1976) presented the results of extensive studies on the availability of phosphorus in urban stormwater drainage to the growth of algae in receiving waters. They found that only a small part of the particulate phosphorus in urban and rural drainage is available to support algal growth (Cowen and Lee, 1976; Lee et al., 1980). The same situation is true for heavy metals in urban stormwater drainage. Were the total concentrations of heavy metals in urban stormwater drainage available, it would expected that such discharges would cause high degrees of toxicity to aquatic life. This is not the case, and it is now clear that much of the heavy metals in urban stormwater drainage are in particulate forms that are not toxic. Therefore, if technically valid, cost-effective approaches are to be developed for judging NPDES permit violations using chemical analyses, these analyses must focus on available forms of contaminants, not on total forms.

Figure 1 is a diagrammatic representation of the aquatic chemistry of the elements. For each oxidation state of an element there is a variety of chemical reactions that affect the actual chemical species in a particular water. Many of the chemical species present are non-toxic or not available to aquatic life; it is not typically possible to precisely distinguish between available and unavailable forms using chemical analytical techniques. While as discussed by Lee and Jones (1983) there are inadequacies in assuming that ambient-water-pH-"soluble" forms of contaminants are the available forms, measuring the soluble forms generally provides a much better estimate of available-toxic forms than measuring total forms. It is therefore recommended that if numeric water quality standards are to be used to judge whether there is a potential impact associated with a "violation" of a stormwater NPDES permit, ambient-water-pH-soluble forms (with separation using a 0.45 u pore-size membrane filter) be used. The concentrations of soluble forms in samples of receiving water should be compared to US EPA criteria promulgated in July 1985 properly adjusted for exposure duration as discussed below. As discussed by Lee and Jones (1987a), while evaluation and control programs have focused in the past on effluent characteristics and concentrations, such an approach can yield unreliable assessments when the concern is for toxic chemicals. Therefore, impact evaluations and compliance should focus on receiving water containing the discharge.

Even this approach provides more stringent discharge control than is needed for protection of aquatic life because it does not properly consider the relationships between concentrations of available forms and duration of organism exposure that govern the impacts that available forms of contaminants have on aquatic life. Figure 2 illustrates these relationships which have been known since the late-1960's. It shows that aquatic organisms are able to tolerate without adverse impact significantly elevated concentrations of available forms of toxic contaminants if the duration of exposure is sufficiently short. Typically, the concentrations that can occur without impact from several-day (acute) exposure are 50 to 100 times greater than those that can be tolerated with prolonged (chronic) exposure. As shown in Figure 2, typically urban stormwater drainage results in exposure on the order of hours rather than days. At this time, there is no body of

Figure 1. Basic Aquatic Chemistry of Chemical Contaminants



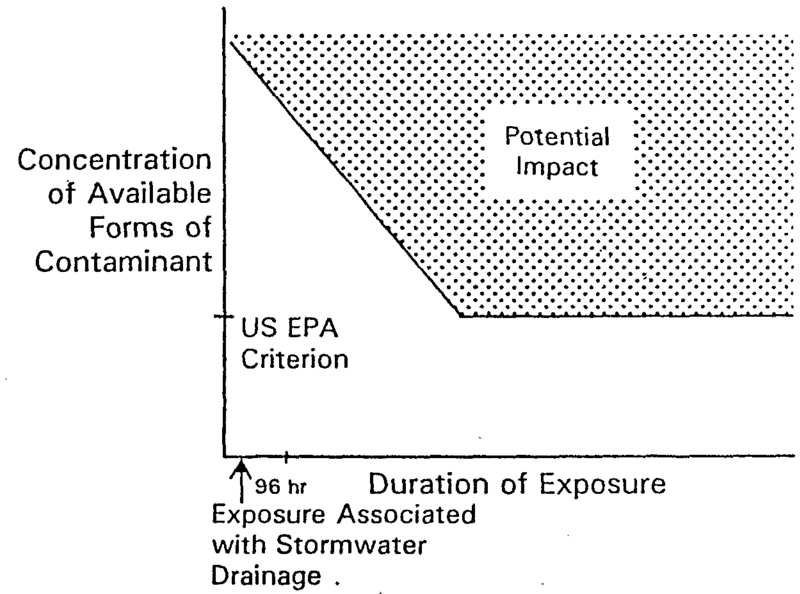
Distribution Depends on Kinetics & Thermodynamics of Reactions in a Particular Aquatic System

Each Chemical Species Has Its Own Toxicity Characteristics

Many Forms Are Non-Toxic

Toxic Forms Are Typically Aqueous Aquo-Species of Metals

Figure 2. Concentration of Available Forms--Duration of Exposure Relationship for Toxic Chemicals



US EPA Criteria List 1-hr-Average Maxima and 4-day-Average Maxima

Not Valid for Assessing Potential Impacts of Urban Stormwater Drainage information to enable regulatory agencies to adjust the chronic, or for that matter acute exposure-based, US EPA criteria to apply to typical exposures that aquatic organisms would receive in waters receiving urban stormwater-associated contaminants. Such information is urgently needed. If generalized relationships can be developed between toxicity during typical urban stormwater drainage exposures and during acute or chronic exposures, it may be possible to use a combination of ambient-water-pH-soluble form concentrations in the receiving water and short-term exposure--impact relationships to determine whether contaminants in the stormwater drainage pose a real threat to aquatic life in the receiving waters. It is clear, however, that it would be very rare that heavy metals and other contaminants in urban stormwater drainage (that does not receive significant amounts of industry/commerce-derived contaminants through illegal connections or illicit dumping, or combined sewer overflow) would cause adverse impacts on the uses of receiving waters. Therefore, it is generally inappropriate to require that municipalities and industries control contaminant concentrations in their stormwater discharges to the point of not exceeding water quality standards numerically equal to US EPA water quality criteria applied to total contaminant concentrations.

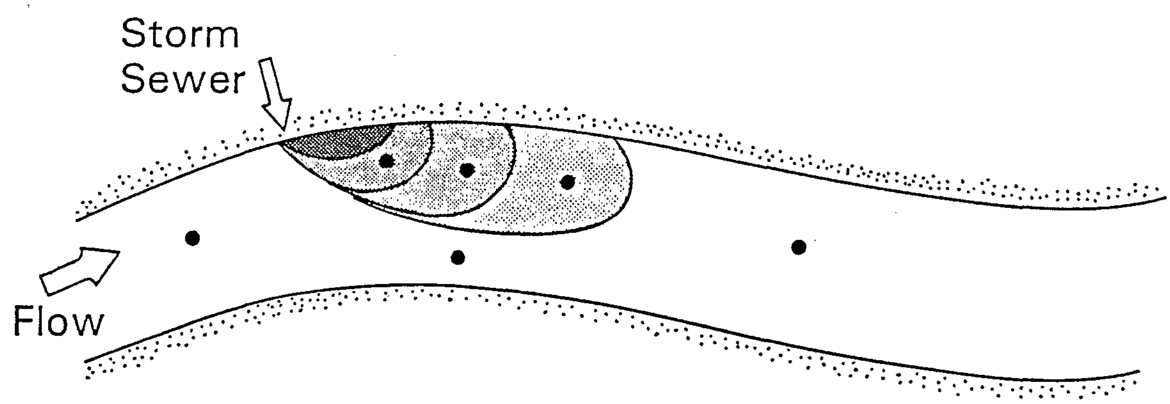
Because of the lack of information on critical concentrations of available forms of contaminants for very short durations of organism exposure characteristic of urban stormwater drainage discharges, it is suggested that the water quality standards approach not be used for determining violations of NPDES stormwater discharge permits; the technical information is simply inadequate to employ that approach in a technically valid, cost-effective manner. Instead, waters receiving stormwater discharges should be tested for toxicity to larval forms of fish or to zooplankton. The US EPA's short-term methods for estimating chronic toxicity to aquatic life are valuable tools for assessing whether contaminants in a stormwater discharge, whatever their forms, have a potential to adversely affect aquatic life when mixed in the receiving waters. For freshwater systems the Fathead Minnow Larval Survival and Growth Test or the Ceriodaphnia dubia Survival and Reproduction Test (US EPA, 1989) should be used. For stormwaters discharged to marine waters, the Sheepshead Minnow Embryo-Larval Survival and Teratogenicity Test or Inland Silverside Larval Survival and Growth Test should be used (US EPA, 1988). Because of the high variability and many unknown factors governing response, it is highly questionable whether the mollusc larval or sea urchin fertilization tests that are being used for wastewater effluents are sufficiently reliable for use in assessing potential impacts of stormwater discharges on receiving waters. The Microtox testing approach should be avoided as it is not reliable for assessing toxicity of chemical mixtures in aquatic systems without extensive and repeated verification with methods such as those noted above (Lee and Jones, 1987a).

The tests suggested above should focus not on the stormwater itself but on receiving water that contains the stormwater discharge, collected at the time of stormwater runoff into the receiving waters. If a sample of the mixture at the edge of an appropriately sized mixing zone shows toxicity in these tests using a daily static renewal testing procedure, there is presumptive evidence that there could be adverse impacts in the receiving waters due to toxicity to aquatic life. It is important, however, that proper attention be given to data interpretation since the tests are designed to estimate toxicity from long-term exposure whereas stormwater runoff typically results in only very short-term exposure. It is important to not follow the approaches being used today for municipal and industrial wastewater discharges of arbitrarily establishing a TUa (Toxicity Unit, acute) or TUc (Toxicity Unit, chronic) for the effluent. Increasing evidence is accumulating that such requirements necessitate overly stringent (and hence costly) contaminant removal than is justified to protect designated beneficial uses of receiving waters. This would be especially true for urban stormwater runoff because of the typically exceedingly short durations of organism exposure. It is therefore very important that toxicity testing for stormwater discharges be done on samples of ambient water that contain the stormwater discharges with exposure periods that match exposure in the receiving waters.

The US EPA and many states are adopting regulations that prohibit acute toxicity in the *discharge* waters. That approach is not based on a technically valid assessment that acute toxicity at the end of the pipe manifests itself as acute toxicity in or impairment of beneficial use of the receiving waters. Figure 3 illustrates a general sampling regime for discharges of stormwater. It is suggested that a sampling program for a particular location be developed based on information derived from following drogues released at the point of stormwater discharge, that move with the ambient water/discharge water mixture. By sampling at various times down the drogue path, it is possible to estimate the rate of dilution that occurs in the ambient waters and therefore the times that should be used to estimate the duration of exposure of the test organisms in the toxicity tests. It is strongly recommended that efforts be made to control stormwater-associated contaminants through end-of-the-pipe treatment works only if properly conducted toxicity tests of this type show potential toxicity in the receiving waters.

In addition to focusing concern on toxicity of contaminants in urban stormwater drainage, concern must also be focused on whether such contaminants bioaccumulate in the tissue of aquatic organisms to a sufficient extent to render them unsuitable for use for human food or by higher trophic level organisms. There are no reliable laboratory bioaccumulation tests that can be used to determine whether a contaminant in a sample of urban stormwater drainage will, when diluted in receiving waters, result in excessive bioaccumulation in ambient water organisms. There is a wide variety of factors that tend to cause laboratory "bioaccumulation" tests to overestimate the actual bioaccumulation that would occur in receiving waters. It is therefore suggested that the most expedient way to proceed to determine whether bioaccumulation is a potential problem in receiving waters due to contaminants in urban stormwater drainage is to determine if key aquatic organisms in the receiving waters have bioaccumulated excessive concentrations of the chemicals for which there are established standards in edible tissue, such as the FDA action levels. If the organisms downstream of a stormwater discharge do not have excessive concentrations of the chemicals of potential concern for bioaccumulation, it is logical to conclude that the stormwater discharges are not causing such problems. If, however, excessive concentrations of chemicals such as PCB's are found in edible flesh, then site-specific evaluations must be made to determine whether the stormwater discharges are the source of the chemicals leading to the excessive bioaccumulation. This type of testing can be done through

Figure 3. General Chemical and Bioassay Sampling Regime
for Urban Stormwater Runoff



(Dots Indicate Sampling Sites)

caged organism studies.

It is suggested that where there is evidence of receiving water toxicity or bioaccumulation based on the types of studies outlined above, municipalities and industries should focus management efforts and resources on controlling illegal connections and illicit dumping of contaminants into storm sewers, and combined sewer overflows. Municipalities and industries should implement a water quality monitoring program at various locations throughout the storm sewer system to detect illicit dumping of highly hazardous chemicals. That monitoring program should not be used to try to predict impacts on receiving waters since, as discussed above, that is not possible to do at this time.

SEDIMENT DETENTION BASINS

One of the most frequently used approaches for "managing" water quality problems associated with urban runoff is to construct a sediment retention basin on the storm sewer discharge. Unfortunately there is widespread confusion about the effectiveness of such basins in controlling water quality problems. While sediment, itself, can cause problems - primarily associated with the filling of the receiving waterbody or burial of spawning areas - it is rare that sediment-associated contaminants cause water quality problems in the receiving waters. It is for this reason that control of erosion, while desirable

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because of potential physical impacts on aesthetics-turbidity and aquatic habitats, would not be expected to be effective in controlling toxicity problems.

It is sometimes suggested that urban stormwater contaminant control programs should include removal of particulate forms of contaminants since those forms could cause water quality problems in the receiving waters where they are deposited. Technical evidence from a variety of sources does not support that concern. Lee and Jones (1987b) recently summarized the information available on the water quality significance of sediment-associated contaminants. Much of that information evolved from the Corps of Engineers' multi-million dollar research effort devoted to this topic started in the early-1970's. It is clear from those efforts as well as other studies that particulate forms of the types of contaminants of greatest concern in urban stormwater drainage (e.g., heavy metals) are non-toxic in the watercolumn and do not contribute significantly to sediment toxicity when redeposited in the sediments. Further, it is quite clear from the literature that re-suspension of heavy metals associated with sediments does not result in their release to the watercolumn or their having an adverse impact on aquatic life.

If site-specific studies show that sediment-associated contaminants are causing problems in the receiving waters, it would be very important to conduct studies on the ability of the sediment detention basins to remove the size-fractions of the sediments that are contributing the contaminants that are causing the problems. It is well-known that sediment-associated contaminants are bound to sediment in differing degrees depending on particle size, and matrix and surface composition. It is highly unlikely that sediment-associated contaminants that could adversely affect water quality would be associated with large sediment particles that could be readily removed in sediment detention basins. It is more likely that the fine sediment particles, which are typically not removed in sediment detention basins, would be the cause of such problems. It is therefore concluded that, in general, there is little or no justification to construct sediment detention basins for stormwater discharges for the purpose of removing sediment-associated contaminants.

ALUM TREATMENT OF STORMWATER DISCHARGES

If it is found that stormwater-associated contaminants are having an adverse impact on receiving water quality and that those contaminants cannot be controlled at the source, consideration should be given to treatment of the discharge waters to control available forms of contaminants that are responsible for the problems. It is suggested that before treatment works are constructed, consideration be given to adding alum to the stormwater during the discharge periods for the purpose of binding (rendering unavailable) the contaminants of concern. This approach has considerable potential merit, and for a relatively low cost could be highly effective in controlling many available forms of contaminants. While there may be some concern about allowing the alum floc to settle in the receiving waters, from the substantial amount of work that has been done over the years on alum-treatment of lakes to control excessive fertilization it is concluded that the accumulation of alum in sediments does not represent a potentially significant water quality problem nor does it have a significantly detrimental impact on aquatic organisms.

CONCLUSIONS

Urban stormwater drainage contains a wide variety of chemical contaminants at potentially significant concentrations that could have an adverse impact on receiving water quality. It is, however, very important not to mistakenly conclude that the presence of those elevated concentrations of contaminants indicates adverse impact on receiving water quality. Many of the contaminants present in urban stormwater drainage are in unavailable, non-toxic forms. Further, the relationships between concentration of available forms and duration of organism exposure associated with most stormwater discharges into receiving waters are such that it would be rare that toxicity would be caused by stormwater discharge. Those characteristics make it inappropriate to control urban stormwater discharges based on application of US EPA criteria-based standards to the total concentrations of contaminants at the edge of a mixing zone for the discharge. At this time there are no reliable chemical methods for appropriately judging violations of NPDES stormwater permits. It is recommended that the US EPA short-term methods for estimating chronic toxicity be conducted in waters receiving urban stormwater discharge, in conjunction with consideration of the duration of exposure that exists in the ambient waters for the discharge.

The primary focus of the stormwater management programs should be the control of illegal connections and illicit dumping of hazardous chemicals, and combined sewer overflow to storm sewers. Since large particles typically contain only a small part of the contaminants that are potentially available to affect water quality in receiving waters, sediment detention basins are likely to be largely ineffective in controlling the water quality impacts of urban stormwater drainage. In areas where such impacts are found through site-specific investigations of the type discussed above, treatment of the discharge waters with alum prior to discharge to the receiving waters may be highly cost-effective for controlling water quality impacts associated with stormwater discharge.

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REFERENCES

Cowen, W. F. and Lee, G. F., 1976. "Phosphorus Availability in Particulate Materials Transported by Urban Runoff." Journ. Water Pollut. Control Fed. 48:580-591.

Lee, G. F., 1973. "Chemical Aspects of Bioassay Techniques for Establishing Water Quality Criteria." Water Res. 7:1525-1546.

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

Lee, G. F., and Jones, R. A., 1983. "Translation of Laboratory Results to Field Conditions: The Role of Aquatic Chemistry in Assessing Toxicity." Aquatic Toxicology and Hazard Assessment: 6th Symposium, ASTM STP 802, ASTM, Philadelphia, pp. 328-349.

Lee, G. F., and Jones, R. A., 1987a. "Assessment of the Degree of Treatment Required for Toxic Wastewater Effluents." Proc. Int. Conf. on Innovative Biological Treatment of Toxic Wastewaters, US Army Construction Engineering Research Laboratory, Champaign, IL, pp. 652-677.

Lee, G. F., and Jones, R. A., 1987b. "Water Quality Significance of Contaminants Associated with Sediments: An Overview." Fate and Effects of Sediment-Bound Chemicals in Aquatic Sediments, Pergamon Press, Elmsford, NY, pp. 1-34.

Lee, G. F., and Jones, R. A., 1990a. "Comments on January 29, 1990 Draft Functional Equivalent Document - Development of Water Quality Control Plans for Inland Surface Waters of California and Enclosed Bays and Estuaries of California." Report to the State Water Resources Control Board Sacramento, CA, March 31.

Lee, G. F., and Jones, R. A., 1990b. "Comments on Draft Statewide Water Quality Control Plans for 1. Inland Surface Waters of California (California Inland Surface Waters Plan) 2. Enclosed Bays and Estuaries of California (California Enclosed Bays and Estuaries Plan) Dated November 2, 1990 and November 26, 1990." Report to the State Water Resources Control Board Sacramento, CA, December 10.

Lee, G. F., Jones, R. A., and Rast, W., 1980. "Availability of Phosphorus to Phytoplankton and Its Implication for Phosphorus Management Strategies" Phosphorus Management Strategies for Lakes, Ann Arbor Press, Ann Arbor, MI, pp. 259-308.

Lee, G. F., and Jones, R. A., and Newbry, B. W., 1982. "Water Quality Standards and Water Quality." Journ. Water Pollut. Control Fed. 54:1131-1138.

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

US EPA, 1988. "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms." EPA 600/4-87/028, US EPA Cincinnati.

US EPA, 1989. "Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms." EPA 600/4-89/001, US EPA Cincinnati.

US EPA, 1990. "National Pollutant Discharge Elimination System Permit Application Regulations for Stormwater Discharges; Final Rule." 40 CFR Parts 122, 123, and 124, Federal Register 55(222):47990-48091, Nov. 16.

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