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STORMWATER RUNOFF WATER QUALITY EVALUATION AND MANAGEMENT PROGRAM FOR HAZARDOUS CHEMICAL SITES: DEVELOPMENT ISSUES

REFERENCE: Lee, G. F. and Jones-Lee, A., **"Stormwater Runoff Water Quality Evaluation and Management Program for Hazardous Chemical Sites: Development Issues,"** *Superfund Risk Assessment in Soil Contamination Studies: Third Volume, ASTM STP 1338,* K. B. Hoddinott, Ed., American Society for Testing and Materials, 1998.

ABSTRACT: The deficiencies in the typical stormwater runoff water quality monitoring from hazardous chemical sites and an alternative approach (Evaluation Monitoring) for monitoring that shifts the monitoring program from periodic sampling and analysis of stormwater runoff for a suite of chemical parameters to examining the receiving waters to determine what, if any, water quality use impairments are occurring due to the runoff-associated constituents is presented in this paper. Rather than measuring potentially toxic constituents such as heavy metals in runoff, the monitoring program determines whether there is aquatic life toxicity in the receiving waters associated with the stormwater runoff. If toxicity is found, its cause is determined and the source of the constituents causing the toxicity is identified through forensic analysis. Based on this information, site-specific, technically valid stormwater runoff management programs can be developed that will control real water quality impacts caused by stormwater runoff-associated constituents.

KEYWORDS: hazardous chemical site, stormwater runoff monitoring, water quality impact evaluation

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Introduction

Increasing attention is being given to managing the water quality impacts of stormwater runoff from "superfund" and other sites where hazardous chemicals exist in the near-surface or surface soils. Stormwater runoff from these areas could cause

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This publication is a condensed version of the report:
Lee, G. F. and Jones-Lee, A., "Development of a Stormwater Runoff Water Quality Evaluation and Management Program for Hazardous Chemical Sites," Report of G. Fred Lee & Associates, El Macero, CA, April (1997) available at http://www.gfredlee.com/Runoff/stmhzpap.pdf

significant water quality impairment in off-site surface and groundwaters. This paper is a condensation of a more complete discussion of this topic. The more comprehensive review includes discussion of translocation as a source of stormwater runoff hazardous chemicals, cooperative watershed-based receiving water studies, aquatic sediment issues, atmospheric sources of toxic chemicals, importance of non-hazardous chemicals, wastewater discharges from site, groundwater recharge, data management and presentation, and duration of stormwater runoff monitoring. Information on these topics, as well as others, is available from Lee and Jones-Lee (1997a).

Deficiencies in Typical Stormwater Runoff Water Quality Monitoring Programs

In accord with US EPA stormwater runoff water quality regulatory requirements, the stormwater manager for the site is supposed to conduct analyses for any constituent that is likely to be present in stormwater runoff that could impair receiving water quality (US EPA 1990). For those sites complying with the minimum federal/state industrial site stormwater monitoring requirements, measurements are made of a stormwater sample's TDS, pH, TSS and TOC. For sites at which a wide variety of potentially hazardous chemicals have been manufactured, used, managed or disposed of, the stormwater runoff could justifiably be analyzed for the suite of Priority Pollutants.

Inappropriate Standards

At some hazardous chemical sites, drinking water quality is the focus of the site investigation where the stormwater runoff data are compared to drinking water MCLs in an approach similar to that followed in superfund site groundwater monitoring. For many of the heavy metals and some organics, the critical concentrations of constituents that are adverse to aquatic life are orders of magnitude lower than the concentrations that are acceptable in domestic water supplies. It is, therefore, important to consider the full range of potential impacts of stormwater runoff-associated constituents on the beneficial uses of the receiving waters for the stormwater runoff as part of developing a credible hazardous chemical site stormwater runoff water quality monitoring program.

Inappropriate Analytical Methods

One of the areas of particular concern in developing technically valid stormwater runoff water quality monitoring programs is the selection of analytical methods. At some sites, methods that are typically suitable for groundwater investigation are also used for surface water runoff. Such an approach can generate large amounts of "non-detect" data in which the detection limits are well above the potentially significant critical concentrations for adverse impacts of chemical constituents in the stormwater runoff to aquatic life in the receiving waters for the runoff.

An area that is often not adequately investigated in stormwater runoff from hazardous chemical sites is the potential for some of the runoff-associated constituents, such as chlorinated hydrocarbon pesticides, PCBs, dioxins and mercury, to bioaccumulate to excessive concentrations in the receiving water aquatic organisms to render these organisms unsuitable for use as human food because of an increased cancer risk or, in the case of mercury, neurological damage to those who consume the organisms. For many constituents, the concentrations in water that can lead to excessive bioaccumulation in fish are well below the analytical method detection limits typically used in "superfund" site investigations. This can lead to the superfund contractor incorrectly reporting that no water quality problems are associated with stormwater runoff from the site, since the concentrations of constituents found in the stormwater runoff are below the detection limits of the analytical methods used. Yet the fish in the waters receiving the stormwater runoff have bioaccumulated sufficient concentrations of hazardous chemicals derived from the site, as well as possibly elsewhere, to be hazardous for human consumption. These fish may also be hazardous for consumption by higher trophic level organisms such as fish-eating birds and mammals.

Even if appropriate analytical methods are used in measuring stormwater runoff-associated constituents from hazardous chemical sites and the data are properly compared to appropriate water quality criteria/standards designed to protect all beneficial uses such as fish and aquatic life, domestic water supply, agricultural water supply, etc., and an adequate sampling program has been conducted to measure the first-flush characteristics as well as the concentrations of constituents at other times during the runoff event for representative storms, it is still not possible to determine, from such monitoring programs what, if any, significant adverse impacts are occurring in the receiving waters for the stormwater runoff due to chemical constituents derived from the site in runoff waters.

Interpretation of Stormwater Runoff Data

The objective of a stormwater runoff water quality monitoring and evaluation program should be to determine whether the chemical constituents and/or pathogenic organisms in the runoff waters, when mixed into the receiving waters for the runoff, cause an impairment of the designated beneficial uses of the receiving waters, including downstream waters. The designated beneficial uses of concern are typically domestic water supply, fish and aquatic life, contact and other recreation, wildlife habitat, agricultural water supplies, etc. The typical approach used to determine whether stormwater runoff from a hazardous chemical or other site is adverse to the beneficial uses of the receiving waters involves comparing the concentrations of constituents found in the runoff waters to water quality criteria/standards. If an exceedance of the standard is found in the runoff waters, then it is often said that the stormwater runoff-associated constituent causing the exceedance is adverse to the beneficial uses of the receiving waters. However, in order to properly evaluate whether an exceedance of a water quality criterion/standard for a regulated chemical is adverse to fish and aquatic life in the receiving waters for the stormwater runoff, it is necessary to determine the concentrations of toxic/available forms of the constituent of concern in the receiving waters for the runoff at the point of mixing and downstream relative to the concentrations of this constituent that are known to be adverse to the forms of aquatic life present in, or that could be present in, receiving waters of concern for the site stormwater runoff waters. Also, the duration of exposure of the aquatic organism to toxic/available forms of the constituents in the runoff waters and in the receiving waters must be evaluated.

Use of US EPA Water Quality Criteria

As discussed by Lee and Jones (1991), Lee and Jones-Lee (1994a, 1995, 1996a,b, 1997b) and in references cited therein, the exceedance of a water quality criterion/ standard in stormwater runoff waters should not be interpreted to mean that a real water quality use impairment is occurring in the receiving waters for the runoff. Aquatic life-based water quality criteria/standards are typically developed based on worst-case, or near worst-case situations with respect to the constituent being adverse to the aquatic life. Normally, these criteria and standards assume that the constituents of concern are in 100% toxic/available forms and the potentially impacted organisms received extended-chronic exposures to these forms. The typical stormwater runoff event is normally of short duration relative to the critical duration-concentrations of toxic/available forms for aquatic life. Further, many of the chemical constituents in stormwater runoff are associated with particulates and are, therefore, in non-toxic, non-available forms. In some instances, the concentrations of constituents in stormwater runoff can be orders of magnitude above the water quality criterion/standard and not be adverse to the aquatic life-related beneficial uses of the receiving waters for the stormwater runoff. It cannot, however, be assumed that because this situation occurs at some locations that it will always occur at all locations and at all times. Site-specific investigations must be conducted to determine if the exceedance of a water quality standard represents a real water quality use impairment.

Under-Protective Nature of Some US EPA Water Quality Criteria

The authors have encountered a situation with chromium VI (Cr VI), where the US EPA water quality criterion of 10 μg/L would not necessarily be protective of aquatic life in receiving waters in which there is limited dilution of the stormwater runoff or wastewater discharges to a waterbody. Certain forms of aquatic life, such as zooplankton, which serve as important components of larval fish food, have been found to be adversely impacted by Cr VI at less than 0.5 μg/L. Lee and Jones-Lee (1997d) have reviewed the chromium chemistry/toxicity issues focusing on the deficiencies in the current regulatory approaches for control of chromium discharges to surface waters. Further, some regulatory agencies allow chromium III (Cr III) to be discharged in wastewaters and stormwaters at 50 μg/L, i.e. the chromium drinking water MCL. Such practice, however, can readily lead to chromium toxicity to aquatic life since Cr III can convert to Cr VI in some aquatic systems. It is important to understand that meeting the US EPA water quality criterion in ambient waters associated with stormwater runoff does not mean that the criterion constituent will not be adverse to some forms of aquatic life in the waterbody. In light of the information available today, it is appropriate to limit the total chromium concentration in a waterbody to 0.5 μg/L unless it can be shown that concentrations above this level are non-toxic to zooplankton, such as *Daphnia,* at the point of discharge for stormwater runoff and wastewater inputs, as well as downstream from this discharge/runoff.

There are a number of chemicals, such as arsenic, which are regulated as hazardous chemicals that will likely have their water quality standard significantly decreased within a few years. Arsenic has been used widely as a pesticide and herbicide. There are many former and current agricultural soils and some industrial areas that have sufficient arsenic in the surface soil to be of concern with respect to stormwater transport from the area. There is widespread recognition that arsenic at 50 µg/L (current drinking water MCL) represents a significant potential to cause cancer in people who consume domestic water supplies at or near these concentrations. The US EPA is reviewing the development of new, stricter drinking water standards for arsenic. The concentrations being considered are 0.2, 2.0, and 20 µg/L. It appears likely that a value of a few µg/L will be adopted, even though that value would still represent a significant cancer risk to those who consume waters with that concentration compared to the one in a million cancer risk that is typically accepted today as an appropriate risk for domestic water supplies.

The arsenic drinking water standard situation points to an important issue that needs to be considered in developing stormwater runoff water quality monitoring programs. Typically today, those establishing such programs only consider arsenic concentrations above 50 µg/L to be of potential concern with respect to water quality impacts. With new, stricter arsenic standards likely to be promulgated in the next few years, it is important to be certain that the analytical methods used are appropriate not only for today's regulatory situation but for those that can be reasonably expected to occur in the foreseeable future. Those conducting stormwater runoff monitoring programs from hazardous chemical sites should be cognizant of not only existing water quality criteria for water supplies, aquatic life, etc., but also of proposed changes such as will likely occur within a few years for arsenic or other constituents that have criteria currently under review. If, as in the case of arsenic, proposed lower concentration levels exist, then the stormwater managers should be using analytical methods that will measure the constituent at levels below the proposed criterion.

Unregulated Chemicals

One of the areas that should be of primary concern associated with stormwater runoff from a hazardous chemical site is the evaluation of the potential adverse impacts of the large number of potentially hazardous unregulated chemicals present in stormwater runoff. Typically, a comparison between the total organic carbon content of runoff waters and the total concentrations of specific organics measured in the runoff waters as determined by a Priority Pollutant scan shows that most of the organics in stormwater runoff are not identified/characterized. It is known that there are over 75,000 chemicals used in the US today. Only about 100 to 200 of these are regulated. Further, many chemicals can be transformed to other chemicals through chemical/biochemical processes that are also of concern with respect to impacting water quality as part of the unregulated chemicals in stormwater runoff. It is also known that each year newly developed and discovered hazardous chemicals are added to the list of hazardous chemicals that need to be regulated as a result of acquiring new information on their potential impacts. Therefore, it should never be assumed that because a stormwater runoff contains no constituents that cause an exceedance of a water quality criterion/standard in the runoff waters or receiving waters that the runoff-associated constituents from a hazardous chemical site or other area where complex mixtures of hazardous chemicals are present will not have an adverse impact on aquatic life and other beneficial uses of the receiving waters for the runoff.

A properly developed stormwater runoff impact evaluation and management program will include not only examination of the runoff waters and receiving waters for the regulated chemicals, but also include determining if the presence of unregulated, as well as regulated, chemicals in the runoff waters and the receiving waters are adversely impacting aquatic life and other beneficial uses of the receiving waters for the runoff. In evaluating the impact of stormwater runoff-associated constituents on receiving water water quality, it is important to examine the combined impacts of constituents in the stormwater runoff when mixed with constituents in the receiving waters. It is possible that adverse impacts will occur even though no impacts are potentially predicted based on examining the concentrations of regulated chemicals in the runoff waters. A combination of regulated and unregulated chemicals in the runoff waters and receiving waters could have an adverse impact that would not occur in either water alone. As discussed in a subsequent section of this paper, toxicity testing of discharge in ambient waters can be used to screen for combined effects of potentially toxic regulated and unregulated chemicals on receiving water aquatic life.

In addition, it is necessary to consider not only potential impacts at the point of mixing of the runoff waters with the receiving waters, but also downstream of this point where, associated with chemical/biochemical transformations, regulated and unregulated hazardous chemicals and non-hazardous chemicals are converted to hazardous forms. An example of this type of situation occurs with Cr III which some regulatory agencies allow to be discharged at 50 μg/L based on toxicity to humans. Generally, because of its low level of toxicity to aquatic life, Cr III is regulated based on drinking water standards of 50 μg/L. However, since Cr III can convert to Cr VI in aerobic surface waters, which can be toxic at about 0.5 μg/L, the discharge of Cr III at 50 μg/L, which is non-toxic at the point of discharge, can lead to aquatic life toxicity in the receiving waters downstream of the discharge due to the conversion of Cr III to Cr VI. As discussed by Lee and Jones-Lee (1997d). This conversion can take place in a few hours or over several days, depending primarily on receiving water conditions.

Another issue of concern with respect to the discharge of Cr III to a waterbody is the accumulation of the Cr III in the waterbody sediments. Cr III has a strong tendency to sorb to particulates and precipitate. This tends to cause Cr III particulate forms to accumulate in receiving water sediments during low-flow conditions. These areas of accumulation can, however, be scoured into the water column during high-flow conditions, suspending the particulate Cr III into the water column. This could cause significantly elevated levels of Cr III to pass downstream during elevated flow conditions. It was recently reported by Gunther (1997) that elevated flow conditions have apparently scoured Cr III from sediments in the Sacramento River system and have bioaccumulated in mussels in San Francisco Bay. This situation raises the question of whether the scoured Cr III, either through bioaccumulation or through conversion to Cr VI, is adverse to the beneficial uses of downstream waters where Cr III has accumulated.

The Cr III discharge situation provides another example of the inappropriateness of assuming that just because stormwater runoff contains constituents that, in the runoff or at the point of mixing with the receiving waters, are not adverse to aquatic life, that these constituents will not be adverse to aquatic life at some time in the future under a different flow regime. It is essential that receiving water studies be conducted to determine whether adverse conditions are found in the receiving waters due to stormwater runoff-derived constituents at the time of discharge as well as in the future under different flow or other conditions that can exist in the receiving waters.

Regulatory agencies and dischargers often use an arbitrary fixed distance (such as 50 or 100 meters) for sampling the receiving waters for discharges. The downstream sampling station should be selected based on a site-specific evaluation of mixing distances at various receiving water flows. Since the distance for mixing is dependent upon the receiving water velocity, consideration must be given to how the velocity of the receiving waters changes as a function of flow in selecting downstream sampling stations. Further, the rates of reactions of potential concern, such as the conversion of Cr III to Cr VI, must be considered.

An Alternative Monitoring/Evaluation Approach

In order to be protective of aquatic life and other beneficial uses of receiving waters for stormwater runoff, it should be assumed that the exceedance of a water quality criterion/standard due to runoff-associated constituents from a hazardous chemical site represents an adverse impact that should be evaluated by the stormwater manager to determine if the potential impact is, in fact, manifested in the receiving waters for the runoff. Lee and Jones-Lee (1996a,b, 1997b,c) have developed an Evaluation Monitoring (EM) approach that can be used to determine whether exceedances of water quality criteria/standards in stormwater runoff are causing real water quality use impairments in the receiving waters for the runoff. This approach can also detect some water quality problems due to unregulated chemicals. EM focuses on finding a real water quality problem-use impairment in the receiving waters for the stormwater runoff, identifying its cause and determining whether stormwater runoff-associated constituents derived from a particular site cause a water quality use impairment(s) in the receiving waters for the runoff. It should not be assumed, as it is often done, that an exceedance of a water quality standard represents a real water quality use impairment. Exceedances can readily reflect the overly-protective nature of many water quality criteria/standards which fail to consider the toxic, available forms of the constituents in runoff waters as well as the duration of exposure to excessive concentrations of available forms of constituents in the receiving waters.

The EM approach should be implemented as a watershed-based water quality management program in which all stakeholders (dischargers, regulatory agencies and potentially impacted parties) work together to define whether stormwater runoff from a particular location causes real, significant water quality problems in the receiving waters for the runoff. Where such problems are found, the stakeholders work together to control them. All of the designated beneficial uses for the receiving waters are considered in implementing the EM approach. These may include domestic water supply, fish and aquatic life, public health, contact and other recreation, wildlife habitat, agricultural water supply, groundwater recharge, excessive fertilization, etc. Presented below is a summary of some of the issues that need to be considered in implementing the EM approach to determine whether stormwater runoff from a hazardous chemical site is adversely impacting some of the beneficial uses of receiving waters for the runoff. Additional information on this topic is provided in the references listed for this paper.

Aquatic Life Toxicity

There are basically two concerns for the protection of aquatic life and their use as food associated with the discharge of hazardous/deleterious chemicals from hazardous chemical sites and other areas where there are complex mixtures of regulated and unregulated chemicals. One of these is aquatic life toxicity; the other is excessive bioaccumulation. Lee and Jones (1991) and Lee and Jones-Lee (1994a,1996a,b,c) recommend that all stormwater runoff water quality evaluation programs include measurement of the aquatic life toxicity to sensitive forms of aquatic life in the stormwater runoff waters as well as the receiving waters mixed with the stormwater runoff near the point of mixing and downstream thereof. The chronic toxicity endpoint should be used.

Appropriately conducted aquatic life toxicity tests can screen stormwater runoff waters for potential adverse impacts of all regulated and unregulated chemical constituents that are of concern with respect to being potentially toxic to aquatic life in the receiving waters. Such tests can and usually show that exceedances of water quality criteria for potentially toxic regulated chemicals in stormwater runoff do not necessarily translate to toxicity in the receiving waters for the runoff that is adverse to aquatic life in these waters. Further, such testing, if appropriately conducted, can detect toxic components in the unregulated chemicals in the stormwater runoff. Aquatic life toxicity testing using standardized US EPA toxicity test methods for freshwater systems using fathead minnow larvae and *Ceriodaphnia* (Lewis et al.1994) is a powerful tool that should be used on a routine basis to determine whether potentially toxic regulated and unregulated chemicals in stormwater runoff cause significant toxicity in receiving waters for the runoff.

Toxicity testing of the stormwater runoff waters should be done for at least two storms each season. In addition to testing the runoff waters for aquatic life toxicity, the receiving waters should be sampled and tested for aquatic life toxicity just downstream of where the runoff waters enter and are mixed with the receiving waters. The degree of mixing should be established at that point by measurements of specific conductance and/or temperature in the receiving waters. Further, toxicity testing should be done further downstream to detect whether non-toxic constituents in the runoff waters convert to toxic constituents in the receiving waters in sufficient amounts to be toxic to aquatic life, i.e. Cr III to Cr VI conversion.

It was through the use of aquatic life toxicity testing of stormwater runoff that diazinon and chlorpyrifos, organophosphate pesticides that are widely used in urban areas and in agriculture, were found to cause potentially significant aquatic life toxicity due to their presence in stormwater runoff from urban areas, highways and some rural areas.

Lee and Taylor (1997) have recently reviewed the stormwater runoff organophosphate toxicity issue. Diazinon is one of the unregulated chemicals that is causing widespread aquatic life toxicity in receiving waters for stormwater runoff. There are periods of time for several weeks each year in north-central California where diazinon applied to orchards as a dormant spray causes significant aquatic life toxicity in all runoff waters from urban and rural areas. A significant portion of this diazinon is volatilized at the time of application and transported through the atmosphere. It becomes surface water runoff through atmospheric scouring associated with rainfall and fogfall. Similarly, urban area stormwater runoff has been found to contain diazinon and chlorpyrifos toxicity due to homeowner structural and landscape use of these chemicals. There are other organophosphate and carbamate pesticides that are not now being adequately regulated which are likely causing similar problems in stormwater runoff from urban and rural areas.

It is important, when using aquatic life toxicity testing, to properly interpret the results of such tests. It should not be assumed that because aquatic life toxicity is found in the stormwater runoff waters that this will lead to significant aquatic life toxicity in the receiving waters for the runoff. As discussed by Lee and Jones (1991) and Lee and Jones-Lee (1994b, 1996c), the short-term episodic nature of stormwater runoff events, coupled with the approach used in aquatic life toxicity testing where the tests are conducted for approximately one week, can over-estimate toxicity that occurs in the receiving waters due to the discharge of toxic stormwater runoff. Typical aquatic life toxicity testing requires several days to about a week duration of test organism exposure. It is unusual in a stormwater runoff event for aquatic organisms to receive a week-long duration of exposure to toxic conditions. There are, however, significant differences in the rate at which various types of chemicals exert a toxic effect. There are fast-acting chemicals where, at elevated concentrations, the toxicity can be manifested within a few hours. There are other chemicals where, either due to low concentrations or the typical rate at which toxicity is manifested, several days of exposure must occur before the organisms are adversely impacted.

The recommended approach is to use the standard toxicity test to screen stormwater runoff for potential adverse impacts associated with the discharge of potentially toxic regulated and unregulated chemicals in the stormwater runoff. If toxicity is found in the runoff waters that persists for a sufficient period of time in the receiving waters to be potentially adverse to aquatic life, then additional toxicity testing should be conducted in which the toxicity-duration of exposure relationship that occurs in the receiving waters for the runoff is mimicked in the toxicity test. Lee and Jones (1991) and Lee and Taylor (1997) provide additional information on this topic.

Bioaccumulation

The bioaccumulation of hazardous chemicals in aquatic life tissue is one of the major adverse impacts that can occur due to stormwater runoff constituents. The chemicals of greatest concern for excessive bioaccumulation are the chlorinated hydrocarbon pesticides such as DDT and chlordane, PCB's, dioxins, and mercury. These chemicals have been found to bioaccumulate to a sufficient extent in aquatic life tissue to cause the use of aquatic organisms as food to be hazardous due to increased cancer risk or other adverse impacts on human health. For many years, the Food and Drug Administration (FDA) Action Levels were used to determine excessive concentrations of hazardous chemicals in aquatic life tissue. The US EPA (1994) adopted risk-based tissue concentrations which consider the potential hazard that a particular concentration of a hazardous chemical in an organism tissue represents through its cancer potency as well as the amount of tissue consumed. Generally, the risk-based excessive concentrations of hazardous chemicals are one or more orders of magnitude lower than the FDA Action Levels. This has created a situation where concentrations of hazardous chemicals in stormwater runoff that were not considered to have adverse impacts in the past are now being recognized as a potential significant source of excessive concentrations of the chemicals in fish tissue. Lee and Jones-Lee (1996b,d) have provided guidance on assessing excessive bioaccumulation of chemicals in aquatic organisms associated with stormwater runoff situations.

Similar problems occur with mercury where mercury is determined with analytical methods that do not have the necessary sensitivity to determine whether, under worst-case conditions such as those used by the US EPA in developing bioaccumulation-based water quality criteria, measured concentrations could result in excessive bioaccumulation in the receiving water organisms. The technically valid, cost-effective approach for assessing excessive bioaccumulation is a direct measurement of edible aquatic organism tissue residues. This is the approach that Lee and Jones-Lee (1996a,b,d) recommend as part of implementing the EM approach for stormwater runoff. Direct measurements of excessive bioaccumulation can readily be accomplished with the analytical methods available today. Such measurements provide information that can be used to determine whether all sources of a bioaccumulatable chemical in fish tissue contributes sufficient amounts of the chemical to the waterbody in available forms to lead to a bioaccumulation-caused use impairment of the waterbody. If the concentrations of chlordane, mercury or some other constituent are below excessive levels within aquatic organisms taken within the waterbody and downstream of the point at which the stormwater runoff enters the waterbody, then it can be concluded that excessive bioaccumulation is not occurring and, most importantly, that the stormwater runoff does not contain sufficient concentrations of a potential bioaccumulatable chemical to cause a water quality use impairment in the receiving waters due to that chemical.

If, however, the fish and/or other aquatic organisms used as human food in the receiving waters potentially impacted by stormwater runoff from a hazardous chemical site contain excessive concentrations of a chemical such as chlordane or mercury, then it is necessary to conduct additional studies to determine whether the stormwater runoff is a significant contributor of the constituent of concern to cause or contribute to the excessive bioaccumulation problem. Lee and Jones-Lee (1996a,b 1997b) have discussed the use of forensic procedures with caged organisms and/or laboratory studies that can determine whether stormwater runoff-associated potentially bioaccumulatable constituents could be significant contributors to excessive bioaccumulation in receiving water aquatic organisms. The bioaccumulation studies of stormwater derived from hazardous chemical sites should involve measurement of receiving water aquatic organism tissue levels for the conventional suite of potentially significant bioaccumulatable chemicals, such as the chlorinated hydrocarbon pesticides, PCBs, dioxins and mercury, for a several-year period. The bioaccumulation studies should be conducted each spring and fall to examine seasonal differences. Higher trophic level predator organisms should be sampled as well as the organisms that tend to have higher concentrations of fat in their tissue. Generally, the chlorinated hydrocarbon pesticides and PCBs accumulate in high lipid content tissue to a greater degree. The lipid content of the tissues collected and analyzed should also be determined.

Caution must be exercised in using US EPA water quality criteria, such as the US EPA (1987) "Gold Book" criteria, in predicting bioaccumulation that will occur in receiving waters for stormwater runoff. The US EPA water quality criteria for bioaccumulation are based on worst-case conditions which tend to over-estimate the actual bioaccumulation that will occur in many waterbodies. Lee and Jones-Lee (1996d) have discussed the current information in using chemical concentration data in water and/or sediments to estimate excessive bioaccumulation that occurs in receiving water aquatic organisms. There are a wide variety of factors which influence whether a particular chemical constituent, as typically measured by standard water quality monitoring analytical procedures, will bioaccumulate to excessive levels. The most important factor is the aqueous environmental chemistry of the constituent. Many of the potentially bioaccumulatable chemicals exist in a variety of chemical forms which are non-available to bioaccumulate within aquatic organisms. Since the analytical methods typically used in water quality investigations rarely only measure available forms of constituents, most measurements of bioaccumulatable chemicals tend to over-estimate the actual bioaccumulation that will occur when the concentrations are used with US EPA bioaccumulation factors. It is for this reason that the primary tool for determining whether excessive bioaccumulation occurs in a waterbody due to stormwater runoff-associated constituents is the actual bioaccumulation in aquatic organisms in the receiving waters. This is a more reliable approach than the approach that is typically used today of trying to measure concentrations of bioaccumulatable chemicals in runoff waters and then extrapolating these concentrations to excessive concentrations in receiving water aquatic organisms.

Aquatic Sediment Issues

The transport of hazardous chemicals from superfund and other hazardous chemical sites occurs with dissolved chemicals and chemicals attached to particulate matter. The dissolved chemicals can interact with the receiving water particulates to become part of the particulate-associated hazardous chemicals derived from the site. Since the particulate-associated chemicals are transported differently and represent significantly different hazards in the environment, it is important to determine whether hazardous conditions exist in the receiving waters due to the release of hazardous chemicals from the site that are in particulate forms or become particulate in the receiving waters.

Generally, particulate forms of hazardous chemicals are non-toxic and non-available and therefore represent minimal hazards in the environment. There are situations, however, where the accumulation of particulate forms in bedded sediments represents a potential cause of water quality deterioration due to either aquatic life toxicity to benthic or epibenthic organisms, or serve as a source of bioaccumulatable chemicals that can be adverse to the beneficial uses of a waterbody through causing a health hazard to humans who use the aquatic life as food. There is also the potential for the bioaccumulation of hazardous chemicals to be adverse to higher trophic level organisms, such as fish-eating birds and terrestrial mammals.

The US EPA (1995) has officially recognized that particulate forms of many heavy metals are non-toxic and non-available and now recommends regulating these heavy metals based on ambient water dissolved forms. The Agency should adopt the same approach for many of the potentially toxic organics and other constituents that tend to become associated with particulates. The Agency still recommends measuring total recoverable metals in discharge waters and the use of a generic or site-specific translator to translate dissolved forms of metals to particulate forms and vice versa in the ambient waters receiving the heavy metal input. This is based on the concern that particulate forms present in the discharge would convert to dissolved forms in the receiving waters. It is the authors' experience that such a conversion would be extremely rare.

Manuscript page limitations prevent the inclusion of a discussion of receiving water bedded sediment water quality issues. Such issues are important at many hazardous chemical sites. For a discussion of these issues, consult Lee and Jones-Lee (1997a).

Overview of Recommended Stormwater Monitoring for Hazardous Chemical Sites

Typically, stormwater runoff from urban areas and highways has been found to have limited adverse impact on the beneficial uses of the receiving waters for stormwater runoff (Lee and Jones-Lee 1996e). However, this is not necessarily the situation for stormwater runoff from hazardous chemical sites or other areas where large amounts of potentially hazardous chemicals are used in such a way as to possibly be present in elevated concentrations in stormwater runoff from the area. Sites of this type deserve special monitoring and proper interpretation of the US EPA's General Industrial Permit requirements for monitoring for "toxic" chemicals that could be present in the stormwater runoff. There is growing recognition that conventional end-of-the-pipe/edge-of-the-pavement/property monitoring of stormwater runoff for the conventional as well as the Priority Pollutants provides limited information on the impact of the stormwater runoff on receiving water quality-beneficial uses (Lee and Jones-Lee 1994a,b, 1996a,b,c, 1997b,c). There is widespread recognition that the conventional monitoring approach for stormwater runoff needs to be shifted from runoff water monitoring to receiving water monitoring and evaluation. The EM approach, in which the regulated entity (the PRP for a hazardous chemical site under remediation), regulatory agencies and the impacted community work together in a watershed-based water quality evaluation and management program to define what, if any, real water quality use impairments are occurring in the receiving waters for the stormwater runoff, if implemented properly, can be a technically valid, cost-effective approach. A key component of an appropriate stormwater runoff monitoring program is the examination of the runoff waters and receiving waters for aquatic life toxicity and excessive bioaccumulation of hazardous chemicals that cause receiving water organisms to be considered hazardous for use as human food.

It is important in developing a stormwater runoff water quality evaluation and management program for a hazardous chemical site to not over-regulate stormwater discharges and thereby waste public and private funds in unnecessary monitoring. In situations where adequate monitoring and evaluation have been conducted which show with a high degree of certainty that there is limited likelihood of significant adverse impacts on the beneficial uses of the receiving waters for the runoff, there is no point in continuing intensive monitoring and management programs. A low-level, on-going monitoring program should be continued in order to be certain that new problems do not occur in the future that were not detected previously or that the site characteristics changed sufficiently to significantly change the concentrations of constituents in the stormwater runoff.

The overall approach that should be used in a monitoring and management program of hazardous chemical sites is to err on the side of public health and environmental protection in those situations where definitive information on the impact of runoff from a site is lacking. Regulatory agencies should require that the burden of proof should be on the PRP - stormwater discharger to reliably demonstrate that stormwater runoff from the site is not adverse to the beneficial uses of the receiving waters.

Conclusions

The development of a technically valid, cost-effective stormwater runoff monitoring and evaluation program for a hazardous chemical site requires a high degree of understanding of aquatic chemistry, aquatic toxicology, hydrodynamics and water quality. The US EPA's General Industrial Permit stormwater runoff monitoring program will not ordinarily provide adequate monitoring to ensure that hazardous chemical site stormwater runoff-associated constituents do not have an adverse impact on the beneficial uses of the receiving waters for the runoff. Credible stormwater runoff monitoring programs must involve in-depth, reliable examination of the water quality characteristics of the receiving waters for the runoff. The EM approach provides a focused examination of receiving waters in which these waters are examined for water quality use impairments of potential concern to the public and others who utilize these waters. If properly implemented, the EM approach can significantly reduce the cost of monitoring of hazardous chemical sites' stormwater runoff and focus the funds spent on monitoring on detecting real water quality problems that need to be addressed in order to protect the designated beneficial uses of the receiving waters for the stormwater runoff.

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Copies of the authors' reports which serve as background to this paper are available from their web site (http://members.aol.com/gfredlee/gfl.htm).