Development of Appropriate Stormwater Infiltration BMPs: Part I
Potential Water Quality Impacts, Monitoring and Efficacy Evaluation[1]

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Biographical Sketch

Dr. G. Fred Lee is President of G. Fred Lee & Associates, an environmental consulting firm. For 30 years, until 1989, he held university graduate-level environmental engineering teaching and research positions. During this time, he conducted over $5 million in research and published over 500 papers and reports. Two of his areas of particular activity are urban and highway stormwater runoff water quality management and groundwater quality protection from pollution by wastes disposed on land. This paper provides guidance on the appropriate use of urban area and highway stormwater infiltration as a best management practice for stormwater runoff water quality management.

Abstract

Urban stormwater runoff water quality management typically involves the potential use of structural and non-structural best management practices (BMPs). Infiltration of stormwater into groundwater systems is a conventional BMP. Infiltration basins will likely be used with greater frequency with the implementation of the regulatory goal of having to "treat" urban stormwater runoff to ultimately achieve water quality standards in the runoff. While, if properly designed, operated, maintained, and monitored, urban stormwater infiltration can control urban stormwater runoff-associated constituents so they do not cause or contribute to water quality standards violations, as typically developed today, stormwater infiltration can lead to groundwater and surface water pollution - use impairment. This paper presents Part I of a two-part presentation of guidelines on how urban stormwater infiltration BMPs can be developed that will protect groundwater and surface water quality. Consideration is given in this paper to infiltration systems site selection, monitoring and evaluation of effectiveness. The recommended approach for developing urban area and highway stormwater runoff infiltration as a BMP involves the use of a plausible, worst-case scenario evaluation of the potential problems that could arise from a proposed stormwater infiltration system. Issues that should be considered in making this evaluation are discussed in this paper. Part II of the paper (Taylor and Lee 1998) presents information on siting, design, operation and maintenance of stormwater runoff BMP infiltration systems.

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Introduction

Urban area and highway stormwater runoff water quality managers face the problem of ultimately having to control the chemical and biological characteristics of stormwater runoff so that runoff-associated constituents do not cause or contribute to violations of water quality standards in the receiving waters at the point of discharge of the runoff. This situation is causing a critical examination of the ability of various best management practices (BMPs) to "treat" urban area and highway stormwater runoff to a sufficient degree to reduce the concentrations of regulated constituents, i.e. those for which there are water quality criteria/standards, so that their concentrations in the BMP-treated water do not exceed the water quality criterion/standard. One of the BMPs that is receiving increased attention is the infiltration of stormwater runoff into the groundwater system of the area. There is concern, however, about whether the chemical constituents and pathogenic indicator organisms present in urban area and highway stormwater runoff that are infiltrated into a groundwater system could cause pollution of the groundwater, impairing its use for domestic or other purposes.

The Water Environment Federation and the American Society of Civil Engineers published "Urban Runoff Quality Management, Manual of Practice," (WEF ASCE, 1998) which devotes several pages to stormwater infiltration as a BMP for managing urban area stormwater runoff water quality impacts. Jones-Lee and Lee (1998a) have discussed some of the significant technical problems with this manual relative to providing reliable current information on the use of BMPs for managing urban area stormwater runoff water quality problems. This 1998 manual did not address many of the key water quality issues that urban area stormwater runoff water quality managers must consider in developing technically valid, cost-effective stormwater runoff water quality management programs. This "Manual of Practice" fails to present information on the potential problems with stormwater infiltration as a BMP. Of particular concern is the failure to discuss the work of Pitt *et al*. (1994) "Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration." This US EPA report provides a discussion of the potential problems associated with urban area stormwater infiltration as a cause of groundwater pollution.

In 1996 the Federal Highway Administration (FHWA, 1996) released "Evaluation and Management of Highway Runoff Water Quality," which, in the manual, is stated to present information devoted to the available and appropriate prediction and mitigation tools for use during highway project planning development and activities. While this manual devotes 33 pages to the design of infiltration trenches and basins, it provides essentially no information on the potential for highway stormwater infiltration to cause groundwater pollution.

Urban stormwater runoff contains constituents (heavy metals, organics, pathogenic organisms, and in some areas, de-icing salts) that represent a threat to groundwater quality for domestic water supply purposes. Further, where groundwaters receiving infiltrated stormwater enter surface waters near the infiltration trench or basin, urban stormwater constituents can be a threat to surface water quality. Site selection for infiltration trenches/basins is the key component in protecting groundwaters from pollution by stormwater runoff-associated constituents. The proper development of a stormwater infiltration system requires a good understanding of the groundwater hydrology and groundwater/aquifer characteristics of the area in which the infiltration system is to be located.

The development of a stormwater infiltration system should involve a plausible, worst-case scenario evaluation of the potential for constituents in the stormwater runoff to cause ground and/or surface water pollution/impaired use. This paper reviews the appropriate use and potential problems associated with urban area and highway stormwater runoff infiltration as a BMP for managing the potential water quality impacts associated with the direct discharge to surface waters. Guidance is provided on the development of an appropriate evaluation of the suitability of a particular area for a stormwater infiltration system, as well as for monitoring of infiltration trenches/basins and the potentially impacted groundwaters to ensure that groundwater pollution is not occurring. This paper is Part 1 of a two-part series devoted to this topic where Part 2 (Taylor and Lee, 1998) discusses the application of the information provided in this paper to the development/design of urban area and highway stormwater runoff infiltration systems.

Evaluation of the Potential Impacts of Urban Area and Highway Stormwater Runoff on Ground/Surface Water Quality

There are a number of chemical constituents, such as heavy metals (Cu, Zn, Cd, Pb); organics, such as PAHs, pesticides, petroleum hydrocarbons, oil and grease, etc.; pathogenic organisms, such as bacteria, viruses and protozoan parasites; and salts where de-icing compounds are used, that represent potential threats to surface water quality associated with the direct discharge of urban area and highway stormwater runoff to surface waters. The infiltration of urban area and highway stormwater runoff provides the opportunity for the aquifer system to remove many of the constituents of concern associated with direct stormwater runoff to surface waters. This removal is due to the sorption and, for some constituents in some aquifers systems, chemical precipitation of the constituent of concern onto the aquifer solids, and for certain organics, biotransformations to less harmful constituents. This removal (treatment) can, if properly evaluated and utilized, provide for the safe management of urban area and highway stormwater runoff-associated chemical constituents and pathogenic organisms that cause human disease.

The sorption characteristics of an aquifer system (vadose - unsaturated zone and the saturated parts of the aquifer) are directly dependent on the physical and chemical characteristics of the aquifer. The greatest sorption capacity for removal of constituents of concern associated with urban area and highway stormwater runoff occurs with those aquifer systems that consist primarily of clays or silts with substantial clay present. These systems, however, tend to have low infiltration rates and therefore to be effective in infiltrating urban area and highway stormwater runoff for potential pollutant removal, large areas for infiltration have to be available or a large amount of the stormwater added to the infiltration trench/basin will be bypassed to the surface watercourse during times when the rate of infiltration is less than the rate of filling of the infiltration trench/basin.

The removal of organics in an aquifer system is primarily dependent on the organic carbon content of the aquifer solids. Typically the higher total organic carbon of the solid tends to have higher capacities for removal of dissolved organics present in stormwater runoff. The organic content of the aquifer solids below an infiltration trench/basin will likely change over time due to the coating of the aquifer solids with high molecular weight organics derived from the infiltrating stormwater, as well as any biological growths that occur within the infiltration trenches/basins through the release of aquatic plant excretory products to the infiltrating stormwater. The changes in the sorption capacity for organics over time need to be determined to evaluate the ability of the vadose zone and saturated zone to remove organics from the infiltrating stormwater. This removal will have a finite limit for any types of organics where typically lower molecular weight organics would tend to be displaced from sorption sites by higher molecular weight organics. Wilson, *et al*. (1992) have discussed some of the factors that influence the transport of organics and metals in the vadose zone associated with stormwater infiltration. Caution should be exercised in the use of such models, however, to be certain that they are properly verified for site-specific conditions that can exist for particular stormwater infiltration situations that exist at the time of initiation of the operations of the infiltration trench/basin, as well as over time that the infiltration system is used.

The Ability of Aquifer Solids to Remove Stormwater Runoff Potential Pollutants. The sorption capacity of aquifer solids generally decreases as the permeability of the aquifer increases. Sand and gravel or cavernous limestone systems can provide ideal infiltration basins for stormwater runoff since high per-unit-area infiltration rates can be achieved. However, these types of aquifer systems often provide for poor potential pollutant removal because of low pollutant removal/sorption ability. Similar problems exist with fractured rock aquifer systems where it is possible that fractures that intercept the infiltrating stormwater could serve as a rapid conduit to domestic water supply wells with little removal of the pollutants and thereby lead to impaired use of the groundwaters for domestic and other purposes. High silt/clay soil aquifer solids, on the other hand, while providing high sorption capacity, typically have low permeability and therefore are unsuitable for infiltrating urban area and highway stormwater runoff except under conditions where large infiltration basins are used. Therefore, the design of a reliable stormwater infiltration system requires a good understanding of the permeability of the soils underlying the infiltration trench/basin and the associated aquifer system.

The tendency for suspended sediments and/or algal or other aquatic plant growth that could occur in the infiltration basin to clog the infiltration basin, thereby significantly reducing the permeability of the basin leading to increased bypass, should be evaluated in developing stormwater infiltration basins. Further, for each of the chemical constituents of concern in stormwater runoff that represent a potential threat to groundwater quality, consideration must be given to the ability of the aquifer solids to remove the constituents from the infiltrating stormwater and thereby prevent pollution of the groundwater system and/or any surface waters that could receive the polluted groundwaters via surface discharge.

As discussed by Taylor and Lee (1998), there are considerable differences in recommended approaches toward the development of stormwater infiltration systems relative to the position of the high water table. While the greater depth of the vadose zone underlying an infiltration system provides for enhanced removal of chemical constituents and pathogens in this zone, it should be recognized that there are constituents in urban stormwater runoff that will not be significantly removed in the vadose zone. For these types of constituents, the depth to the high groundwater table determines the time until groundwater pollution occurs; it does not prevent pollution. The depth to the groundwater table should be evaluated on a site-specific basis to determine whether potential pollutants in the urban stormwater runoff will be removed in the vadose zone for a particular proposed infiltration system. Further, the thickness of the vadose zone needed to accomplish this removal should be determined.

There are inappropriate approaches used by some stormwater infiltration project proponents and their groundwater consultants for modeling transport of chemical constituents in the vadose zone. Such practices of assuming the average annual moisture content of the vadose zone in predicting water and constituent transport are obviously technically invalid for percolating precipitation to groundwaters, as well as for infiltrating stormwater runoff. In both cases, it should be assumed that the rate of transport of potential pollutants occurs under saturated flow conditions, which is much faster than that predicted based on unsaturated transport.

Hydraulic Connections to Surface Waters. In evaluating the suitability of an infiltration trench/basin, the groundwater hydrology of the region should be sufficiently well understood to determine whether chemical constituents or pathogens present in the stormwater that are not removed in the soil/vadose zone column underlying the infiltration basin could be adverse to aquatic life and other beneficial uses of surface waters through surface discharges of the groundwater. If there is a hydraulic connection between the groundwaters underlying an infiltration trench/basin and the nearby surface waters, then consideration must be given to whether there are constituents in the infiltrated stormwater runoff that could pass through the vadose zone and saturated groundwaters in sufficient concentrations to be adverse to aquatic life where the groundwater discharges at the surface through above-ground springs or, more commonly, below water surface spring discharges and seepage.

The evaluation of potential impacts of the constituents in the groundwater discharge to surface waters should consider not only the concentrations that would occur in the surface waters as the result of mixing the infiltrated stormwater runoff with the surface waters receiving the polluted groundwater discharge, but also the potential for the polluted waters to enter the waterbody sediments in such a way as to be adverse to benthic and epibenthic forms of aquatic life, including fish eggs that are deposited on the bottom in areas where there is groundwater discharged to the waterbody. This requires an understanding of how the stormwater runoff-polluted groundwaters enter the surface waters and the biological/ecological characteristics of the surface waters in the vicinity of the polluted groundwater discharge.

Stormwater Bypass. As discussed by Taylor and Lee (1998), the proper design of a stormwater infiltration basin for adequate chemical constituent and pathogen indicator organism control requires that, with few exceptions, there not be bypass of stormwater runoff from the basin to the surface watercourses. Substantial bypass could, in effect, largely negate any benefits associated with attempting to infiltrate the stormwater into the groundwater system, rather than allowing it to pass directly to the surface water system of the area. In the past, some stormwater infiltration systems have functioned primarily as a cosmetic BMP which while infiltrating some low flow stormwater runoff, bypass substantial high flow waters to the surface watercourses of the area. Some urban area stormwater infiltration systems have been designed to only infiltrate the first flush-associated constituents, bypassing the constituents that are present after the first flush runoff has occurred. This approach, while possible at some locations, but not all, reduces the amount of chemical constituents that enter the surface waters of the region via infiltrating part of the runoff, but will not, in general, provide adequate treatment of the runoff to prevent violations of water quality standards in the runoff waters as they enter the surface watercourses of the area. Taylor and Lee (1998) discuss the appropriate design of stormwater infiltration systems to minimize stormwater bypass. Such design requires proper consideration of the infiltration ability of the aquifer system in which the infiltration trench/basin is located.

Characteristics of Urban Area and Highway Stormwater Runoff Relative to the Potential to Pollute Groundwaters through Stormwater Infiltration

The primary water quality concern for many stormwater runoff infiltration systems is whether there are constituents in urban area and highway stormwater runoff that are present in the runoff at sufficient concentrations to be adverse to the use of the groundwaters that mix with the infiltrating stormwater that are used near the infiltration basin for domestic water supply purposes. A review of the chemical and pathogen indicator information on the characteristics of urban area and highway stormwater runoff shows that there are a number of chemical constituents in the runoff waters at sufficient concentrations to pollute groundwaters by the runoff-derived constituents, rendering the groundwaters unusable for domestic purposes.

Chemicals. Pitt and Field (1990), Pitt *et al.* (1994, 1996), and US EPA (1998b) summarized the results of the US EPA National Urban Runoff Program (NURP) stormwater monitoring that was conducted during the late 1970s/early 1980s. Except for lead (Pb), which has decreased significantly in urban area and highway stormwater runoff since that time due to its elimination as an antiknock additive to gasoline, the concentrations of other constituents in urban area and highway stormwater runoff are being found to be about the same today as were found in the NURP studies. Barrett, *et al.* (1995, 1998), and Wu, *et al.* (1998) have recently summarized information on the chemical characteristics of current highway and street stormwater runoff. A review of the NURP data, as summarized by Pitt and Field (1990), and post-NURP data summarized by Pitt *et al.* (1994,1996), and the US EPA (1998b), as well as the recent data on highway and street runoff, shows that there are a number of constituents in US municipal stormwater and highway and street runoff that occur at concentrations that are, or could become, threats to the use of groundwaters for domestic water supply purposes.

The current concentrations of several heavy metals in urban area and highway stormwater runoff are above the US EPA maximum contaminant levels (MCLs) for the use of the water for domestic water supplies. An example of a constituent of concern is Pb which has a US EPA water quality action level of 15 µg/L for safe use of a water for domestic purposes. Lee and Taylor (1998) have recently summarized the 1996 - 1998 State of California highway stormwater runoff monitoring data which reports concentrations of total and dissolved Pb in runoff that frequently exceed 15 µg/L. Therefore, Pb currently present in urban area and highway stormwater runoff represents a threat to groundwater quality through stormwater runoff infiltration. The primary issue in developing an appropriately designed infiltration trench/basin for stormwater runoff water quality management is whether the hydrology of the groundwater system and the aqueous environmental chemistry of Pb in this system is such that the dissolved or finely divided colloidal Pb in stormwater runoff could be transported to the groundwater table and through the saturated part of the aquifer at sufficient concentrations so that when pumped from a domestic water supply well, the water user would be exposed to excessive Pb. In making this evaluation, it is important to consider that the water supply pump and plumbing system itself may contribute Pb to the waters delivered at the tap. The additional Pb derived from the Pb originally present in the infiltrated stormwater could add sufficient background Pb to the well water to either cause or increase the hazards of the use of the groundwaters for domestic consumption by children.

Ordinarily, there would be significant dilution of any Pb originally present in the infiltrated stormwater runoff due to mixing of the infiltrated stormwater with the groundwater and at the point of extraction to dilute the excessive Pb compared to drinking water action levels below critical concentrations. The dilution at the point of extraction in the well will likely be the most important mechanism for reducing the concentrations of Pb below critical levels. The nature of the plumes that typically would be generated by infiltrating stormwater runoff would be such that it would be unlikely that large volumes of groundwater would be polluted by Pb above the drinking water action level. Further, the point of extraction of greatest concern would be near the stormwater infiltration trench/basin. Water supply wells located at some distance would, in general, not experience elevated concentrations of Pb at the point of well discharge due to mixing of the stormwater-derived Pb-polluted groundwaters with non-polluted groundwaters. In addition, there would be mixing within the well. Further, in most aquifer systems, there would be some mixing of the infiltrated stormwater containing excessive Pb with the non-polluted groundwaters of the aquifer. There is, however, the potential for some aquifer systems for the Pb in urban stormwater runoff to pollute groundwaters near the point of infiltration, representing a threat to those who use the groundwater for domestic water supply. This situation requires a site-specific evaluation of the potential for chemical constituents in urban area stormwater runoff to be removed/reduced in concentrations that represent a threat to human health from the infiltrating stormwater or from the polluted groundwater before it reaches a domestic water supply well.

Arsenic (As) is another constituent in urban area stormwater runoff that could become a problem with respect to polluting groundwaters, impairing their use for domestic water supply purposes. Pitt and Field (1990) reported that the median concentration of As in urban stormwater runoff monitored in the NURP studies was 7 µg/L. While the current US EPA drinking water MCL for As is 50 µg/L, the US EPA is in the process of lowering this MCL to 20, 2 or 0.2 µg/L, based on the projected cancer risk to humans through consumption of drinking water. If the Agency selects 2 µg/L or less as the new As MCL, then there could be significant problems infiltrating urban area stormwater into a groundwater system that is used for domestic water supply purposes. The factors discussed above for Pb that would impact whether excessive Pb in infiltrated urban area and highway stormwater runoff would be a threat to an individual's or a municipality's domestic water supply would also be applicable to As. There could be situations where infiltrating urban stormwater runoff containing elevated concentrations of As could cause exceedance of the new As MCL that the US EPA could adopt.

The winter use of de-icing chemicals, such as salts, can lead to high concentrations of salts in stormwater runoff. The infiltration of this runoff can cause pollution of the groundwaters by the salt components, impairing their use for domestic water supply purposes. Pitt *et al.* (1994, 1996) and the US EPA (1998) have provided information from the literature on groundwater pollution by stormwater runoff. Their review should be consulted for additional information on this topic.

Pathogens. The potential for urban area and highway stormwater runoff to pollute groundwaters with human pathogens through stormwater infiltration is gaining increasing attention. Urban area and highway stormwater runoff often contains elevated concentrations of fecal indicator organisms, such as coliforms, that are a threat to the sanitary quality of surface waters. Pitt *et al.* (1994, 1996) have summarized some of the information on this topic. An area of increasing concern is the transport of human pathogens in groundwater systems. Certain types of aquifers, such as fractured rock and cavernous limestone, are particularly vulnerable for transporting pathogens for long distances. While it has been generally found that bacteria, such as coliforms, are not transported to a significant extent in groundwaters, provided that the aquifer is composed of fine grain solids, it is now recognized that even such aquifers can transport human pathogen enteroviruses for considerable distances. The US EPA, through its Groundwater Disinfection Rule development (Macler, 1998) is devoting attention to assessing the transport of human viral pathogens through groundwater systems. It is now clear that human enteroviruses are transported for considerable distances in many groundwaters systems.

Urban area and highway stormwater runoff infiltration basins will come under scrutiny as potential avenues of pollution of groundwaters by pathogenic organisms that are present in the infiltrated stormwater. This scrutiny could include required monitoring of the infiltrated groundwater in regions where the stormwater infiltration basins are located near domestic water supply wells. The State of California Department of Health Services is developing guidance on the recharge of reclaimed domestic waste waters for aquifer replenishment, as well as salt water intrusion barriers. The draft guidance has included providing at least a two-year travel time between where the recharge of the reclaimed wastewaters occurs and a domestic water supply well. It generally appears that within two years any residual enteroviruses present in the reclaimed wastewater are removed in the aquifer system.

The National Research Council (1994) Committee on Ground Water Recharge conducted a review of the potential for groundwater pollution associated with enhanced recharge of groundwaters by waters of impaired quality. This committee concluded that, at this time, there are significant questions about the public health safety of enhancing the recharge of groundwaters by waters that contain a variety of potential pollutants and pathogen indicator organisms. This situation applies to widespread use of urban area and highway stormwater infiltration as a means of disposal/management of chemical constituents in the runoff waters that are a threat to the beneficial uses of surface waters. While the discharge of many potential pollutants in urban area and highway stormwater runoff to surface waters is under many situations unlikely to cause pollution - impairment of use, the discharge of these same constituents to groundwaters through infiltration trenches/basins can lead to impaired use of the groundwaters by the associated pollutants in the infiltrated stormwater. The important difference between surface water and groundwaters in the ability to accept potential pollutants is that the discharge of stormwater runoff to surface waters often results in rapid dilution of the potential pollutants in the surface water. On the other hand, infiltrating urban area potential pollutants to groundwaters can cause water quality problems because of the limited dilution that occurs at a point where the infiltrated stormwater mixes with the aquifer waters and the slow rate and extent of mixing within the aquifer.

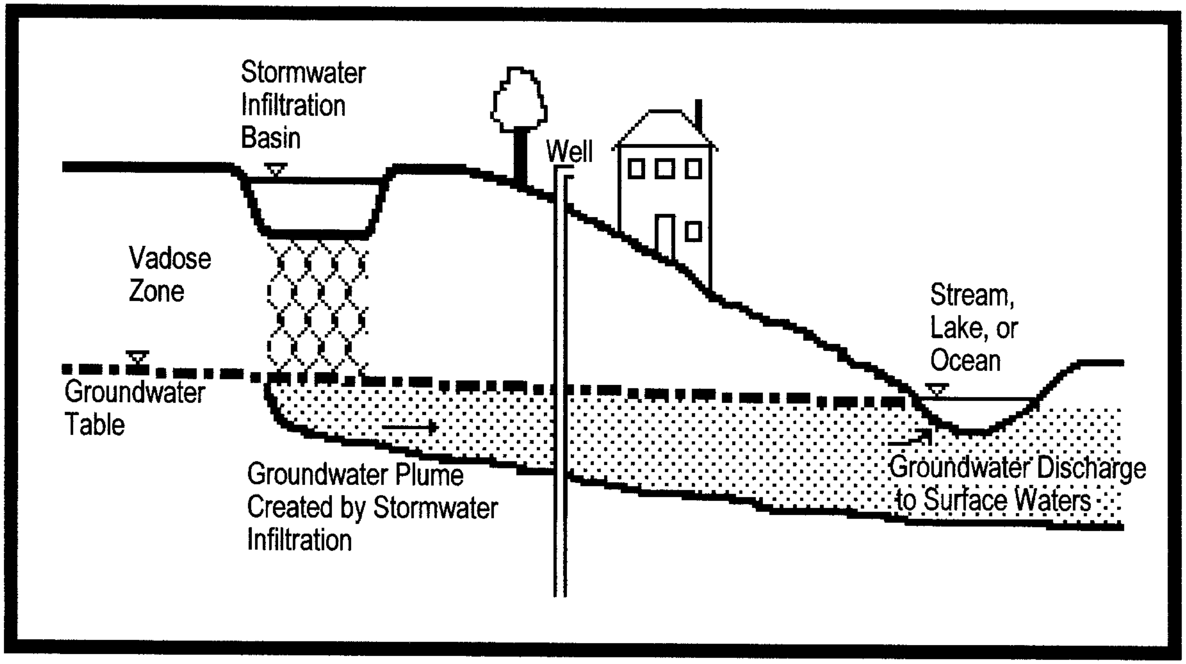
It is important that the approach that is now frequently used of assuming that infiltration of urban area and highway stormwater runoff is significantly beneficial to the environment because of the "water quality problems" caused by the direct discharge of the stormwater to surface waters should not continue to occur. As discussed by Jones-Lee and Lee (1998a,b), it is important, as part of developing a stormwater runoff water quality management program, to reliably identify the real water quality problems associated with urban area and highway stormwater runoff. Where real, significant problems are found, then consider various BMPs to control these problems in a technically valid, cost-effective manner. Any consideration of stormwater infiltration as a BMP should include a plausible worst-case scenario evaluation of potential problems with the proposed infiltration system. Particular attention should be given to pollution of groundwaters by the constituents in the stormwater runoff.

Plausible Worst-Case Scenario Evaluation

The approach that should be used in developing effective and protective urban area and highway stormwater runoff infiltration systems should include a plausible worst-case scenario evaluation of potential problems that could develop with the infiltration system and its impacts on ground and surface water quality, as well as public health and the environment. The typical approach that is sometimes used by project proponents and their consultants and some regulatory agency staff, of assuming that the proposed infiltration system will work as designed without significant problems for extended periods of time, is inappropriate. This approach may enable the development of a stormwater runoff water quality management project at initially less than the ultimate real cost. However, ultimately the cost to the public, either in a failed system that will not infiltrate the necessary volumes of stormwater without significant overflow-bypass, and therefore fail to accomplish its purpose, or cause significant environmental problems due to pollution of ground and surface waters is not in the best interest of the public. By evaluating plausible worst-case scenario failures for the proposed system that could occur over the life of the system and then planning for early detection of these problems and providing the necessary funds to address the problems when they occur, it will be possible to develop technically valid, cost-effective and protective stormwater runoff infiltration systems as a reliable BMP for managing the water quality impacts of direct discharges of urban area and highway stormwater runoff-associated constituents to surface waters.

Figure 1 presents a general representation of the components of a plausible worst-case scenario evaluation of the potential problems associated with urban area stormwater infiltration. Basically this evaluation includes considering the initial concentrations and forms of chemical constituents in the infiltrating stormwater. Based on this information, the potential for transport/removal/dilution of potential pollutants is to be evaluated in each of the principal areas where removal or reduced concentrations could occur, such as at the interface between the bottom and sides of the infiltration trench/basin, within the vadose zone underlying the trench/basin, and in the saturated groundwaters below the trench/basin to a potential receptor such as a water supply well or discharge to the surface waters. Typically, a distance of one mile down groundwater gradient from the point of infiltration should be considered as the area that is vulnerable to pollution by infiltrated stormwater-associated constituents. The one-mile distance recommended for evaluating the potential for urban stormwater runoff infiltration systems used in an urban area as a BMP for managing/disposal of the chemical constituents in the urban area stormwater runoff is based on the experience of the senior author. He has encountered several situations where groundwater pollution plumes

Figure 1. Evaluation of Worst-Case, Plausible Scenario Problems with Urban-Area Stormwater Infiltration as a BMP



Issue:
Will Chemical Constituents & Pathogens in Urban Stormwater Runoff Pollute Groundwater to Impair Its Use for Domestic Water Supply, and/or Pollute Surface Water to Which Groundwater Pollution Plumes Discharge?

associated with disposal of chemicals in pits have extended in sand and gravel aquifer systems for over one mile from the disposal site.

In conducting the worst-case-based problem identification, further, as discussed below, consideration must be given to the accumulation of sufficient chemical constituents and/or pathogens to represent a threat to workers who clean the trenches/basins, and where the residues removed from the trenches/basins are deposited. Of particular concern is the accumulation of hazardous chemicals within the aquifer system that could lead to Superfund-like conditions.

The American Society of Civil Engineers (ASCE) Standards Committee for Artificial Recharge of Groundwater is in the final stages of publication of comprehensive guidance on the enhanced recharge of aquifers to provide additional groundwater resources for a region. This guidance manual, "Standard Guidelines for Artificial Recharge of Ground Water," which should be published within a year, provides detailed discussions of the issues that need to be considered in developing enhanced groundwater recharge systems. The characteristics of groundwater recharge systems and their problems are similar to those of stormwater infiltration trenches/basins. They include such problems as inadequate percolation rates, clogging of trenches/basins, control of biological growths, etc. This guidance manual also includes some discussion of the potential water quality problems associated with infiltrating surface waters, such as urban stormwater runoff, that contains elevated concentrations of potential pollutants. This manual should be reviewed as part of developing an urban area and highway stormwater runoff infiltration system in order to gain insight into the issues that should be considered in developing a worst-case-based scenario for infiltration trench/basin problems.

As part of contributing to the development of the ASCE "Standard Guidelines for Artificial Recharge of Ground Water" guidance manual, Lee and Jones-Lee (1993, 1995a,b,c, 1996) have developed discussions of some of the water quality aspects of natural and enhanced groundwater recharge. They emphasize the importance of properly evaluating the potential pollutional characteristics of the surface waters that are to be recharged, considering the characteristics of the recharge aquifer system. They also discuss the importance of reliably monitoring the characteristics of the recharged groundwaters and the aquifer system where the recharge takes place to detect incipient pollution before widespread pollution occurs.

One of the issues that needs to be considered in conducting a plausible worst-case scenario evaluation of potential problems associated with urban area and highway stormwater runoff management by infiltration is whether there are constituents in urban area and/or highway stormwater runoff that are not now identified in runoff, or could be introduced into runoff in the future, that would become significant threats to groundwater quality through the infiltration of the runoff. The MTBE situation is an example of how a chemical could become part of vehicular traffic emissions - releases that could be a significant threat to groundwater quality. Squillace, *et al.* (1996) have summarized the results of a national study conducted by the USGS on the occurrence of MTBE in groundwaters. While the primary threat associated with MTBE as an additive to gasoline is groundwater pollution associated with leaking storage tanks and the associated plumbing, there could be future "MTBEs" that are not properly evaluated with respect to their potential to pollute groundwaters that could be associated with vehicular traffic and be present in stormwater runoff at sufficient concentrations to be a threat to groundwater quality. Fortunately, this is not the case for MTBE, since it is rapidly lost to the atmosphere under conditions where there is an opportunity for atmospheric exchange.

While the organophosphate pesticides, diazinon and chlorpyrifos, have been used for many years in urban residential areas for structural and lawn and garden pest control, it is only recently that these pesticides have been discovered as widespread, potentially highly significant causes of urban area stormwater runoff aquatic life toxicity. A review of the pesticides that are used in urban areas and/or agricultural areas that can be airborne transported to urban areas shows that there are hundreds of pesticides used for which there is no information on the concentrations in urban area stormwater runoff that could be a significant threat to groundwater quality arising from infiltrating urban area stormwater runoff.

There are also a wide variety of other chemicals associated with vehicular traffic and/or urban areas that are present in stormwater runoff which are not now regulated through water quality criteria/standards or monitored in stormwater runoff. At this time only about 200 chemicals, out of the over 75,000 chemicals that are used in US commerce today, are regulated. An example of a group of chemicals of this type are the benzthiazoles. These chemicals are present in rubber vehicular tires and are present in the urban area and highway stormwater runoff associated with tire wear. They accumulate in receiving water sediment, such as San Francisco Bay, to measurable concentrations. They are believed to be carcinogens. They are not measured in any pollution control or water supply water quality evaluation. Even though they were reported in San Francisco Bay sediments in 1987, there is no information on their impacts on the environment. The benzthiazoles are one group of many groups of chemicals that are present in urban area and highway stormwater runoff that could be threats to surface and/or groundwater quality.

Because of the potential vulnerability of groundwaters to pollution by persistent hazardous and deleterious chemicals present in urban area and highway stormwater runoff, great caution should be exercised in adopting infiltration of urban area and highway stormwater runoff as a means of managing the hazardous or otherwise deleterious chemicals present in such runoff. Those who propose urban area and highway stormwater runoff infiltration as a BMP for managing the chemical constituents and pathogenic organisms present in this runoff that are threats to surface water quality should carefully evaluate whether infiltration of the stormwater runoff could lead to significant groundwater quality problems. As discussed herein, areas of particular concern are the areas which are best suited for stormwater infiltration trenches/basins, i.e. those which have high percolation capacities.

While an individual urban area stormwater infiltration system is unlikely to cause significant widespread groundwater pollution, the use of large numbers of infiltration systems in an urban area for managing stormwater runoff could readily lead to a large number of small groundwater pollution plumes of stormwater-derived constituents that could represent a significant potential to pollute a large amount of groundwater with a variety of chemical constituents, rendering the groundwater unusable for domestic and some other purposes. This situation is similar to that which occurs in some urban areas in which residential properties use septic tanks for wastewater disposal. Canter and Knox (1985) reviewed the pollution of groundwaters by septic tank disposal systems. They reported that there are a number of examples of the pollution of groundwaters by residential septic tank wastewater disposal system-"treated" wastewaters, where a large number of these systems have rendered the groundwaters in the region unusable for domestic purposes. The US EPA (1998a), as part of its recently proposed increased regulation of Class V Injection Wells, has included large cesspools such as those that would be used by a group of residents, as a type of injection well that is to come under increased regulation because of the potential for groundwater pollution. It is in making the worst-case scenario problem assessment to consider the collective impacts of all of the stormwater runoff infiltration systems that are being developed for an area.

Monitoring Stormwater Infiltration for Groundwater Pollution

A key component of a technically valid urban area and highway stormwater runoff infiltration system is the monitoring of the groundwaters that could be impacted by the potential pollutants in the infiltrated stormwater runoff. The groundwater hydrology should be sufficiently well defined so that it is possible to reliably predict the direction and rate of movement of the groundwaters that would first be impacted by the infiltrating stormwater. Wells located both up groundwater gradient and down groundwater gradient of the infiltration trench/basin should be constructed and operated to detect any pollution of the groundwater system near where the infiltrating stormwater mixes with the upper part of the aquifer underlying the area where infiltration occurs. This monitoring should involve sampling of these wells following procedures that are typically used for municipal solid waste landfills. The sampling should focus on detecting increases in the conventional pollutants in the near groundwater table surface down groundwater gradient wells. While many of the Priority Pollutants are not expected to be present in typical urban area and highway stormwater runoff, stormwater infiltration trenches/basins have been found to be polluted by the deliberate illicit discharge of waste materials into the basins. Pitt and Field (1990) have summarized problems of this type.

The Santa Clara Valley Water District, Santa Clara, CA (James, 1998) has experienced a number of instances where waste materials were discharged to drywells or stormwater retention ponds which led to groundwater pollution. The Santa Clara Valley Water District has developed a wellhead protection program that includes detecting potential problems with waste disposal in stormwater runoff infiltration drywells. It is, therefore, important to establish appropriate fencing to restrict access to the stormwater infiltration trenches/basins and to monitor the groundwaters that could be impacted by the recharge basin illicitly receiving waste materials. At least once a year, samples of the near watertable groundwater immediately downgradient from the infiltration basin should be analyzed for the complete suite of Priority Pollutants to be certain that groundwater pollution by potentially hazardous chemicals on the Priority Pollutant list is not occurring.

One of the problems of monitoring groundwater pollution near stormwater infiltration trenches/basins is the intermittent nature of the infiltration of pollutants to the underlying groundwater system associated with stormwater runoff events. This situation results in pulses of potential pollutants in the groundwater system associated with each runoff event. There will be periods between when the rainfall/groundwater infiltration occurs where the groundwaters underlying the infiltration system will receive no or limited amounts of potential pollutants from the overlying vadose zone. This will result in potential pollution plumes of stormwater-derived constituents that, near the point of infiltration, have low concentrations of infiltrated stormwater-derived constituents between pulses of higher concentrations of constituents associated with stormwater infiltration. Conventional quarterly groundwater quality monitoring such as that used at municipal landfills could encounter some of the between stormwater recharge event areas in the pollution plume, and therefore lead to an erroneous conclusion that groundwater pollution was not occurring due to stormwater infiltration. It is, therefore, recommended that the monitoring of the near water table groundwaters just down groundwater gradient from the infiltration point be designed to intercept the pulses of potential pollutants that will reach the monitoring point associated with stormwater infiltration. This will require that a fairly detailed understanding of transport through the vadose zone and within the groundwater system underlying the point of infiltration to the point of monitoring be developed, that includes not only worst-case and average transport rates, but also the potential attenuation/dilution and dispersion/mixing that occurs. It is likely that monitoring frequencies on the order of monthly intervals will be needed at many sites where stormwater infiltration is a potential viable option for a stormwater quality management BMP.

Eventually it may be possible, after a period of several years of frequent monitoring, after the stormwater infiltration plume has reached the monitoring point and no problems are detected, to reduce the frequency of monitoring to bi-monthly or even quarterly. This should be done only after there is substantial evidence that such a monitoring frequency is appropriate for the characteristics of the aquifer where the stormwater infiltration is occurring. Those responsible for managing the monitoring program should not assume that the failure to detect pollutants, i.e., constituents that impair the use of the groundwater at a particular monitoring point, indicates that groundwater pollution will not occur by the infiltration system. Both the vadose zone and saturated part of the aquifer between the point where infiltration occurs and the location of the monitoring wells will have finite, limited abilities to remove some types of potential pollutants through sorption reactions. Where the mechanism of removal is sorption on aquifer solids, eventually the sorption capacity of the solids will be exceeded and the potential pollutants will move further down gradient from the point of infiltration. Further, it will be necessary to monitor stormwater infiltration systems for a number of years after the termination of their use to insure that yet undetected pollution of the groundwaters by the infiltrated chemicals in the stormwater has not occurred.

In those areas where the groundwater table fluctuates more than a few feet seasonally, it will be necessary to use nested wells screened to various depths to reliably detect the groundwater pollution plume arising from stormwater infiltration that will be present near the groundwater table. This plume will initially be relatively thin in the region of infiltration and therefore, sampling of the near-groundwater table waters is essential to detect this plume. Wells screened for long distances can give erroneous information on the pollution of an infiltration system, since much of the water pumped by those wells could be taken below the infiltrated stormwater pollution plume, and thereby dilute the concentrations of the pollutants in this plume.

If the monitoring detects groundwater pollution by the stormwater runoff infiltration system, then the stormwater runoff infiltration system manager must terminate the use of the infiltration system or pre-treat the stormwater runoff before infiltration to remove those constituents that are causing groundwater pollution. Further, the stormwater runoff water quality manager must start a groundwater/aquifer remediation program, typically involving pump and treat, to stop the spread of the polluted groundwater and to remove, to the extent possible, the pollutants from the groundwater system. This will likely require a very long time and can be quite expensive.

Industrial Commercial Stormwater Infiltration

While the focus of this paper is on the use of stormwater infiltration of urban and highway stormwater runoff as a BMP for stormwater quality management, the issues discussed herein are applicable to commercial and industrial stormwater runoff infiltration systems. In addition to the concerns associated with the typical urban area and highway stormwater runoff causing pollution of groundwaters by the normal constituents in such runoff, there is the potential for waste materials arising from industrial or commercial activities that are placed in on-site stormwater infiltration systems or evaporation ponds to cause groundwater pollution. At this time, industrial stormwater infiltration and waste ponds are not adequately regulated to assure that groundwater pollution by the infiltrated wastes and stormwater runoff will not cause groundwater pollution. While the US EPA (1998a), as part of the Agency's current review of proposed regulations governing Class V industrial/commercial Injection Wells, is proposing to severely restrict the use of such wells for waste disposal, inadequate attention is being given to industrial/commercial stormwater injection wells' potential to pollute groundwaters. In addition to the potential for constituents in industrial/commercial stormwater runoff to cause groundwater pollution, there is considerable appropriate concern about such wells becoming locations for illicit or illegal dumping of industrial/commercial wastes. Site-specific characterization of the chemical and pathogenic organism composition of commercial and industrial stormwater runoff and waste disposal should be conducted following the procedures discussed herein to reliably assess whether constituents in this runoff/waste could cause groundwater pollution.

Class V Injection Wells

Stormwater infiltration systems are part of what the US EPA classifies as Class V Injection Wells. The US EPA (undated) includes 30 individual types of injection wells in this category, which range from simple cesspools to geothermal reinjection wells that may be thousands of feet deep. The Agency is in the process of developing regulatory programs for the control of pollution by Class V Injection Wells. This activity includes the recent issuance of additional proposed regulations governing certain types of Class V Injection Wells. The US EPA (1998a) has issued proposed regulations governing three types of Class V Injection Wells. These include wells located in "community water system source water protection areas" which are used for "motor vehicle waste disposal wells," "industrial wells," and "large-capacity cesspools." These regulations are being promulgated under the 1986 Amendments to the Safe Drinking Water Act. According to the proposed regulations, continued use of these types of wells requires pretreatment of the injected wastes to conform to drinking water MCLs. The Agency is considering additional regulations governing other types of Class V Injection Wells, including stormwater surface and subsurface drainage injection wells. It is possible that within a few years, especially if widespread pollution of groundwaters begins to be found associated with increased use of urban area stormwater runoff infiltration as a BMP for stormwater runoff water quality management, that the Agency will promulgate regulations to protect groundwaters from pollution by infiltrated urban area stormwater.

The US Environmental Protection Agency Office of Groundwater and Drinking Water is collecting information on Class V Injection Wells as part of a consent decree with the Sierra Club vs. Carol M. Browner Civil Action No. 93-2644 NHG, 1997, to determine if additional regulations are needed to protect underground sources of drinking water. One of the areas specifically considered in connection with this consent decree are Class V Injection Wells that are used to infiltrate urban area and highway stormwater runoff. With increased attention being given to regulating the potential surface water impacts associated with NPDES-permitted urban area and highway stormwater runoff, water quality managers will likely consider as a relatively inexpensive alternative to treating surface water discharges of urban area and highway stormwater runoff, the infiltration of the runoff into the local groundwater system. While the number of urban stormwater runoff Class V Injection Wells is unknown, there can be little doubt that this number will increase significantly and that there is need for the US EPA and the states to develop regulations to ensure with a high degree of reliability that the chemical constituents and pathogens present in urban area and highway stormwater runoff do not impair groundwaters for existing or potential use for domestic or other purposes. As discussed herein, there is a significant potential for urban area and highway stormwater runoff to pollute groundwaters, impairing their use for domestic water supplies at certain types of geological settings. The information presented in this paper provides a technical base for developing a comprehensive review of the potential for urban area and highway stormwater runoff to cause groundwater pollution through stormwater infiltration.

Monitoring Aquifer Quality for Build-Up of Pollutants

The ability of some types of aquifer solids to remove constituents from the infiltrating stormwater, and thereby protect groundwater quality, can lead to significant aquifer quality problems, where the aquifer solids underlying the stormwater infiltration trench/basin can build up significant concentrations of hazardous or deleterious chemicals. Lee and Jones-Lee (1995a) have discussed the potential long-term liability issues associated with groundwater recharge-associated constituents caused by the build-up of these constituents within the upper parts of the aquifer near where recharge takes place. Urban area stormwater managers are aware that there can be appreciable build-up of heavy metals and some other constituents in the soil layers of a stormwater infiltration basin. An example of this type of situation is the accumulation of Pb in the surface layer of an infiltration basin to sufficient levels to lead to a contaminated soil surface layer that must be disposed of as a hazardous waste. This situation is of particular concern in California, since originally the Department of Health Services (DHS), now the Department of Toxic Substances Control (DTSC), has developed total concentration limits (TTLC) for concentrations of constituents in soils that become wastes. If the TTLC limit, such as for Pb of 1,000 mg/kg is exceeded, then the soil/waste must be managed as a hazardous waste at costs of $300 to $400 per ton, compared to managing waste soils in municipal landfills at typically $20 to $40 per ton.

While it is fairly easy to detect and manage the build-up of hazardous chemicals in the infiltration basin surface sediments, this build-up can also occur within the vadose zone associated with the lower permeability layer. Both heavy metals and a variety of persistent organics could build-up to a sufficient extent in the unsaturated or saturated part of the aquifer through extended use of a stormwater infiltration trench/basin to create a Superfund-like situation, where the urban area stormwater runoff management agency could become a Responsible Party for clean-up of the aquifer. It is, therefore, important that urban area and highway stormwater runoff management agencies monitor the aquifer system sufficiently reliably to determine the fate/persistence of the potential pollutants that are present in the infiltrated stormwater runoff. A mass balance approach should be used to evaluate the fate of the infiltrated hazardous chemical within the infiltration trench/basin and aquifer system. If the monitoring program reveals that the constituents of potential concern, such as some of the heavy metals and organics, are being removed in the aquifer below the surface layers of the infiltration trench/basin, then a specific sampling program should be initiated to periodically sample the part of the aquifer that is accumulating the materials to ensure that the concentrations of the constituents are not building up to hazardous levels that would cause the area to be considered a Superfund site.

DTSC is in the process of changing its hazardous waste classification approach, which could bring more materials that accumulate in infiltration trench/basin sediments under regulation as a hazardous waste or special hazardous waste than is occurring today. These regulations will likely impact the management of residues that occur in the urban area stormwater infiltration basin sediments. While not considered by DTSC in its existing or proposed regulatory requirements, the accumulation of human pathogens, such as cyst-forming protozoan parasites - *Cryptosporidium*, in the infiltration trench/basin sediments can represent a threat to those cleaning the basins, as well as the management of the sediments removed as part of enhancing infiltration rates as fill where there could be human contact with the fill, or transport of the organisms from the areas where the fill has been deposited to domestic water supplies and/or areas for contact recreation.

Suggested Approach for Developing an Urban Area Stormwater Runoff Infiltration BMP

Jones-Lee and Lee (1998a) provided recommendations on the appropriate development of BMPs for managing urban area and highway stormwater runoff. They recommend that considerable work be done prior to beginning to select any BMP to manage urban area and highway stormwater runoff water quality problems to define the real, significant water quality problems associated with the chemical constituents and pathogen indicator organisms present in the stormwater runoff as they impact the beneficial uses of the receiving waters for the runoff. Their guidance includes the following.

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

- Determine if there is an exceedance of a receiving water water quality standard that is caused by or contributed to by the stormwater runoff.
- Determine if a real water quality use impairment (pollution) of the receiving water is occurring in the receiving waters for the stormwater runoff that is due to constituents in the stormwater runoff.

Evaluate Whether Administrative Exceedance of Water Quality Standards Is Occurring

- If a water quality standard violation occurs without a significant use impairment of the receiving waters, then petition the regulatory agencies for a variance from having to meet water quality standards in the runoff/receiving waters based on there being no use impairment occurring in the receiving waters due to the stormwater runoff-associated constituents.

Determine the Cause of the Pollution and the Source of the Pollutant

- If a water quality use impairment is found in the receiving waters for the stormwater runoff, determine the specific causes of the use impairment and through forensic studies, whether the toxic/available form of the specific constituent(s) responsible for the use impairment is derived from the stormwater runoff of concern.
- Determine if the constituents responsible for the use impairment can be controlled at the source through source control.

Evaluation of the Potential Use of Stormwater Infiltration as a Water Quality BMP

- If it is found that chemical constituents in the urban area and/or highway stormwater runoff are causing real, significant use impairments of the receiving waters for the runoff, then consider whether stormwater infiltration is a viable, cost-effective BMP for managing the water quality problems associated with direct discharge of stormwater runoff to surface waters.
- Conduct the necessary field studies to evaluate the permeability of the area and the physical and chemical character of the aquifer solids and groundwaters into which the stormwater could be infiltrated.
- If the area available for stormwater infiltration has sufficient permeability to infiltrate the stormwater with little possibility of stormwater bypass which could cause violations of water quality standards in the receiving waters for the stormwater runoff due to the constituents in the bypassed water, then evaluate the groundwater hydrology of the aquifer system to determine the direction of flow of the groundwaters that would receive the infiltrated stormwater. Pay particular attention to any existing or potential individual or municipal water supply wells that exist now or could be developed in the future that would intersect the groundwater plume created by the infiltrating stormwater.
- Evaluate the aqueous environmental chemistry of the constituents of concern in the infiltrated groundwaters with respect to their potential transport and transformations through the vadose zone and the saturated aquifer to existing as well as possible water supply wells that could be constructed in the future.
- If the groundwater hydrology is such that within one mile of the infiltration basins, the groundwaters will be discharged to surface water systems, then evaluate the potential for the constituents in the infiltrating stormwater to be present in the groundwater discharged to surface waters at concentrations that could be adverse to aquatic life or other beneficial uses of these waters.
- If it appears that the potential pollutants in the stormwater runoff will not cause water quality problems for domestic water supplies that could be developed on adjacent or nearby properties to the infiltration trench/basin and there are no potentially significant surface water quality problems associated with the discharge of the infiltrated stormwater to surface waters, then proceed with the design and construction of the infiltration trench/basin. It may be necessary to pretreat the stormwater runoff to remove certain constituents before infiltration of the runoff into the groundwater system in order to protect groundwater and aquifer quality.
- Develop and implement water quality and aquifer quality monitoring programs that will assess the build-up of chemical constituents within the surface sediments of the infiltration basin and within the aquifer. Also, monitor the chemicals and pathogens present in the infiltrated water within the near watertable groundwater just downgradient of the infiltration trench/basin and along the path of the plume that will be developed from the infiltrating stormwater mixing with the groundwaters that occurs under the infiltration trench/basin.
- Establish a contingency fund of sufficient magnitude to ensure that funds will be available throughout the life of the infiltration project to address plausible, worst-case failure scenarios of the infiltration system, and pollution of the groundwaters.

Detection of Future Stormwater Runoff Water Quality Problems

- Develop an ongoing monitoring/evaluation program to search for subtle and new water quality use impairment associated with stormwater runoff to nearby surface waters if the stormwater is not completely infiltrated. Also consider subtle and new water quality problems that could develop associated with the infiltration of stormwater runoff-derived constituents into the aquifer system.

Appropriate adoption of this program will provide the necessary information to ensure that any development of a stormwater runoff BMP, including infiltration, will be justified based on direct discharge of the stormwater runoff to surface waters causing significant adverse impacts to the beneficial uses of these waters. It will also ensure that the infiltration of stormwater runoff will not cause significant water quality problems due to the chemical constituents and pathogenic organisms in the infiltrated waters.

Summary

Table 1 presents a summary of the key issues that need to be addressed in reliably evaluating the potential for urban area and highway stormwater runoff associated constituents to cause pollution of groundwaters through stormwater infiltration BMPs.

Table 1

**Developing Urban Stormwater Runoff Water Quality Infiltration Systems:
Issues That Need to be Considered**

Clearly Define the Water Quality Problem(s) Caused by Current Stormwater Runoff to Nearby Surface Water Characteristics of Urban Stormwater Runoff That Require a BMP to Control Water Quality Impacts. Identify the Real Significant Water Quality Use Impairment(s) in the Surface Waters that are Caused by NPDES-Permitted Stormwater Runoff-Associated Constituents that Require the Development of a BMP(s) to Control the Constituent Concentrations in Runoff.

- Is the Water Quality Impairment Due to a Real Use Impairment of Concern to the Public or an "Administrative" Impairment Related to the Application of Worst-Case Based US EPA Water Quality Criteria/Standards to the Runoff?

Evaluate Hydraulic and Economic Feasibility of Stormwater Infiltration

Evaluate the Potential to Infiltrate Stormwater Runoff without Allowing Runoff Bypass that Causes Receiving Water Use Impairment and/or Violations of Water Quality Standards

- Is the Permeability of the Soils/Aquifer in the Area Adequate to Infiltrate the Needed Volumes, and is there Land Available to Infiltrate the Stormwater Runoff and Protect Surface Water Quality from the Bypass of Stormwater Runoff?

Evaluate Groundwater Hydrology and Water Quality Characteristics

Using Plausible Worst-Case Situations for Potential Water Quality Problems Due to Stormwater Infiltration, Evaluate the Potential for Groundwater Pollution and Surface Water Pollution to Occur Due to Stormwater Infiltration

If Stormwater Infiltration is Possible Based on the Vadose and Saturated Zones Hydraulic Characteristics, Determine the Groundwater Hydrology, Water Quality Characteristics and the Existing and Potential Groundwater Use in the Area that Could be Impacted by Stormwater Infiltration.

- Physical Characteristics of Aquifer
  - Groundwater Flow Direction and Velocity (Mean and Maximum)
    - Permeability of Vadose Zone and Saturated Zone
  - Homogeneous Character of Vadose and Saturated Zones
    - Sand/Gravel Lenses - Low Permeability Layers
      - Cracks in Clay Layers
        - Age of Groundwater, to Evaluate Time Associated with Groundwater Recharge
  - Depth to the Water Table
    - Variability of Water Table Depth

Evaluate the Potential for the Chemical Constituents and Human Pathogens in Stormwater Runoff to Pollute the Groundwaters and Surface Waters.

Predict Transport and Fate of Potential Pollutants in the Infiltrated Runoff

If Removal of Potential Pollutants in the Aquifer is Required to Protect Groundwater Quality, Determine How and Where in the Aquifer This Removal Will Occur.

Evaluate whether the Removal of Potential Pollutants Could Lead to Buildup of Hazardous Chemicals that Could Cause the Site to Become a Superfund Site.

Is the Groundwater Potable and Palatable?

Amount of Nearby Use of Groundwater

Potential Future Use of Groundwater

Groundwater Discharge to Surface Waters

Discharge Rate to Surface Waters

How Does Groundwater Enter Surface Waters?

Springs or Seepage Through Sediments

Characteristics of Surface Waters

Sensitive Ecosystem?

Design and Implement Infiltration Project

If the Stormwater Infiltration Project is Found to be Feasible and Cost Effective, Then Proceed with Design and Implementation of the Project.

Develop Infiltration Basin/Trench Groundwater and Aquifer Monitoring Programs that are Designed to Detect Incipient Problems with the Project.

Develop a Contingency Plan with Reliable, Well-Defined Funding Sources to Address all Plausible Worst-Case Scenario Failures of the Project.

Consider the Potential for Significant Aquifer and Groundwater Pollution.

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