# Groundwater Quality Protection Issues

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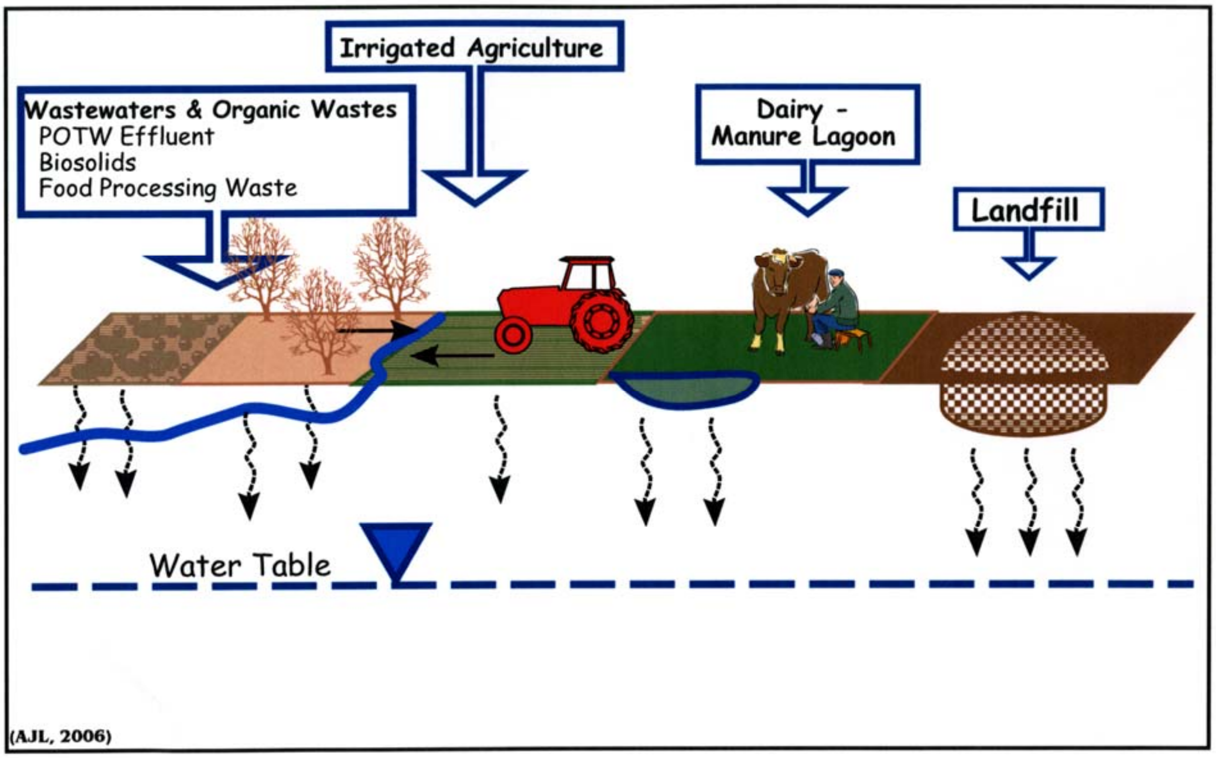


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## Background to Developing This Report

Over the past couple of years we (Drs. G. Fred Lee and Anne Jones-Lee) have observed increased interest on the part of the California Central Valley Regional Water Quality Control Board (CVRWQCB) in developing and implementing regulatory approaches for protection of groundwater from pollution resulting from activities that take place on the land surface. This is a long-standing interest of ours, where for a number of years we have observed that the State and Regional Water Quality Control Boards allow activities on the land surface that will obviously lead to groundwater pollution. Presented herein is a discussion of some of the deficiencies in the approaches that we have observed in regulating situations associated with waste disposal on land, and other activities, such as irrigated agriculture, that can ultimately lead to groundwater pollution.

G. F. Lee's work on improving groundwater quality protection was initiated in 1960 while he held the position of Professor of Water Chemistry and Director of the Water Chemistry Program at the University of Wisconsin, Madison. The Water Chemistry Program was developed by Dr. Lee as a graduate-degree program designed to prepare individuals with a chemistry or chemical engineering background for careers in investigating and managing surface water and groundwater quality.

Beginning in the early 1960s Dr. Lee initiated studies on the role of agricultural activities (row crops, dairies) in a lake's watershed in contributing nutrients to the lake through surface runoff and groundwater discharges to the lake. Also, Dr. Lee became involved in investigating the potential role of municipal solid waste (MSW) landfills as a cause of groundwater pollution. In the 1970s Dr. Lee became involved in US Environmental Protection Agency (EPA)-sponsored research on the ability of various types of landfill and waste lagoon liners to effectively prevent groundwater pollution by waste-derived constituents. In the 1980s Dr. Anne Jones (now Jones-Lee) and he, as part of their university graduate-level teaching and research, worked together on a variety of groundwater pollution issues at various locations in the US and in several other countries. Particular emphasis in their investigations was on protecting groundwaters from pollution that could impair their use as a domestic water supply.

In 1989, when Dr. Lee retired after 30 years of graduate-level teaching and research, he and Dr. Jones-Lee became full-time consultants on surface water and groundwater pollution issues. Through their firm, G. Fred Lee & Associates, they continue this activity today. Throughout Dr. Lee's over-45-year professional career, he has repeatedly encountered situations where regulatory agencies allow activities on the land surface that will cause groundwater pollution by chemicals associated with these activities.

This report presents a summary of Drs. Lee and Jones-Lee's experience in these areas, with references to the literature on groundwater pollution issues and approaches that can be used to minimize/control this pollution. Particular attention is given to the situation in the Central Valley of California, where the authors have lived and worked for the past 17 years.

# Executive Summary

The State Water Resources Control Board (through the Porter-Cologne Water Quality Control Act), as well as the Regional Water Quality Control Boards' Basin Plans, contain explicit requirements that the quality of groundwaters in California be fully protected from pollution/impairment. A critical review of the situation that has occurred over the years and continues to occur today shows that there are a variety of activities that take place on the land surface that have polluted and are continuing to pollute groundwaters. This report provides a summary of a number of the issues that need to be considered in protecting groundwaters from pollution.

In the early 1990s, Dr. Lee initiated efforts with the California-Nevada American Water Works Association and the Association of California Water Agencies to develop committee/ subcommittee activities in improving groundwater quality protection. He found that there was limited interest by members of these organizations in developing approaches that would determine the current degree of groundwater pollution and/or detect incipient groundwater pollution. Because of this situation, Dr. Lee discontinued efforts to have these agencies become involved in these areas.

Also, during the 1990s and early 2000s, Dr. Lee repeatedly found that regulatory agencies (the State and Regional Boards) were not, in general, taking aggressive action to protect groundwaters from pollution from land surface activities such as landfills, dairies and other confined animal facilities, irrigated agriculture, etc. Recently, however, it appears that this situation is changing and that there is a potential to develop more effective approaches for regulating land surface activities that can lead to groundwater pollution.

**Irrigated Agriculture**
Irrigated agriculture is a well-known, long-standing cause of groundwater pollution throughout the state of California. Of particular concern are problems caused by inadequate management of nitrogen compounds (fertilizers) that lead to groundwater pollution by nitrate. Also of concern is the pollution of groundwaters by pesticides, salts derived from utilization/evaporation of irrigation water, etc. The magnitude of groundwater pollution associated with irrigated agriculture is dependent on a variety of factors, such as chemicals/materials applied to the land/crops, soil/aquifer characteristics and water management. While it is not possible to completely stop groundwater pollution by irrigated agriculture while maintaining high crop productivity, there is a potential, through the Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Agricultural Waiver) that the Central Valley Regional Water Quality Control Board will, at some time in the future, develop requirements for irrigated agriculture to minimize groundwater pollution.

The Tulare Lake Basin groundwaters are polluted by TDS, nitrate, several pesticides (including DBCP) and several solvents (including TCE and DCE). These and other chemicals are also causing groundwater pollution in the Sacramento River and San Joaquin River basins.

A key component of minimizing pollution of groundwaters by irrigated agriculture is the development of groundwater monitoring programs to assess current degrees of pollution and the

potential for further pollution before additional pollution occurs. These monitoring programs will need to measure not only the concentrations of pollutants, but also the water flux that is transporting the pollutants to the water table.

One of the most significant groundwater pollution issues in the Central Valley of California is the pollution by salts (salinity). In an effort to begin to control this type of pollution from various sources (such as irrigated agriculture, domestic wastewater disposal on land, etc.), the CVRWQCB has developed and is beginning to implement a "Salinity Policy." This policy focuses on controlling the pollution of groundwaters by salinity and nitrate. A key issue in the development of this policy that will need to be addressed is the approach that is used to manage any salt residues that arise from the evaporation of brines. Previously the US Bureau of Reclamation (USBR) has indicated that conventional landfills could be used for disposal of these brine residues. It is important that the landfilling of any salt residues be conducted in such a way as to preclude pollution of groundwaters by the landfilled salts when the landfill liner systems eventually fail.

There is an urgent need for the CVRWQCB to develop a comprehensive assessment of groundwater quality in the region, to define those parts of the region that are particularly vulnerable to groundwater pollution by various types of land use activities, and to begin to more effectively regulate land use activities that can lead to groundwater pollution than is occurring today.

***DPR's Regulation of Pesticides.*** The California Department of Pesticide Regulation (DPR) is making progress toward regulating pesticide use that leads to groundwater pollution. DPR has developed a probabilistic pesticide transport modeling approach that can predict the potential for a particular pesticide to be transported to groundwaters, based on pesticide and aquifer characteristics. This information is being used as part of DPR's registration of pesticides and their re-evaluation. The California State Water Quality Control Board and the Regional Boards need to develop similar programs for other contaminants that have caused or could cause groundwater pollution.

**SWRCB GAMA**

The California State Water Resources Control Board (SWRCB) is conducting state-legislature-mandated studies of the degree of pollution of the state's groundwaters. This Groundwater Ambient Monitoring and Assessment (GAMA) program is providing information on the pollution of groundwaters that are used for domestic water supply in selected areas of the state. Also, in cooperation with the US Geological Survey (USGS), GAMA is providing an overall assessment of the water quality of the state's groundwater basins (the Statewide Basin Assessment project). The GAMA program also includes special purpose studies by Lawrence Livermore National Laboratories (LLNL) devoted to characterizing the age of groundwaters and conducting special-purpose groundwater pollution studies, such as from dairies and domestic wastewaters. Limited information is available at this time on the results of these studies.

**USGS Groundwater Studies**

The US Geological Survey, as part of its National Water-Quality Assessment (NAWQA) program has been conducting focused studies on groundwater quality in the Central Valley of

California. These studies examine the relationship between land use and underlying groundwater quality. Studies have been conducted in both urban and agricultural areas in the Sacramento and San Joaquin Basins. They have shown that land use activities in these areas are causing groundwater pollution. Of particular concern are fertilizers/nutrients/nitrate, salinity, solvents (VOCs), and pesticides/herbicides.

**DWR Groundwater Program**

The California Department of Water Resources (DWR) has been charged by the legislature to conduct a groundwater resources program. DWR's responsibilities include mapping the state's groundwater basins, keeping well reports that are filed when a well is drilled, assigning well numbers, conducting investigations and collecting groundwater data. DWR is not responsible for protection of groundwater quality or for regulation or management of groundwater. Through the DWR's data collection activities, information is compiled on the water quality characteristics of California's groundwaters. DWR has developed a set of "Findings and Recommendations" for more appropriately managing groundwater resources in the state, which is included in this report.

**California Comparative Risk Project**

In the early 1990s the California Office of Environmental Health Hazard Assessment (OEHHA) conducted the California Comparative Risk Project. One of the conclusions of the Human Health Committee of this Project was that naturally occurring radon and arsenic in some of the state's groundwaters is a significant threat to cause cancer in those who use these waters for domestic purposes.

**Application of Nitrogen-Containing Waste to Land**

One of the methods for managing organic wastes that contain nitrogen compounds (such as food processing wastes, animal manure, domestic wastewaters and sludges [biosolids], etc.) is through land application. Typically, attempts are made to apply these types of organic wastes at so-called "agronomic rates," where the nitrogen in the wastes is applied to the soil at loading rates approximately equal to the expected plant uptake of nitrogen for crop growth. It has been found, however, that, while this approach, if properly applied, can be successful for inorganic forms of nitrogen (such as ammonia and nitrate), preventing pollution of groundwaters and surface waters by nitrate derived from organic wastes is difficult because of the slow rates of mineralization of the organic wastes.

High-nitrogen wastes, such as from dairies, confined animal facilities, etc., are often managed through storing the liquid parts of these wastes in clay-lined or plastic sheeting lined lagoons. Studies have shown that plastic sheeting (HDPE) liners in waste lagoons can deteriorate rapidly – within a few years of installation. The CVRWQCB requires that groundwater monitoring wells upgradient and downgradient from the lagoons be developed. The regulatory agencies typically ignore the fact that the initial leakage from plastic sheeting lined lagoons will occur through limited areas of deterioration of the plastic sheeting, with the result that finger-like plumes of polluted groundwaters will be generated that will have limited lateral dimensions. This can result in a situation where considerable groundwater pollution can occur through leakage through the lagoon liner that is not being detected by the downgradient groundwater monitoring well(s). A double composite lined lagoon, where there is a leak detection system between the two composite liners, can be used to determine when the upper composite liner fails and there is need to repair the plastic sheeting layer in this liner.

The development of groundwater monitoring wells associated with waste lagoons and other waste management units that have the potential to pollute groundwaters requires consideration of a variety of factors, such as the depth of well screens, position and movement of the water table from summer to winter, density of the waste relative to groundwater, etc., in order to achieve a reliable groundwater monitoring system that can detect initial pollution by the waste management unit.

**Vadose Zone Transport of Pollutants**

With few exceptions, the pollution of groundwaters is associated with vadose zone (unsaturated zone) transport of pollutants from the soil surface/root zone to the water table. There are a variety of factors that influence the rate of transport of pollutants through the vadose zone, including the moisture content of the unsaturated part of the aquifer, and preferential pathways. Problems exist with regulatory agencies allowing inappropriate assumptions in modeling vadose zone transport of pollutants, in which average annual moisture content is sometimes used rather than the potential for wetted front transport following rainfall events. Also, this modeling typically ignores preferential pathways for rapid transport of pollutants through the vadose zone. The net result is that models based on average moisture content and the lack of preferential pathways can greatly underestimate the rate of movement of pollutants through the vadose zone to the water table.

There is need to evaluate the potential for properly conducted vadose zone monitoring to assist in evaluating whether pollutants in the root zone are being transported in sufficient quantities to cause groundwater pollution. Consideration will need to be given to wetted-front and preferential pathway transport in assessing the magnitude of transport of pollutants through the vadose zone to the water table, as well as the mixing of the percolating water with the upper area of the saturated part of the aquifer.

**Monitoring of Lined Waste Management Units**

Several types of waste management units, such as lagoons/ponds, landfills, etc., utilize plastic sheeting (HDPE) liners. Some regulatory agencies fail to understand and properly prepare for the eventual failure of the plastic sheeting to serve as an effective barrier to waste transport through it. Frequently, one upgradient and one or two downgradient monitoring wells will be used to try to detect when such failure occurs. However, a critical review of how failure of plastic sheeting liners will occur shows that limited areas of deterioration, cracks, punctures, etc., will be the initial areas of leakage. Such discrete points of failure can lead to groundwater pollution plumes of limited lateral dimensions, which could readily pass by the downgradient monitoring wells without being detected by them. In order to reliably monitor plastic sheeting lined waste management unit failure, it is necessary to construct a double composite lined system (two liners, each consisting of plastic sheeting and underlying clay), with a leak detection system between the two composite liners. This approach has a high probability of determining when the upper liner system fails.

**MSW Landfilling**

Municipal and industrial solid waste landfills are well-known causes of groundwater pollution near the landfill. Groundwater pollution plumes extending for several miles from the landfill have been found. In the mid-1980s, the SWRCB adopted potentially highly effective landfill design requirements (Chapter 15 of the California Code of Regulations, which is now called Title 27) that could, if adequately implemented, control the pollution of groundwaters by landfill leachate. These regulations require that the Regional Boards, as part of permitting a solid waste landfill, conduct a site-specific evaluation of the liner system needed to comply with the regulatory requirements of protecting groundwater quality from pollution by landfill leachate for as long as the wastes in the landfill would be a threat. In "dry tomb"-type landfills of the type mandated by the US Congress in the 1980s, where the wastes in a landfill are to be isolated from moisture that can generate leachate and landfill gas, the wastes will be a threat effectively forever.

***Inappropriate Implementation of Chapter 15 Regulations.*** As part of implementing Chapter 15, the Regional Water Quality Control Boards assumed that the minimum design requirement specified in Chapter 15 (the 1984 regulations) of a one-foot-thick soil (clay) liner with a permeability no greater than $10^{-6}$ cm/sec would comply with the groundwater quality performance standard of protecting groundwaters from pollution by landfill leachate for as long as the wastes in the landfill would be a threat. A simple Darcy's Law calculation would have shown that this is a technically invalid assumption, since one foot of clay with a permeability of $10^{-6}$ cm/sec will be penetrated within a few months. Solid Waste Assessment Test (SWAT) studies by the SWRCB conducted in the late 1980s found that clay-lined and unlined landfills were polluting groundwaters to about the same extent, confirming the conclusion based on the Darcy's Law calculation.

With the US EPA adoption of Subtitle D regulations in the early 1990s, which specify that the minimum landfill liner design is a single composite liner consisting of an HDPE plastic sheeting liner and two feet of compacted clay with a maximum permeability of $10^{-7}$ cm/sec, California was required to upgrade its minimum landfill liner design requirements to those of Subtitle D. At the time of adoption, the US EPA acknowledged that a single composite liner would eventually fail to prevent groundwater pollution by landfill leachate, associated with the deterioration of the plastic sheeting in the landfill liner. However, the US EPA was under pressure from environmental groups to promulgate municipal landfill regulations in accord with the deadline established by the US Congress. In order to avoid the political consequences of increasing the cost of municipal solid waste management, the Executive Branch of the federal government opted for the US EPA's adoption of a single composite liner, knowing that it would not be protective over the long term. The California SWRCB's adoption of the single composite liner minimum design led to the Regional Boards' ignoring the fact that such a liner system would not be expected to comply with the regulatory requirements of meeting the performance standard of protection of groundwater from pollution by landfill leachate.

The Regional Boards also failed, and continue to fail, to properly evaluate the reliability of groundwater monitoring using monitoring wells at the point of compliance spaced hundreds of feet apart to detect groundwater pollution by landfill leachate when it first reaches the point of compliance. The net result is that the municipal solid waste landfills that have been developed since the early 1990s that comply with minimum Subtitle D design requirements will, at some time in the future, pollute groundwaters by landfill leachate, which will likely first be detected in offsite property production wells.

Beginning in the mid-1990s, after the SWRCB adopted US EPA Subtitle D minimum landfill liner design requirements for the landfilling of MSW, Drs. Lee and Jones-Lee initiated efforts to get the CVRWQCB and the SWRCB to address the fundamental problem of a minimum design Subtitle D landfill not being able to conform to Chapter 15 requirements of protecting groundwaters from pollution by landfill leachate for as long as the wastes in the landfill will be a threat. It is understood that in a "dry tomb"-type landfill, many of the MSW waste components will be a threat, effectively forever, to produce landfill gas and leachate when contacted by water.

***University of California, Davis, Landfills.*** The focus of Drs. Lee and Jones-Lee's efforts in this regard was the University of California, Davis, proposed development of campus landfill number five. This landfill was to be another campus landfill located near campus landfill number four. Campus landfills numbers one through four were at that time known to be polluting groundwaters with a variety of constituents derived from the UCD campus. Drs. Lee and Jones-Lee found that the CVRWQCB and the SWRCB were unwilling to review the potential for the proposed landfill number five to also eventually cause groundwater pollution.

It was further learned that the State Board staff had issued a memorandum to the Regional Boards, without public review, indicating that the minimum design Subtitle D landfill, by definition, complied with Chapter 15 requirements of protecting groundwaters from landfill leachate for as long as the wastes in the landfill would be a threat. The public was not given an opportunity to review this policy adopted by the SWRCB. As Dr. Lee documented in his presentations to the Boards, this politically developed policy was obviously technically invalid. However, the politics of this situation were dominated by landfill owners/operators and others who did not want to increase the cost of MSW management by requiring a double composite lined system and groundwater monitoring that would be highly protective of groundwater quality and have the potential of conforming to the state's regulatory requirements of protecting groundwaters from landfilled wastes. Drs. Lee and Jones-Lee found, after repeated efforts, that neither the State Board nor the CVRWQCB was willing to adequately and reliably consider the deficiencies in the minimum design Subtitle D landfill in complying with the Chapter 15 (now Title 27) groundwater protection standard of no impaired use of groundwaters for as long as the wastes are a threat.

Recently, several of the California Regional Boards have, on their own initiative, begun to require that some of the new landfills, including part of the UCD landfill number five expansion, contain a double composite liner. Unfortunately, all of the landfills permitted in California with a single composite liner and groundwater monitoring based on vertical monitoring wells spaced hundreds of feet apart at the point of compliance will ultimately pollute groundwaters with landfill leachate.

***Azusa Landfill Pollution Issues.*** The pollution of groundwaters by the Azusa Landfill in the San Gabriel Basin is an example of where Regional Board politics has played a major role in the

Regional Board's failing to enforce regulations governing the pollution of groundwaters by landfill leachate. For years during the 1990s the Los Angeles Regional Water Quality Control Board ignored the existing pollution of groundwaters by the Azusa Landfill. Ultimately the US EPA declared that the Azusa Landfill was part of the San Gabriel Basin Superfund site, and required that action be taken to clean up the polluted groundwaters.

***Leachate Recycle.*** There are two processes that govern the potential for municipal solid waste to pollute the environment. One of these is the bacterial fermentation of some of the organic components of the MSW, to produce landfill gas (methane and carbon dioxide), which can cause explosions in offsite structures, and contains a variety of hazardous VOCs and odorous compounds. The other is the leaching of chemicals from the wastes, to produce leachate. Both fermentation and leaching are dependent on the moisture content of the wastes. It has been found that the addition of water (or leachate) to an MSW landfill could greatly increase the rate of landfill gas production and thereby shorten the time that the landfill would be a threat through gas production to nearby property owners/users. In the 1980s there was interest in exploring leachate recycle as a means of "stabilizing" MSW landfills. However, at that time, several states (such as New Jersey) banned leachate recycle, because the increased hydraulic loading to the landfill could lead to increased groundwater pollution by landfill leachate.

In the mid-1980s Dr. Lee and his associates conducted studies on the potential benefits and problems of practicing leachate recycle at US Army military base MSW landfills. They reported that leachate recycle would shorten the time that landfill gas would be produced and thereby help "stabilize" the landfill. They also pointed out that leachate recycle could lead to increased groundwater pollution.

In the early 1990s Lee and Jones-Lee discussed how leachate recycle could be practiced to reduce the time for landfill gas production, without leading to potentially increased groundwater pollution. This approach required that the solid wastes be shredded and placed in a double composite lined landfill with a leak detection system between the two composite liners. Landfill leachate would be introduced into the landfill until such time as gas production had essentially ceased. At that time clean water would be added to the landfill to leach any residual pollutants in the wastes. The leachate produced in the clean-water washing would not be recycled, but would be treated offsite. This approach could produce a stable, fermented and leached landfill waste residue that represented little threat to public health and the environment.

***Heavy Metals.*** Heavy metals present in municipal solid waste landfill leachate have the potential to pollute groundwaters, rendering them unusable for domestic and some other water supply purposes. The increase in electronic wastes deposited in the municipal solid waste stream has raised concern as to whether the electronics could contribute heavy metals to MSW landfill leachate that would increase the potential for heavy metals in the leachate to cause groundwater pollution. In 2004 the Solid Waste Association of North America (SWANA) released a report claiming that heavy metals in MSW landfill leachate do not represent a threat to cause groundwater pollution. However, the technical basis for this conclusion was flawed. There are situations where heavy metals in MSW leachate can, for some aquifer systems, cause groundwater pollution. In some MSW landfills, the lead concentrations in leachate are sufficient so that it can be a cause of groundwater pollution, in those situations where the hydrogeology of the aquifer underlying the landfill allows the transport of leachate with little or no attenuation of lead and other pollutants.

**Fractured Rock Aquifer Systems**

Some municipal solid waste and hazardous waste landfills, as well as other waste management units, are sited above fractured rock/clay aquifer systems. This situation can readily lead to an inability to reliably monitor the groundwater for pollution by the inevitable landfill liner deterioration. Fractured rock aquifer systems can, therefore, represent a significant potential for landfill leachate to pollute offsite groundwaters with hazardous and deleterious chemicals. There are legitimate questions about whether minimum design Subtitle D single composite lined landfills should be allowed to be sited above fractured rock aquifer systems. This report provides a summary of G. F. Lee and A. Jones-Lee's studies over the years on landfills situated above fractured rock aquifer systems, with references to the literature for further information on each of theses situations.

**Construction and Demolition Wastes**

Increasing attention is being given to the potential for the disposal of construction and demolition (C&D) wastes to be a cause of groundwater pollution. While it is sometimes assumed by state and local regulatory agencies that such wastes are "inert," several studies have shown that such an assumption is inappropriate. C&D wastes have a significant potential to pollute groundwaters with a variety of hazardous and deleterious chemicals, and therefore should be managed in a double composite lined landfill with a leak detection system between the two composite liners.

**Enhanced Groundwater Recharge**

With ever-increasing water demand in California associated with increased population, there is need to develop additional storage of surplus winter/spring surface water runoff. Because of the difficulties in developing new reservoirs for surface storage of water, increasing attention is being given to storing surplus runoff waters in the unsaturated part of aquifers. Enhanced groundwater recharge, through infiltration or injection (aquifer storage and recovery [ASR]) is receiving increased attention by the state regulatory agencies and others. An issue of particular concern in the Central Valley is the injection of treated domestic water supplies into an aquifer as part of an ASR project. The current California Department of Health Services position that a treated domestic water that meets MCLs is appropriate for groundwater recharge in an ASR project is shortsighted and technically invalid. It is now becoming understood that there are chemicals (such as TOC, trihalomethanes and others) present in treated domestic wastewaters which meet current drinking water maximum contaminant levels that can have an adverse impact on the quality of water recovered, as well as on the long-term ability of the aquifer to function effectively in an ASR project.

There are situations where surface waterbodies incidentally recharge groundwaters. This recharge can lead to groundwater pollution by constituents in the surface waters. All National Pollutant Discharge Elimination System (NPDES) permits issued for wastewater discharges should include an evaluation of the potential for chemicals in the wastewater discharge to pollute groundwaters through incidental groundwater recharge.

**Stormwater Infiltration and Injection Wells**

The development of urban area and highway stormwater runoff infiltration systems as a means of controlling the pollution of surface waters by stormwater runoff-associated pollutants is being used as a best management practice (BMP) for stormwater water quality management. This approach, however, has the potential to cause groundwater pollution. It is essential that all stormwater infiltration systems be reliably monitored to determine if they are causing groundwater pollution.

The US EPA has the responsibility of regulating Class V shallow groundwater injection wells. These types of wells are used in some areas to inject waters that can contain pollutants into an aquifer. At this time the US EPA does not require adequate monitoring of the groundwaters receiving Class V injection well waters.

**Deep Well Injection**

Deep well injection of wastewaters can cause groundwater pollution. While current regulatory approaches are somewhat improved in protecting groundwater from near-term pollution by the injected wastewaters, there are potential long-term problems that can occur where the injected wastewaters pollute groundwaters when the injection containment system no longer maintains its protective character.

**Septic Tanks**

Septic tank wastewater disposal systems are a well-known cause of groundwater pollution. A properly working septic tank system that is not causing pollution of the land surface through surfacing of septic tank effluent is likely, for many situations, to be polluting groundwaters. This pollution can represent an isolated situation in areas of low residential development, although even there, an individual residential well can be polluted by the household septic tank. In areas of intense residential development, large-scale pollution of groundwater can occur.

**Shallow Groundwater and Surface Water Interaction**

There are numerous examples in the Central Valley and elsewhere where there is a fairly close coupling between waste disposal on land, such as domestic wastewaters, and polluted shallow groundwater that, near the area of wastewater disposal, discharges to surface waters, thereby causing surface water pollution. At this time there is inadequate regulation of this type of situation in the Central Valley and elsewhere.

An example of close interaction between shallow groundwater and surface water occurs in the Lake Tahoe watershed, where it has been found that fertilization of lawns, golf courses, etc., near the lake leads to the discharge of nitrogen and phosphorus to the lake through groundwater transport. Further, shallow groundwaters polluted by formerly used septic tank systems in the lake's watershed can be a source of nutrients for the lake.

**Dust Suppressants**

Increasing attention is being given to controlling dust from dirt roads and areas of development. A variety of chemicals, including some wastes, are being used as dust suppressants. Some of these chemicals have the potential to cause surface water and groundwater pollution. This report provides guidance to the literature on how to evaluate dust suppressant chemicals for their potential to cause surface water and/or groundwater pollution.

**Unrecognized Pollutants**

The current US EPA and state regulatory agency approach for regulating water quality focuses on about 100 "Priority Pollutants" and a variety of conventional pollutants. There are over 22 million known chemicals, with over 6 million in commercial production. The current regulatory approach is significantly deficient in evaluating the potential for the vast arena of chemicals that can be present in surface waters and groundwaters to cause pollution/impairment of these waters.

A group of chemicals that is receiving increasing attention are the pharmaceuticals and personal care products (PPCPs) that are discharged in wastewaters and deposited in the municipal solid waste stream. These chemicals are also present in confined animal facilities (such as dairies, feedlots, poultry farms, etc.). A number of these chemicals are being found in surface waters and groundwaters at concentrations that are a potential threat to the use of these waters as a domestic water supply and to aquatic life. At this time, these chemicals are not regulated as potential water pollutants. They are part of the unregulated chemicals that are a threat to surface water and groundwater quality. Attention is now being given to determining the presence of PPCPs in various wastewaters and solid wastes, as well as in surface waters and groundwaters. Ultimately, information will be developed on the need to regulate these types of chemicals to protect water quality.

A variety of unregulated chemicals that have been present in surface waters and groundwaters that have the potential to be adverse to human health and the environment are now being found. An example of this type of chemical is perchlorate. Perchlorate is an unregulated and unmonitored chemical that has been discharged to the environment from rocket-testing and chemical manufacturing facilities. Several of these facilities have caused widespread surface water and groundwater pollution that is a threat to human health. The presence of perchlorate in surface waters and groundwaters is not new. It has been present at potentially significant concentrations for many years. However, the limited-scope monitoring programs required by the US EPA and state regulatory agencies did not include examination of the waters for perchlorate, even though it was known to be used in large amounts in some areas. While perchlorate is beginning to be monitored for and regulated, it is an example of just one of the vast arena of potential pollutants in surface waters and groundwaters that are not being adequately investigated, monitored for and regulated.

Areas that contain TOC/DOC in groundwaters near waste disposal areas that have received complex mixtures of wastes are areas that could readily contain unrecognized pollutants. Situations of this type should be recognized as areas that may need further remediation as the components of the TOC/DOC are identified in future studies.

**Sealing of Wells**

Abandoned wells and existing wells are often sealed from surface water infiltration and between aquifer layers traversed by the well with cement or bentonite clay. Both cement and bentonite clay seals have tendencies to crack and thereby allow water transfer through them. Of particular concern is the use of sodium bentonite as a well seal in a high-calcium-magnesium water. The calcium and magnesium will substitute for sodium on the bentonite clay lattice, causing it to shrink and crack. It is important to recognize that there are potentially significant long-term problems associated with the sealing of water wells, due to cracking of the seals.

**Chlorinated Solvents**

Since the 1970s it has been found that chlorinated solvents (such as chloroform, TCE, PCE, etc.) and other solvents are widespread pollutants of groundwaters. These chemicals tend to be highly mobile and persistent in groundwater systems. They are of water quality concern since many of them are known or are suspected to be carcinogens. A discussion is presented in this report of the pollution of groundwaters by solvents, and some of the sources of this pollution.

At one time it was thought that chlorinated solvents could cause clay liners used in waste disposal lagoons and landfills to crack due to dehydration of the packed clay. It has been shown, however, that chlorinated solvents with even small amounts of water associated with them do not cause cracking of clay layers.

The Sacramento Rail Yard Site located in downtown Sacramento is an example of a local groundwater pollution problem by TCE. As part of maintenance of locomotives and rail cars, the Southern Pacific Transportation Company used TCE for degreasing of the parts. The waste TCE was allowed to be disposed of in a pit, which polluted groundwaters. Associated with the TCE was the pollution of these same groundwaters by organics. This combination led to the bacterial dehalogenation of TCE to form vinyl chloride. An extensive TCE vinyl chloride plume was developed that is now being remediated by pump-and-treat of the plume and extraction at the source.

Nationally, TCE is one of the most common groundwater pollutants, especially at Superfund and other hazardous chemical sites. A recent National Academy of Sciences report indicates that the current US EPA maximum contaminant level (MCL) for TCE may not be protective and therefore may need to be lowered. Should this occur, even more Superfund and hazardous chemical sites will be found to need remediation.

**Underground and Aboveground Leaking Tanks and Spills**

Leaks from underground storage tanks have caused localized groundwater pollution in many areas. While the initial focus of leaking tanks was on liquid leaks, today vapor leaks from the tanks are also causing pollution. Of particular concern is the storage of fuel, such as gasoline. Initially, the leakage from gasoline storage tanks was focused on BTX compounds; however, subsequently it was found that MTBE was polluting groundwaters. MTBE is more persistent, and therefore travels further, than BTX compounds. MTBE is a common pollutant of groundwaters in several areas of the Central Valley and the state.

**Natural Attenuation**

In a number of groundwater pollution situations, those responsible advocate that natural attenuation, through dilution and transformation, be allowed as a means of remediation of the pollution. It is important in adopting this approach to conduct comprehensive monitoring for the pollutants, other pollutants that may be present, and their transformation products, in assessing whether natural attenuation is a reliable approach for remediating polluted groundwaters.

**Protection of All Aspects of Groundwater Quality**

There is a problem with some regulatory agencies at the federal, state and local levels focusing investigation and remediation of polluted groundwaters on “Priority Pollutants” or on only some of the pollutants that would impair the waters for domestic and other purposes. At some Superfund sites, the US EPA and the states allow remediation of the Priority Pollutants but do not address (remediate) other pollutants, such as compounds that cause tastes and odors in domestic water supplies associated with a hazardous chemical site remediation. This leads to situations where, after spending many millions of dollars removing Priority Pollutants in a groundwater, the groundwater is still not usable for domestic and some other purposes.

**Overall**

Groundwater pollution in the Central Valley of California and elsewhere is a highly significant problem that is not being adequately controlled by regulatory agencies, such as the State and Regional Water Quality Control Boards. There is an urgent need to fully implement the groundwater protection requirements of Porter-Cologne, to control all land surface activities that can lead to groundwater pollution. A key component of this program will be reliable, comprehensive monitoring of the potential for groundwater pollution to occur, which is implemented in such a way as to detect incipient pollution before widespread pollution occurs.

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## Acronyms and Abbreviations

| | |
|---|---|
| ACT | Agricultural Chemicals and Transport |
| ACWA | Association of California Water Agencies |
| AGUA | El Pueblo para el Aire y Agua Limpio (Kettleman City, California) |
| ASCE | American Society of Civil Engineers |
| ASR | aquifer storage and recovery |
| AWWA | American Water Works Association |
| BFI | Browning-Ferris Industries |
| BMP | best management practice |
| BTX | benzene, toluene, and xylene |
| C&D | construction and demolition |
| CAFs | confined animal facilities |
| $CCl_4$ | carbon tetrachloride |
| CEQA | California Environmental Quality Act |
| $CHCl_3$ | chloroform |
| CIWMB | California Integrated Waste Management Board |
| COCs | constituents of concern (in Superfund site investigation and remediation) |
| CRPE | Center on Race Poverty and the Environment |
| CVRWQCB | California Regional Water Quality Control Board, Central Valley Region |
| DBCP | 1,2-dibromo-3-chloropropane |
| DCE | dichloroethane |
| DOC | dissolved organic carbon |
| DOE | United States Department of Energy |
| DPR | California Department of Pesticide Regulation |
| DSCSOC | Davis South Campus Superfund Oversight Committee |
| DTSC | California Department of Toxic Substances Control |
| DWR | California Department of Water Resources |
| EC | electrical conductivity |
| EDB | ethylene dibromide |
| FLUTe | Flexible Liner Underground Technologies |
| GAMA | Groundwater Ambient Monitoring and Assessment |
| GEIMS | Geographic Environmental Information Management System |
| GIS | geographical information system |
| GWPA | groundwater protection area |
| HDPE | high density polyethylene |
| HHC | Human Health Committee (of the California Comparative Risk Project) |
| $K_d$ | sorption/desorption distribution coefficient |
| LDEQ | Louisiana Department of Environmental Quality |
| LEHR | Laboratory for Energy-related Health Research |
| LLNL | Lawrence Livermore National Laboratory |
| MCLs | maximum contaminant levels (for protection of drinking water) |
| MSW | municipal solid waste |
| MTBE | methyl tertiary butyl ether (gasoline additive) |
| N | nitrogen |
| NAS | National Academy of Sciences |

## Acronyms and Abbreviations (continued)

| | |
|---|---|
| NAWQA | National Water-Quality Assessment |
| NPDES | National Pollutant Discharge Elimination System |
| OECD | Organization for Economic Cooperation and Development |
| OEHHA | California Office of Environmental Health Hazard Assessment |
| OMB | United States Office of Manpower and Budget |
| PAHs | polycyclic aromatic hydrocarbons |
| PCBs | polychlorinated biphenyls |
| PCE | perchloroethylene |
| PCPA | Pesticide Contamination Prevention Act |
| PMZ | pesticide management zone |
| POTWs | publicly owned treatment works (municipal wastewater treatment plants) |
| PPCPs | pharmaceuticals and personal care products |
| RI/FS | remedial investigation/feasibility study |
| SAIC | Science Applications International Corporation |
| SNV | Specific Numerical Values procedure |
| SP | Southern Pacific |
| SQO | sediment quality objectives |
| SWANA | Solid Waste Association of North America |
| SWAT | Solid Waste Assessment Test |
| SWRCB | California State Water Resources Control Board |
| SYRCL | South Yuba River Citizens League |
| TAG | US EPA Technical Assistance Grant |
| TANC | Transport of Anthropogenic and Natural Contaminants |
| TCE | trichloroethylene |
| TCLP | Toxicity Characteristic Leaching Procedure |
| TDS | total dissolved solids |
| THMs | trihalomethanes |
| TMDL | total maximum daily load |
| TOC | total organic carbon |
| UCD | University of California, Davis |
| US | United States |
| US EPA | United States Environmental Protection Agency |
| USGS | US Geological Survey |
| VOCs | volatile organic compounds |
| WERF | Water Environment Research Foundation |

# Groundwater Quality Protection Issues

## California Requirements for Groundwater Quality Protection

In California, the State Water Resources Control Board (SWRCB), through its Regional Boards, develops approaches to implement the legislature's water quality management regulations. The Porter-Cologne Water Quality Control Act (SWRCB 2006), Division 7, Chapter 1, section 13000, states,

> *"The Legislature finds and declares that the people of the state have a primary interest in the conservation, control, and utilization of the water resources of the state, and that the quality of all the waters of the state shall be protected for use and enjoyment by the people of the state."*

Chapter 2, section 13050, paragraph (e) defines "waters of the state" as *"any water, surface or underground, including saline waters, within the boundaries of the state."*

Porter-Cologne requirements are implemented through the Regional Boards' Basin Plans. These plans establish the water quality standards and other regulations governing water quality protection in the Region. For the Central Valley Regional Water Quality Control Board (CVRWQCB) the Basin Plans are available online at
http://www.waterboards.ca.gov/centralvalley/water_issues/basin_plans/index.shtml.

The CVRWQCB (1998) Basin Plan, in Chapter III Water Quality Objectives, on page III-10.00 under the section entitled, "Water Quality Objectives for Ground Waters," states, *"Ground waters shall not contain chemical constituents in concentrations that adversely affect beneficial uses."* Beneficial uses are defined in Chapter II of the Basin Plan, where it states on page II-3.00 under "Ground Water,"

> *"Unless otherwise designated by the Regional Water Board, all ground waters in the Region are considered as suitable or potentially suitable, at a minimum, for municipal and domestic water supply (MUN), agricultural supply (AGR), industrial service supply (IND), and industrial process supply (PRO)."*

Further, on page III-2.00 of the Basin Plan, it is stated that,

> *"Chief among the State Water Board's policies for water quality control is State Water Board Resolution No. 68-16 (Statement of Policy with Respect to Maintaining High Quality of Waters in California). It requires that wherever the existing quality of surface or ground waters is better than the objectives established for those waters in a basin plan, the existing quality will be maintained unless as otherwise provided by Resolution No. 68-16 or any revisions thereto."*

Chapter IV of the Basin Plan, under the section on "Water Quality Concerns," states,

> *"A variety of historic and ongoing point and non-point industrial, urban, and agricultural activities degrade the quality of ground water. Discharges to ground water*

*associated with these activities include industrial and agricultural chemical use and spills; underground and above ground tank and sump leaks; landfill leachate and gas releases; septic tank failures; improper animal waste management; and chemical seepage via shallow drainage wells and abandoned wells. The resulting impacts on ground water quality from these discharges are often long-term and costly to treat or remediate. Consequently, as discharges are identified, containment and cleanup of source areas and plumes must be undertaken as quickly as possible. Furthermore, activities that may potentially impact ground water must be managed to ensure that ground water quality is protected."*

Overall, the State Water Resources Control Board and Central Valley Regional Water Quality Control Board regulations have a long-standing explicit requirement that activities that take place on the land surface not cause pollution of groundwaters. Porter-Cologne defines "Pollution" as *"... an alteration of the quality of the waters of the state by waste to a degree which unreasonably affects either of the following: (A) The waters for beneficial uses. (B) Facilities which serve these beneficial uses."* As discussed herein, the State and Regional Boards have not been adequately implementing the regulatory requirements for protection of groundwater quality.

**Efforts to Improve Groundwater Quality Protection**

In the early to mid-1990s, the authors (Drs. G. Fred Lee and Anne Jones-Lee) made several attempts to develop a statewide, proactive groundwater quality protection strategy in California (Lee and Jones-Lee 1993a). While holding the position of Professor of Water Chemistry and Director of the Water Chemistry Program at the University of Wisconsin, Madison, Dr. Lee was instrumental in having the state of Wisconsin Department of Natural Resources work with the US Geological Survey in developing a statewide groundwater quality monitoring program. Based on G. F. Lee's experience with working on groundwater quality protection in Wisconsin and other states prior to moving back to California in 1989, he attempted, through the California-Nevada American Water Works Association (AWWA) Water Quality Committee, to gain interest by water utilities in establishing a comprehensive groundwater monitoring program. While the utility members agreed with the development of a Groundwater Quality subcommittee, there was no interest on the part of the utility members in actively participating in this subcommittee. Because of this lack of interest Dr. Lee terminated his efforts to develop improved water quality protection through the California-Nevada section of the AWWA.

At about the same time, G. F. Lee became active with the Association of California Water Agencies (ACWA) as a member of the Groundwater Committee, where he was successful in getting this Committee to organize a Groundwater Quality subcommittee, which he chaired. When he suggested to the Groundwater Committee that there was need to develop proactive water quality monitoring to detect incipient groundwater pollution by various types of activities, including irrigated agriculture, waste disposal on land, etc., the Groundwater Quality subcommittee was disbanded by ACWA. It was clear that there was little or no interest by this group in developing a proactive groundwater quality protection program in the state.

The current situation of not controlling groundwater pollution has been known for many years. At the 19th Biennial Conference on Groundwater, organized by the University of California

Water Resources Center, Letey (1994) presented a discussion of issues pertinent to understanding how activities on a land surface (such as waste disposal, irrigated agriculture, etc.) can lead to groundwater pollution. His paper provides important background information to many of the issues that need to be considered in managing irrigated agriculture and waste disposal on land in order to minimize groundwater pollution. The Letey (1994) paper, "Dilemma: Managing Ground Water Quality and Irrigated Agriculture," is appended to this report as Appendix A.

At the same conference, Lee and Jones-Lee (1994a) presented a paper, "An Approach for Improved Ground Water Quality Protection in California," in which they discussed various aspects of land surface activities that lead to groundwater pollution. The discussion presented herein represents an update of their 1994 discussion. It is of interest to find that little if any progress has been made over the past 12 years toward controlling groundwater pollution by irrigated agriculture and waste disposal on land.

**Agricultural Waiver of Waste Discharge Requirements**

In June 2006 the CVRWQCB, as part of the adoption of the extension of the Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Agricultural Waiver), indicated again that agriculture must practice pollutant control to protect both surface water and groundwater. However, while the issue of protection of groundwater was discussed by the Board members at the June hearing (as it had been at previous Agricultural Waiver workshops and hearings), the Board again did not formally adopt an approach designed to implement the regulations for protection of groundwater quality from irrigated agriculture. There is considerable opposition by some agricultural interests to the Board's inclusion of protecting groundwaters from pollution by irrigated agriculture in the Agricultural Waiver requirements for monitoring and management of discharges/releases from irrigated lands. Since the protection of groundwaters is mandated by California water quality regulations (the Porter-Cologne Act – SWRCB 2006), it remains to be seen when and how this requirement will be implemented. Information on the CVRWQCB's Irrigated Lands Program is available at http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/.

***Nitrate Pollution of Groundwaters.*** In 1993 *The Davis Enterprise* (Davis, California, local newspaper) carried a series of three special reports on "The Water We Drink," which included an article by O'Hanlon (1993), "Fertilizer by the Glass." This article discussed the widespread pollution of groundwater in the Davis, California, area by nitrate (ammonia and organic nitrogen sources) used as fertilizer on agricultural fields. This problem occurs in many areas of the state, such as in Dr. Lee's home town of Delano, California, where, from the 1950s through the 1980s, the nitrate concentrations in the groundwater near Delano increased sufficiently so that the water was no longer safe for consumption by infants. This water contained sufficient nitrate to cause methemoglobanemia (blue babies).

The CVRWQCB (1998) Basin Plan, on page IV-2.00, states,

> *"Nitrate and DBCP (1,2-Dibromo-3-chloropropane) levels exceeding the State drinking water standards occur extensively in ground water in the basins and public and domestic*

*supply wells have been closed because of DBCP, EDB, nitrates, and other contaminants in several locations."*

In the subsection entitled "Animal Confinement Operations" under the section on Agriculture, the Basin Plan states on page IV-3.00,

*"Runoff from animal confinement facilities (e.g., stockyards, dairies, poultry ranches) can impair both surface and ground water beneficial uses. The animal wastes may produce significant amounts of coliform, ammonia, nitrate, and TDS contamination. The greatest potential for water quality problems has historically stemmed from the overloading of the facilities' waste containment and treatment ponds during the rainy season and inappropriate application of wastewater and manure."*

The Basin Plan also states on page IV-3.00,

*"The Regional Water Board approaches problems related to irrigated agriculture as it does other categories of problems. Staff are assigned to identify and evaluate beneficial use impairments associated with agricultural discharges. Control actions are developed and implemented as appropriate …"*

However, based on our following CVRWQCB activities over the past 17 years, we have seen no evidence that this approach is being implemented for irrigated agriculture.

Letey (1994) provided a discussion of the issues that need to be understood and managed in order to minimize groundwater pollution by nitrate and other pollutants associated with fertilization of irrigated agricultural lands. Letey (see Appendix A) discusses the dilemma of trying to limit groundwater pollution by nitrate associated with application of nitrogen fertilizers to land, while maximizing crop yield and optimizing irrigation water application. He concludes that, *"Elimination of all pollutant migration from agricultural lands to ground water is technically impossible,"* but provides what he calls *"guiding principles … to reduce ground water degradation potential while maintaining high agricultural productivity."* His "guiding principles" are provided in the attached paper.

Letey (pers. comm., 2006) has brought to the authors' attention the Nitrate Groundwater Pollution Hazard Index developed for Irrigated Agriculture in the Southwest (http://lib.berkeley.edu/WRCA/WRC/wqp_hazard.html). According to this website, the purpose of this index is,

*"To provide information for farmers to voluntarily target resources for management practices that will yield the greatest level of reduced nitrogen contamination potential for groundwater by identifying the fields of highest intrinsic vulnerability.*

*How it Works: The index works with an overlay of soil, crop, and irrigation information. Based on the three components, an overall potential hazard number is assigned and management practices are suggested where necessary."*

Additional information on the details of this index is provided through links on the webpage.

Letey (1994) discussed the use of "Precision Farming" to potentially reduce the groundwater pollution by irrigated agriculture while optimizing crop yield. Precision Farming involves adjusting water and fertilization rates to the specific needs of the soil/crop type in each region of a farm. Letey (pers. comm., 2006) has indicated that, while precision farming can lead to more effective utilization of fertilizers, it can potentially cause greater groundwater pollution. Lee and Jones-Lee (2002) have provided additional information on the use of Precision Farming to reduce surface water and groundwater pollution. This approach, if implemented, can be effective in minimizing groundwater pollution by irrigated agriculture.

Denitrification (conversion of nitrate to nitrogen gas) can be an important mechanism for removal of nitrate in the shallow groundwater, and thereby reduce/prevent groundwater pollution by nitrate. Letey (1994) discussed the conditions that lead to denitrification. Denitrification requires an energy source, such as degradable organic carbon, and low dissolved oxygen in the shallow aquifer. Singleton et al. (2006) recently presented a model describing saturated zone denitrification associated with nitrate derived from dairy waste in the Central Valley of California. Under certain conditions it is possible to significantly reduce the nitrate content of waters migrating from the root zone to groundwater, through denitrification.

***Pollution of Groundwater by Salt.*** One of the major issues that will need to be addressed in managing groundwater pollution by irrigated agriculture is the pollution of groundwaters by salts (total dissolved solids [TDS] as measured by electrical conductivity [EC]) that accumulate in the soils. Letey (1994) has indicated that irrigated agriculture leads to groundwater pollution by salts and other constituents. In addition, the Basin Plan (CVRWQCB 1998) on page IV-2.00 indicates,

> *"Salt management is becoming increasingly important in the San Joaquin Valley for urban and agricultural interests. If current practices for discharging waters containing elevated levels of salt continue unabated, the San Joaquin Valley can have a large portion of its ground water severely degraded within a few decades."*

With increasing CVRWQCB emphasis on control of salt discharges in the San Joaquin River watershed, which lead to excessive salts in surface waters, there could be a tendency to reduce salt flushing from the soils to surface waters, with the result that there will be increased potential for salt migration to groundwaters. The CVRWQCB is developing a salinity management plan. Information on this "Salinity Policy" is available at
http://www.waterboards.ca.gov/centralvalley/water_issues/salinity/index.shtml.

A key issue in the development of this policy that will need to be addressed is the approach that is used to manage any salt residues that arise from the evaporation of brines. Previously USBR (2001) has indicated that conventional landfills could be used for disposal of these brine evaporation residues. It is important that the landfilling of any salt residues be conducted in such a way as to preclude pollution of groundwaters by the landfilled salts when the landfill liner systems eventually fail. It would not be appropriate to attempt to use minimum design single composite lined landfills for brine residue storage because of the eventual failure of the liner system and the inability to detect groundwater pollution before widespread pollution occurs. Lee and Jones-Lee (2008) have provided a discussion of the potential water quality problems associated with landfilling of wastes in a minimum design Subtitle D landfill. As discussed, the liner systems allowed in this type of landfill will eventually fail to prevent migration of waste components in leachate, including salts, to groundwaters.

***Water Quality Monitoring.*** A key component of implementing the Agricultural Waiver requirements for protection of groundwater from pollution by irrigated agriculture is the development of monitoring programs that can assess current degrees of groundwater pollution and assess the potential for transport of pollutants from the root zone to groundwater. Letey (1994) has discussed some of the issues that need to be considered in interpreting near-root-zone pollutant concentrations as they may relate to groundwater pollution. He points out that it is not just the concentration of a potential pollutant, but also the subsurface water flow from the root zone to the water table that is of concern – i.e., it is the flux of pollutants that must be evaluated. The problem in reliably monitoring the potential for groundwater pollution is the difficulty in making reliable assessments of the water flux from the root zone to the water table. A complicating factor in this assessment is the occurrence of preferential pathways for water migration.

Conventional groundwater monitoring through sampling of production wells is not reliable to detect incipient groundwater pollution before widespread pollution occurs. Vadose zone monitoring or specially designed monitoring wells are needed for this purpose. The CVRWQCB needs to provide guidance on the groundwater monitoring program that agricultural interests will need to develop in order to implement the Agricultural Waiver requirement of groundwater quality protection. The development of this guidance will likely have to be done through the formation of an expert panel of individuals who are knowledgeable in the transport of pollutants from the land surface to saturated groundwaters.

It will be important for the CVRWQCB to establish widespread, reliable groundwater monitoring programs to detect incipient groundwater pollution by irrigated agriculture, in order to avoid further pollution of groundwater basins. This monitoring program will have to consider not only the concentrations of potential pollutants, but also the amount of subsurface flow of water which can transport these pollutants to the groundwater table. Also, consideration will need to be given to the mixing of the subsurface flow to the water table with the upper parts of the saturated aquifer, in order to interpret the pollution of the aquifer near a source of pollutants.

### Assessment of Current California Central Valley Groundwater Quality

While the SWRCB and the Regional Boards largely focus their groundwater protection activities on individual site permitting situations, the US Geological Survey (USGS) has been conducting studies on the relationship between land use and underlying groundwater quality. A summary of the SWRCB Groundwater Ambient Monitoring and Assessment (GAMA) program, the USGS studies, as well as comments on groundwater quality issues in the Tulare Lake Basin, is provided below.

***SWRCB GAMA Program.*** In January 2007 John Borkovich of the State Water Resources Control Board's (SWRCB) Groundwater Ambient Monitoring and Assessment (GAMA) program, made a presentation to the CVRWQCB on the current status of this program (Borkovich, 2007). The PowerPoint slides used in this presentation are not available on the State Board website.

Based on the presentation by Borkovich (2007), the GAMA program has three components. The SWRCB is conducting a domestic water supply well water quality assessment. The US Geological Survey (USGS) is conducting a Statewide Basin water quality assessment, and the Lawrence Livermore National Laboratory (LLNL) is conducting special studies as part of the GAMA program.

Borkovich has indicated that over 40 percent of the state's water supply is from groundwater and that 8,000 public water wells have had to be removed from service since 1984 because of pollution. Because of the widespread concern about groundwater pollution and its impact on domestic water supplies, the state legislature in 1999 adopted the requirement that the State Water Board conduct a comprehensive ambient groundwater monitoring program (GAMA). This program was expanded in 2001 with the passage of AB 599 and Proposition 50. The sampling program was initiated in 2002.

Borkovich has indicated that the *"domestic well water quality in California is largely unknown."* He also indicated that the Central Valley water supply well water quality program focuses on wells located in Yuba, El Dorado, Tehama and Tulare Counties, and that the analytical program analyzes the well water for the following constituents: *"total and fecal coliforms, general minerals (e.g., sodium bicarbonate), inorganics (e.g., lead, arsenic, and nitrate), organics (e.g., MTBE, PCE, TCE), and additional constituents (e.g., perchlorate)."*

While the individual water well results are reported only to the water well owner, a summary of the results by county are posted on the SWRCB GAMA website,

http://www.waterboards.ca.gov/gama/index.html.

This summary provides an indication of the degree of groundwater pollution in the areas studied. The cumulative project totals for the 928 wells tested were as follows: 27 percent (248 wells) were above drinking water standards for total coliforms, 4 percent (35 wells) were above drinking water standards for fecal coliforms, 9 percent (86 wells) were at or above the maximum contaminant level (MCL) for nitrate, and 3 percent (27 wells) were high for both total coliforms and nitrate. As Borkovich pointed out in his presentation, the wells tested in Tulare County had nitrate and bacteria results higher than the cumulative average of the other focus areas.

At the January 25 CVRWQCB meeting, Ken Belitz of the USGS presented a summary of the GAMA Statewide Basin Assessment studies being conducted by the USGS. His presentation focused on the characteristics of the program without giving specific water quality information on the results of the program conducted thus far. Information on the USGS assessment of the Central Valley groundwater basin water quality is presented in a subsequent section of this report.

The LLNL part of GAMA was summarized at the January meeting by Jean Moran, where she indicated that the focus of these studies is on groundwater age, recharge conditions, trace organics and pesticides, and major dissolved gases (nitrogen and methane). LLNL has conducted special studies associated with the pollution of groundwater near two dairies in Merced and Kings Counties, where, according to Moran's slide entitled, "Dairies – The Bad News,"

- *"Very high Nitrate concentrations in shallow wells with groundwater ages <2 years demonstrate that the nitrate source is overlying dairy operations*
- *Multiple lines of evidence indicate lagoon seepage."*

She also points out that part of the nitrate in dairy lagoon waters that seeps into the groundwaters is denitrified (converted to nitrogen gas), thereby reducing the magnitude of groundwater pollution by dairy-waste-derived nitrogen compounds that become nitrate in the aquifer. These results are in accord with what has been established previously by other studies.

LLNL is also using tracer compounds to identify the pollution of groundwaters by domestic wastewaters.

Overall, the GAMA program is providing some additional data on the pollution of groundwaters in the Central Valley and the state. This program will need to be significantly expanded to more adequately define the current pollution, the constituents responsible, and the sources (activities) that lead to groundwater pollution. Based on this information it should be possible to begin to formulate control programs that will comply with state of California Porter-Cologne requirements of protecting groundwaters from pollution.

***USGS Central Valley Groundwater Quality Studies.*** In response to a request for information on the USGS groundwater quality program for the California Central Valley, J. Domagalski (pers. comm., 2006), Supervisory Hydrologist for the Sacramento office of the USGS, provided the following information:

> *"The U.S. Geological Survey (USGS) maintains an active ground water monitoring and research program within the Central Valley as part of the National Water Quality Assessment (NAWQA) Program and associated studies and statewide through the Groundwater Ambient Monitoring and Assessment (GAMA) Program (http://www.swrcb.ca.gov/gama/). NAWQA studies are currently divided between Status and Trends assessments and Topical studies. The status and trends studies include periodic monitoring of well networks in major aquifer sub-divisions of the Central Valley and land-use networks, which include both agricultural and urban regions. The major aquifer network of the Sacramento Valley is located east of the Sacramento River and occupies approximately one third of that portion of the valley. The two land use networks are rice and the Sacramento urban region. The land use networks have recently been re-sampled, and the major aquifer system will be re-sampled in 2007. Further information on those networks and the results of prior sampling are available (http://ca.water.usgs.gov/sac_nawqa/).*
>
> *Most of the USGS ground water activities take place in the San Joaquin Valley. Three land-use studies include a corn, alfalfa, vegetable network, a vineyard, and an almond network. Recent samplings have also been completed and the results of previous work*

*are available (http://ca.water.usgs.gov/sanj/). Two major topical studies are also in progress as part of the NAWQA Program. Topical studies for NAWQA are designed to increase our understanding of the processes affecting contaminant chemistry in major and representative regions of the United States. The first is entitled "Transport of Anthropogenic and Natural Contaminants" (TANC, http://oh.water.usgs.gov/tanc/NAWQATANC.htm) and the second is part of the "Agricultural Chemicals and Transport" study (ACT, http://in.water.usgs.gov/NAWQA_ACT/index.shtml). Both of these topical studies are national in scope in that similar studies are taking place elsewhere and data will be interpreted and analyzed across all study areas. The TANC study area is the greater Modesto metropolitan region and the ACT study area is the lower Merced River. Sampling activities have concluded for both of these studies and final reports are currently being written. A ground water flow and transport model will also be developed for each of the topical studies. The USGS intends to hold a public meeting on these and other San Joaquin Valley studies on November 15 and 16, 2006, in Modesto. Details of the meeting can be obtained from Joseph Domagalski (joed@usgs.gov).*

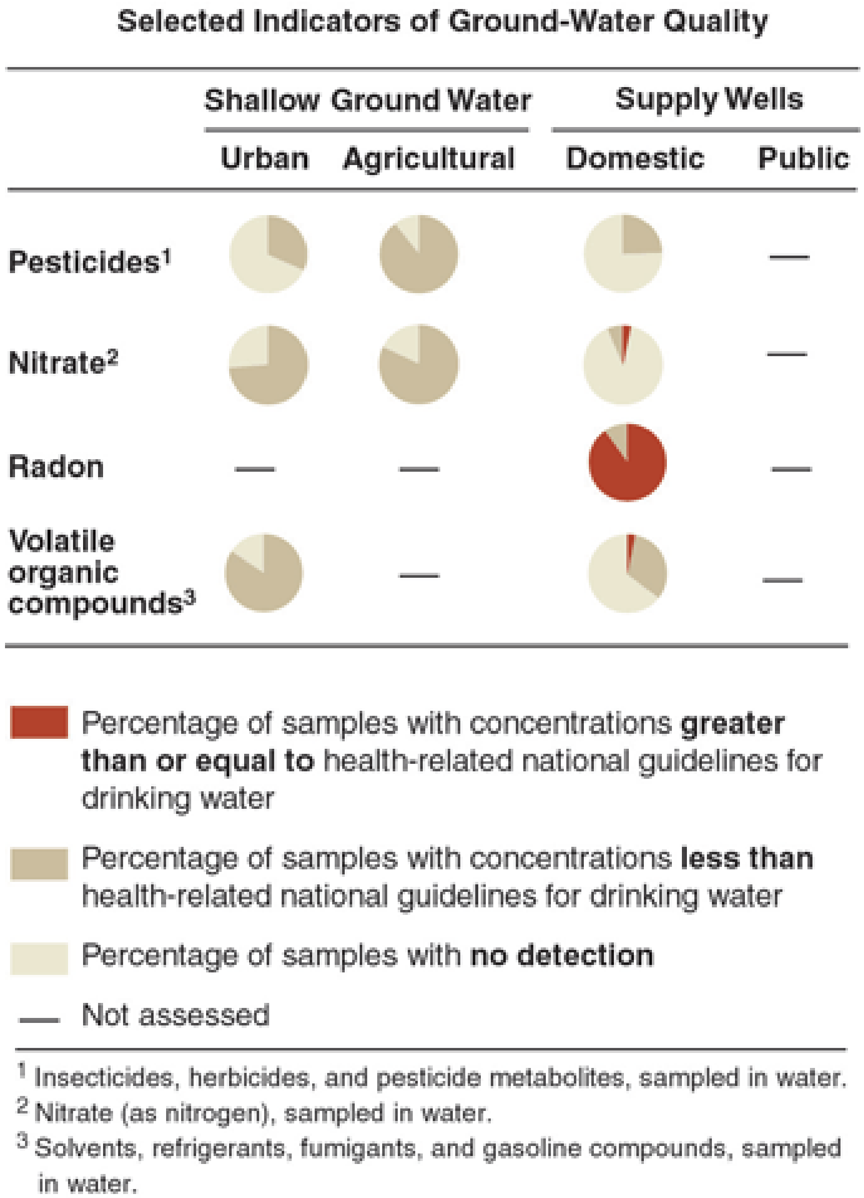
*The GAMA program is a statewide assessment and eventually will include all of the major ground water use areas in California. Two reports are available from the GAMA website on the San Diego study unit and North San Francisco Bay study unit. Several study units have been completed in the Central Valley including the South Sacramento Valley, Northern San Joaquin, and Central San Joaquin. This program will take several more years to complete the statewide assessment."*

The findings from the USGS NAWQA studies on groundwater quality in the Sacramento River Basin are summarized by Domagalski et al. (2000) at http://pubs.usgs.gov/circ/circ1215/summary.htm#ground, and are presented below.

"**Ground-Water Highlights**

Ground water of the Sacramento Valley accumulated in aquifers from precipitation in low hills surrounding the valley and from infiltration of rain, rivers, and irrigation on the valley floor. Ground water is affected by agricultural and urban land uses.

- Bentazon, a herbicide applied to rice fields, was detected in 71 percent of shallow wells sampled in the rice-growing area, despite having been suspended from use since 1989. Bentazon concentrations measured in this study did not exceed any existing drinking-water standard. To protect rivers from pesticide contamination, the rice-field water is required, by means of mechanical controls, to remain on the fields for about 1 month. During that time, pesticide levels decrease by various processes, but evaporation of the water may increase the salinity of the shallow ground water by leaving salts behind.
- Urban growth of the Sacramento metropolitan area has affected ground-water quality. Nitrate concentrations are elevated but are below drinking-water standards in most wells.
- Some of the most heavily used portion of the south-eastern Sacramento Valley aquifer was shown to generally have good water quality suitable for drinking and other uses. Only about 3 percent of the ground-water samples collected had nitrate or trichloroethene concentrations that exceeded a drinking-water standard. Radon concentrations exceeded guidelines in most of the domestic wells sampled."




The findings from the USGS NAWQA studies on groundwater quality in the San Joaquin–Tulare Basins are summarized by Domagalski (1997) at

http://ca.water.usgs.gov/sanj/pub/usgs/wsp2468.html

for Cycle 1, and by Gronberg et al. (2004) at

http://pubs.usgs.gov/fs/2004/3012/

for Cycle 2. Excerpts from these papers related to groundwater are presented below.

From Domagalski (1997):

> "**Abstract**
> Available pesticide data (1966-92) for surface and ground water were analyzed for the San Joaquin Tulare Basins, California, one of 60 large hydrologic systems being studied as part of the National Water-Quality Assessment Program of the U.S. Geological Survey. Most of the

pesticide data were for the San Joaquin Valley, one of the most intensively farmed and irrigated areas of the United States. Data were obtained from the Storage and Retrieval data base of the U.S. Environmental Protection Agency, the water-quality data base of the U.S. Geological Survey, and from data files of State agencies.

Pesticides detected in surface water include organochlorine pesticides, organophosphate pesticides, carbamate pesticides, and triazine herbicides. Pesticides detected in ground water include triazine and other organonitrogen herbicides and soil fumigants. Surface-water data indicate seasonal patterns for the detection of organophosphate and carbamate pesticides, which are attributed to their use on almond orchards and alfalfa fields. Organochlorine pesticides were detected primarily in river-bed sediments. Concentrations detected in bed sediments of the San Joaquin River near Vernalis are among the highest of any major river system in the United States. Patterns and timing of pesticide use indicate that pesticides might be present in surface-water systems during most months of a year.

The most commonly detected pesticide in ground water is the soil fumigant, dibromochloropropane. Dibromochloropropane, used primarily on vineyards and orchards, was detected in ground water near the city of Fresno. Triazine and other organonitrogen herbicides were detected near vineyards and orchards in the same general locations as the detections of dibromochloropropane. Pesticides were detected in ground water of the east side of the valley floor, where the soils are sandy or coarse-grained, and water-soluble pesticides with long environmental half-lives were used. In contrast, fewer pesticides were detected in ground water of the west side of the valley, where soils generally are finer grained."

From Gronberg, et al. (2004):

"**Ground Water**
Wells used in a major aquifer study (of the San Joaquin–Tulare Basins) and in three agricultural land-use studies conducted in the first cycle are being resampled as part of the ground-water trends assessment for the second cycle.

The area of the major aquifer study is defined by the extent of the eastern alluvial fans physiographic region, which has been intensively farmed and irrigated since the early 1900s. The large quantity of fertilizers and pesticides used in this area, the intense irrigation, and the generally permeable sediments have resulted in a history of ground-water contamination problems. Most of the population and ground-water use in the San Joaquin–Tulare Basins is in the eastern alluvial fans region.

The vineyard, almond, and corn–alfalfa–vegetable land-use study areas are nested within the major aquifer study area. Vineyards and almonds continue to be valuable and dominant crops in the study area, ranking second and tenth, respectively, in total production and value in 2001 in the State. The corn–alfalfa–vegetable land-use group encompasses a large variety of crops and therefore a large variety of pesticide applications.

Thirty wells from each study were sampled in 2001 or 2002. These wells will continue to be sampled on a decadal schedule. A subset of wells from each study will be sampled biennially to evaluate the temporal trends within the decadal sampling period. The subset of wells sampled biennially will be sampled seasonally from fall of 2003 to summer of 2004 to determine how much the water quality varies seasonally in these study areas."

***Groundwater Quality in the Tulare Lake Basin.*** The Central Valley groundwater aquifer system consists of three major areas: one associated with the Sacramento River Valley, the second associated with the San Joaquin River Valley, and the third, the Tulare Lake Basin. While the Sacramento and San Joaquin River Valley aquifers are connected, the Tulare Lake

Basin, which occurs south of Fresno, to the mountains to the southwest and east, is a closed basin. Recently D. A. Sholes, Senior Engineering Geologist with the Fresno Office of the CVRWQCB, presented a discussion to the CVRWQCB on the geological setting of the Tulare Lake groundwater basin. His discussion included the potential for salt pollution of groundwaters. As a followup to this discussion, in response to a request for an assessment of the occurrence/significance of pollution in the Tulare Lake Basin groundwaters, Sholes (pers. comm., 2006) provided the following comments:

> *"We are somewhat hampered in that regard by our mandate to regulate each site individually. Regional impacts only get dealt with in CEQA documents, or in Basin Planning efforts, which have not been well funded.*
>
> *The Dept of Pesticide Regulations has groundwater protection areas based on the occurrence of pesticides in groundwater and the potential for infiltration or runoff. The GAMA program has collected a lot of groundwater data in Tulare Co. recently, and analyzed for general minerals, nutrients, bacteria, and some pesticides. They have not released the data yet.*
>
> *We have groundwater data from about 40 dairies with monitoring wells, and another 80 dairies where groundwater from irrigation or domestic supply wells was analyzed for general minerals and nutrients. Thomas Harter with UCDavis has studied groundwater impacts from dairies.*
>
> *USGS Water-Resources Investigations Report 97-4284, and 97-4205 talk about Nitrates and Pesticides in Ground Water beneath three agricultural land-use settings in the Eastern San Joaquin Valley, and the Environmental Setting of the San Joaquin and Tulare Basins. USGS Circular 1159 describes Water Quality in the San Joaquin-Tulare Basins 1992-95.*
>
> *Right now there is a big push on salts and irrigated lands, but these are not always focused on ground water quality. Grassroots organizations like AGUA and CRPE are beginning to focus on groundwater issues in the Tulare Lake basin, but so far seem to be focused more on naturally occurring water quality than those related to human impacts."*

The California Department of Water Resources (DWR 2003) update on "California's Groundwater – Bulletin 118, Update 2003" provides a discussion of the Tulare Lake Hydrologic Region. It is available at
http://www.dpla2.water.ca.gov/publications/groundwater/bulletin118/Bulletin118_7-TL.pdf.

Page 178 of this discussion includes the following information on groundwater quality in the Tulare Lake Basin:

> *"In general, groundwater quality throughout the region is suitable for most urban and agricultural uses with only local impairments. The primary constituents of concern are high TDS, nitrate, arsenic, and organic compounds.*
>
> * * *

*Agricultural pesticides and herbicides have been detected throughout the valley, but primarily along the east side where soil permeability is higher and depth to groundwater is shallower. The most notable agricultural contaminant is DBCP, a now-banned soil fumigant and known carcinogen once used extensively on grapes. Industrial organic contaminants include TCE, DCE, and other solvents. They are found in groundwater near airports, industrial areas, and landfills."*

There is an urgent need for the CVRWQCB to develop a comprehensive assessment of groundwater quality in the region, to define those parts of the region that are particularly vulnerable to groundwater pollution by various types of land use activities, and to begin to more effectively regulate land use activities that can lead to groundwater pollution than is occurring today.

**DWR's Groundwater Program**

The California Department of Water Resources is charged with the responsibility of developing a program for managing certain aspects of California's groundwater resources. DWR has developed an online Groundwater Information Center: *"…a guide to programs, data and technical assistance offered by the Department of Water Resources."* This Center is located at http://www.groundwater.water.ca.gov/index.cfm. According to the webpage entitled "DWR's Role in California's Groundwater,"

*"DWR responsibilities include:*

- *mapping the state's groundwater basins*
- *keeping well reports that are filed when a well is drilled*
- *assigning well numbers*
- *conduct investigations and collect groundwater data*

*DWR is not responsible for:*

- *protection of groundwater quality*
- *regulation or management of groundwater"*

As part of this responsibility, DWR has developed Water Well Standards for the State of California (DWR 1981, 1991). Links to these and other publications are available at http://www.groundwater.water.ca.gov/dwr_publications/index.cfm.

DWR has developed a report, "California's Groundwater," (DWR 2003). This is a report to the legislature on the current status of California's groundwater resources. In this report, DWR presents its "Findings and Recommendations." These are presented in Appendix C to this report. Presented below are those findings and recommendations that focus on groundwater quality issues:

**"Findings**

6. **Groundwater quality and groundwater quantity are interdependent and are increasingly being considered in an integrated manner.**
   - Groundwater quantity and groundwater quality are inseparable.
   - Groundwater in some aquifers may not be usable because of contamination with chemicals, either from natural or human sources.

- Unmanaged groundwater extraction may cause migration of poor quality water.
- Monitoring and evaluating groundwater quality provides managers with the necessary data to make sound decisions regarding storage of water in the groundwater basin.
- State agencies conduct several legislatively mandated programs to monitor different aspects of groundwater quality.
- California Department of Water Resources (DWR) monitors general groundwater quality in many basins throughout the State for regional evaluation.

7. **Land use decisions affecting recharge areas can reduce the amount of groundwater in storage and degrade the quality of that groundwater.**
    - In many basins, little is known about the location of recharge areas and their effectiveness.
    - Protection and preservation of recharge areas are seldom considered in land use decisions.
    - If recharge areas are altered by paving, channel lining, or other land use changes, available groundwater will be reduced.
    - Potentially contaminating activities can degrade the quality of groundwater and require wellhead treatment or aquifer remediation before use.
    - There is no coordinated effort to inform the public that recharge areas should be protected against contamination and preserved so that they function effectively."

* * *

13. **The need to monitor groundwater quality and contamination of groundwater continues to grow.**
    - As opportunities for developing additional surface water supplies become more limited, subsequent growth will increasingly rely on groundwater.
    - Human activities are likely the cause of more than half the exceedances of maximum contaminant levels in public water supply wells.
    - New contaminants are being regulated and standards are becoming more stringent for others, requiring increased monitoring and better management of water quality.

14. **Monitoring networks for groundwater levels and groundwater quality have not been evaluated in all basins to ensure that the data accurately represent conditions in the aquifer(s).**
    - Groundwater levels are monitored in about 10,000 active wells including those basins where most of the groundwater is used.
    - Groundwater levels are not monitored in approximately 200 basins, where population is sparse and groundwater use is generally low.
    - Groundwater quality monitoring networks are most dense near population centers and may not be representative of the basin as a whole.
    - Many of the wells being monitored are not ideally constructed to provide water level or water quality information that is representative of a specific aquifer.
    - Many wells are too deep to monitor changes in the unconfined (water table) portion of basins.

## Recommendations

1. **Local or regional agencies should develop groundwater management plans if groundwater constitutes part of their water supply. Management objectives should be developed to maintain a sustainable long-term supply for multiple beneficial uses. Management should integrate water quantity and quality, groundwater and surface water, and recharge area protection.**
    - Groundwater management in California is a local agency responsibility.

- In basins where there is more than one management agency, those agencies should coordinate their management objectives and program activities.
- A water budget should be completed that includes recharge, extraction and change in storage in the aquifer(s).
- Changes in groundwater quality should be monitored and evaluated.
- Stakeholders should be identified and included in development of groundwater management plans.

* * *

4. **Groundwater management agencies should work with land use agencies to inform them of the potential impacts various land use decisions may have on groundwater, and to identify, prioritize, and protect recharge areas.**
    - Local planners should consider recharge areas when making land use decisions that could reduce recharge or pose a risk to groundwater quality.
    - Recharge areas should be identified and protected from land uses that limit recharge rates, such as paving or lining of channels.
    - Both local water agencies and local governments should pursue education and outreach to inform the public of the location and importance of recharge areas.
    - DWR should inform local agencies of the availability of grant funding and technical assistance that could support these efforts

5. **DWR should publish a report by December 31, 2004 that identifies those groundwater basins or subbasins that are being managed by local or regional agencies and those that are not, and should identify how local agencies are using groundwater resources and protecting groundwater quality.**
    - Such information will be necessary to confirm whether agencies are meeting the requirements of SB 1938 (Water Code Section 10753.7).
    - Collection and summary of existing groundwater management plans will provide a better understanding of the distribution and coordination of groundwater management programs throughout the State.
    - Successful strategies employed by specific local agencies should be highlighted to assist others in groundwater management efforts.
    - Similarly, the impact of groundwater management ordinances throughout the State should be evaluated to provide a better understanding of the effect of ordinances on groundwater management.

6. **Water managers should include an evaluation of water quality in a groundwater management plan, recognizing that water quantity and water quality are inseparable.**
    - Local water managers should obtain groundwater quality data from federal, state, and local agencies that have collected such data in their basin.
    - Local agencies should evaluate long-term trends in groundwater quality.
    - Local agencies should work closely with the SWRCB and DWR in evaluating their groundwater basins.
    - Local agencies should establish management objectives and monitoring programs that will maintain a sustainable supply of good quality groundwater.

* * *

8. **Continue to support coordinated management of groundwater and surface water supplies and integrated management of groundwater quality and groundwater quantity.**
    - Future bond funding should be provided for conjunctive use facilities to improve water supply reliability.

- Funding for feasibility and pilot studies, in addition to construction of projects will help maximize the potential for conjunctive use.
- DWR should continue and expand its efforts to form partnerships with local agencies to investigate and develop locally controlled conjunctive use programs.

* * *

10. **Increase coordination and sharing of groundwater data among local, State, and federal agencies and improve data dissemination to the public. DWR should:**
    - Use the established website to continually update new groundwater basin data collected after the publication of California's Groundwater (Bulletin 118-Update 2003).
    - Publish a summary update of Bulletin 118 every five years coincident with the California Water Plan (Bulletin 160).
    - Publish, in cooperation with SWRCB, a biennial groundwater report that addresses current groundwater quantity and quality conditions.
    - Coordinate the collection and storage of its groundwater quality monitoring data with programs of SWRCB and other agencies to ensure maximum coverage statewide and reduce duplication of effort.
    - Make groundwater basin information more compatible with other Geographic Information System-based resource data to improve local integrated resources planning efforts.
    - Compile data collected by projects funded under grant and loan programs and make data available to the public on the DWR website.
    - Encourage local agency cooperators to submit data to the DWR database.
    - Maximize the accuracy and usefulness of data and develop guidelines for quality assurance and quality control, consistency, and format compatibility.
    - Expand accessibility of groundwater data by the public after considering appropriate security measures.
    - State, federal and local agencies should expand accessibility of groundwater data by the public after considering appropriate security measures.
    - Local agencies should submit copies of adopted groundwater management plans to DWR."

The adoption of the DWR recommendations would be a major step toward improving groundwater quality protection in California.

**California Comparative Risk Project**

In the early 1990s, the California Office of Environmental Health Hazard Assessment (OEHHA) organized the California Comparative Risk Project. The purpose of this Comparative Risk Project was to provide advice to the state on public health and ecological issues of greatest significance to the state of California, in terms of their impact on health and the environment. The Project was divided into a number of sub-projects, one of which was human health. Within the human health area, which is the area in which G. F. Lee participated, consideration was given to assessing the comparative risk of contaminants in water, air and soil, as well as food risks with respect to pesticide residue impacts. The Human Health Committee (HHC) consisted of about 50 people, with representatives from health agencies, industry, university researchers and faculty, and consultants.

This Project resulted in a publication, California Comparative Risk Project (1994). This report is available online at http://www.oehha.ca.gov/multimedia/pdf/comprisk1994.pdf. It provides insight into the relative significance of waterborne stressors, versus airborne or food-borne stressors. While the report was completed in the mid-1990s, the results are expected to be largely applicable to the situation today.

The primary conclusions of the HHC were:

> *"From the perspective of environmental stressors, the HHC found that exposures to toxic chemicals and agents have a significant impact on human health."*
>
> *"From the perspective of environmental releases to media, the highest estimated human health risks are associated with various sources of air pollution."*
>
> *"Most topic areas, including many ranked as generally low human health risks, can pose high risks to smaller populations."*

Table 4 of the HHC report presents Human Health Risk Rankings of Environmental Health Stressors from the California Comparative Risk Project (1994) report. This table is presented in part below.

**Table 4**
**Human Health Risk Rankings of Environmental Health Stressors**[1]
**(Populations of disproportionate risk of high impact indicated in parentheses)**

High-ranked Risks

- **Environmental tobacco smoke** (children with parents who smoke)
- **Inorganics** (subsistence fishers; those with contaminated drinking water supplies or living near near emission sources)
- **Persistent organochlorines** (subsistence/sport fishers)
- **Ozone** (people with respiratory conditions; or those who work or exercise outdoors)
- **Particulate matter** (children; people with respiratory conditions)
- **Radionuclides (natural sources)**
- **Radon** (smokers; those living in areas with high radon concentrations or with highly contaminated groundwater)
- **Volatile organics** (those with contaminated drinking water supplies or living near emission sources; users of certain consumer products)

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[1] Topics within each rank are ordered alphabetically.

The HHC stated on page 85 of the California Comparative Risk Project (1994) report,

> *"Among carcinogens, the largest proportion of estimated cancer cases is associated with pollutants of natural origin (radon, natural background radiation, and arsenic)."*

Exposure to radon and arsenic occurs through the use of groundwaters for domestic water supply that naturally have elevated concentrations of these chemicals.

G. F. Lee first became involved in radium-226/radon pollution of surface waters and groundwaters in 1960, where at the University of Wisconsin, Madison, he supervised the PhD dissertation of S. Shearer devoted to the leaching of radium-226 from uranium mill waste solids and river sediments derived from the Colorado Plateau area. The results of this study were published as Shearer and Lee (1964). They found that substantial amounts of radium-226 were leachable from uranium mill tailings, which could pollute surface waters and groundwaters. The decay of radium-226 leads to the formation of radon that can pollute groundwaters.

G. F. Lee was involved in evaluating the potential threat to groundwater quality caused by disposal of uranium waste solids from radium watch dial painting. The state of New Jersey Department of Environmental Protection proposed to dispose of waste solids containing radium-226 by blending with soil and disposal in a gravel pit. The public in the area of the proposed disposal site objected to the state's proposed approach, expressing concern about the potential for this approach to cause groundwater pollution by radon. Dr. Lee provided testimony in litigation that demonstrated that the state of New Jersey's proposed approach was technically invalid and that it could lead to groundwater pollution by radon. This testimony caused the judge reviewing this matter to prohibit the state from proceeding with the disposal of uranium/radium waste at the proposed location. A summary of this situation was presented by Lee and Jones (1987).

**Regulating Pesticides to Protect Groundwater**

Beginning in the early 1990s, the California Department of Pesticide Regulation (DPR) attempted to develop regulations that would enable DPR to evaluate the potential for a new or expanded-use pesticide to cause groundwater pollution in the state. At that time, in order to regulate a pesticide with respect to its potential to cause groundwater pollution, DPR needed to have monitoring evidence that a pesticide had, in fact, caused groundwater pollution at a particular location. As discussed by Lee (2003a), this after-the-fact approach to regulating pollution of groundwater is strongly contrary to protection of groundwater quality, especially in light of the fact that some pesticides have caused widespread groundwater pollution in the state. M. Pepple and J. Troiano (pers. comm., 2006) of the DPR provided the following information on DPR's regulation of pesticides with respect to protecting groundwater quality:

> *"The regulation of agricultural use pesticides to protect groundwater is guided by the Pesticide Contamination Prevention Act (PCPA). The PCPA requires the Department of Pesticide Regulation (DPR) to develop the Groundwater Protection List of pesticides that have the potential to pollute groundwater, and conduct monitoring to determine if those pesticides have migrated to ground water. If a pesticide is found in groundwater due to legal agricultural use, DPR is required to conduct a formal review to determine if continued use should be allowed. In most cases if DPR determines that continued use can be allowed, the PCPA requires DPR to adopt regulations to modify use that result in a high probability that the detected chemical would not pollute the groundwaters of the state. The PCPA does not authorize DPR to regulate the use of a currently registered pesticide to protect groundwater until it was actually detected in ground water.*
>
> *Beginning in the late 1980s, DPR developed regulations to control the use of pesticides found in groundwater due to legal agricultural use in the specific areas (one-square mile*

*sections) where they were detected, called Pesticide Management Zones (PMZs). PMZs were pesticide-specific. The problem with this approach is that it did not prevent contamination of ground water in areas where pesticides had not been reported found.*

*Subsequently, in the 1990's DPR developed a model of spatial vulnerability for the presence of pesticides in groundwater. Areas where pesticides had been found in groundwater were profiled according to soil characteristics in conjunction with measures of the depth to groundwater (Troiano et al. 2000). That analysis has been incorporated into new regulations enacted in May of 2004 whereby PMZs were replaced with areas denoted groundwater protection areas (GWPA). Unlike the process for defining a PMZ, the new identification is more preventative because a GWPA is based on soil type and depth to groundwater conditions similar to areas where pesticides have already been detected and thus does not require previous measures of contamination. Use of pesticides known to contaminate groundwater is restricted in these areas so that a grower must obtain a permit for use and the permit must be conditioned with an enforceable management practice (http://www.cdpr.ca.gov/docs/gwp/index.htm)."*

Troiano and Clayton (2004) of the Environmental Monitoring Branch of the California Department of Pesticide Regulation have described a "Probabilistic modeling for risk assessment of ground water contamination by pesticides." At the request of G. F. Lee, a memorandum describing this approach has been made available. This memorandum includes the following summary:

*"In order to estimate the potential of a pesticide to leach to groundwater, DPR will utilize probabilistic modeling approaches, such as Monte Carlo procedures, as opposed to deterministic approaches for two reasons. First, in contrast to deterministic approaches, which normally use a single set of estimates, probabilistic modeling includes information on variability that is observed in multiple measurements of environmental variables. Second, a distribution of outcomes is produced which enables estimations of risk assessment across a continuous scale of scenarios and which can also be the basis for statistical testing.*

*The procedure to compare leaching potential of a candidate pesticide is based on a Monte Carlo approach developed by Spurlock (2000). That study produced distributions of concentrations of known groundwater contaminants under varied irrigation management treatments applied to a coarse soil located in Fresno County. These distributions will be recomputed and the updated distributions will serve as benchmarks against which distributions derived from the candidate pesticide will be compared.*

*There are some situations that might require a different approach. For example, the LEACHP model does not include anaerobic conditions, so special cropping scenarios such as rice culture may require using the SNV procedure."*

The complete memorandum is appended to this report as Appendix B. It represents a significant advance in being able to predict whether the application of a certain pesticide has a significant potential to cause groundwater pollution.

M. Lee of DPR (pers. comm., 2006) has indicated that one of the areas of DPR's concern about pesticide pollution of groundwaters is through surface runoff containing pesticides that enters a dry well. There is also concern about disposal in dry wells of waste pesticides. M. Lee indicated that,

> *"…dry wells, by my interpretation of Water Code section 13051, may be considered injection wells since agricultural runoff is considered 'waste' by the Regional Board's Irrigated Land Program: 'Waste is broadly defined in the California Water Code to include any and all waste substances that may include, but are not limited to soil, silt, sand, clay, rock, metals, salts, boron, selenium, potassium, nitrogen, pesticides and fertilizer.'*
>
> *DPR now has regulations that address ground water contamination via surface runoff to dry wells or to ditches that have been cut through hard pans. The regulations also address two other pathways: leaching and direct contamination down and around well casings."*

M. Lee also provided the following DPR website URLs:

> *"Update of the California vulnerability soil analysis for movement of pesticides to ground water. <http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh0005.pdf>*
>
> *Sections of land requiring special assignment as runoff or leaching ground water protection areas. <http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh0007.pdf>*
>
> *Update of Ground Water Protection Areas.*
> *<http://www.cdpr.ca.gov/docs/gwp/eh0305update.pdf>*
>
> *DPR's regulations that address the contamination pathways described above can be viewed at <http://www.cdpr.ca.gov/docs/gwp/gwregsum_txt0704.pdf>."*

As discussed, DPR has an aggressive program to control pesticide pollution of groundwaters. The California State Water Quality Control Board and the Regional Boards need to develop similar programs for other contaminants that have caused or could cause groundwater pollution.

**Land Disposal of Food Processing and Other Organic Wastes**

At a June 2006 CVRWQCB meeting, W. Wyels presented a staff report (CVRWQCB 2006a), "Resolution Regarding the Reuse of Food Processing By-Products within Stanislaus County," in which she stated that application of food processing waste to land at "agronomic rates" would be protective of groundwater quality from pollution by nitrate. Agronomic rates are defined as rates of application where the nitrogen loading equals the nitrogen that would be taken up by the crops. While the authors have not previously been involved in this matter, after the meeting we examined this report and found on page 3 the following statement,

> *"The Program attempts to protect groundwater at the land application sites by stating that fields must be cropped and that wastes shall be applied at agronomic rates. However, this only protects groundwater from degradation by plant nutrients. Staff is unaware of any agronomic rates for salinity or metals."*

This statement indicates that the staff believes that the application of organic wastes, such as food processing wastes, to soils at nitrogen-based "agronomic rates," as a means of waste disposal, will not cause groundwater pollution by nitrate. While such statements are often made, we have found that they can readily be in error.

In 2000 G. F. Lee was part of a Water Environment Research Foundation (WERF) panel that was responsible for helping to plan and review the results of a large-scale study devoted to estimating plant-available nitrogen in biosolids (sewage sludge) applied to land. This study resulted in a report, "Estimating Plant-Available Nitrogen in Biosolids" (Gilmour et al. 2000), including Appendix A "Calculating Biosolids Application Rates for Agriculture." The project involved application of sewage sludge (biosolids) derived from various municipal wastewater treatment plants across the US to a number of large test plots at agronomic rates, where the fate of nitrogen in the sludge was followed over several years. It was found that application at an agronomic rate, while at some locations would be protective of groundwaters from nitrate mineralized from the sludge in one year, a second year's application to the same plot of land at the same rate resulted in nitrogen pollution of groundwater (and surface water associated with runoff waters), since part of the organic nitrogen applied during the first year was not mineralized during that year – i.e., it was carried over to the next year.

During the second year a substantial part of the unmineralized organic nitrogen that was present at the end of the first year was mineralized, with the result that the actual loading rate of available nitrogen during the second year exceeded the ability of the crops to take up the available nitrogen. The application of food processing wastes and other types of organic wastes to soils could readily lead to the same kind of problem, where consecutive multi-year applications lead to groundwater pollution by nitrate. It should not be assumed that repeated application at agronomic rates is protective of groundwater from pollution by nitrate. Any application of this type should include unsaturated (vadose) zone monitoring just below the root zone to determine if nitrate is migrating to the water table.

These same agronomic rate issues are applicable to other complex sources of nitrogen, such as animal manures. Letey (1994) has discussed the problems with trying to use agronomic rates of nitrogen application to crop land when the nitrogen is from a complex organic nitrogen source, such as plant material, sewage sludge, manure, etc. Recently, Mathews and Harter (2006) at the international conference on "The Future of Agriculture: Science, Stewardship and Sustainability," discussed the application of dairy manure waste lagoon liquids to soils in order to fertilize crops with minimal groundwater pollution by nitrate. They pointed out that, while it is possible, through accurate metering of the dissolved waste in dairy wastewater lagoons, to achieve agronomic rates of nitrogen addition to soils, if the liquid waste contains organic nitrogen, which will undergo mineralization over a period of time, it is not possible to reliably predict nitrogen loading rates that will just meet crop needs without leading to groundwater pollution by nitrate. This is the same problem that was found in the WERF biosolids studies and those discussed by Letey (1994). There are a variety of factors that influence rates of organic nitrogen conversion to ammonia, which controls the potential for groundwater pollution to occur.

**Vadose Zone Transport and Groundwater Monitoring Issues**

In the 1980s when Dr. Lee held the position of Professor of Civil and Environmental Engineering in the University of Texas system, he became involved in a US Environmental Protection Agency (EPA)-sponsored project (Ramsey and Sweazy 1986; George et al. 1986a,b,c; Camann et al. 1986) devoted to evaluating the potential for land application of domestic wastewaters in the Lubbock, Texas, area to cause pollution of the Ogallala aquifer. This aquifer is a major aquifer extending from western Texas through Nebraska. The US EPA had provided $11 million to conduct a study of this issue. Dr. Lee was involved as a reviewer of the data collected on the transport of various constituents, such as nitrate that was developed from the ammonia and organic nitrogen present in the wastewaters that were applied to the surface of the soil.

The project involved the construction of several approximately 20-ft-diameter by 20-ft-deep excavations where vacuum cup lysimeters were installed in ports in the walls of the excavations at various depths and locations. These lysimeters were operated so that each day the percolate passing the lysimeter porous cup was sampled. The lysimeters were operated so that the pressure at the porous cup head was slightly less than the soil moisture tension. This approach enabled sampling of the vadose zone percolate as it passed by lysimeter locations, without significantly altering the soil moisture tension of the percolate in the vicinity of the lysimeter.

In conducting studies with vacuum cup lysimeters, multiple sets of nested probes designed to obtain percolate from various depths and locations in the area of concern should be developed. It is important to understand that vacuum cup lysimeter systems will need to be replaced every couple of years, in order to maintain the system so that it is properly sampling the percolate passing by the probes.

It was found in the Ramsey and Sweazy (1986) studies that major rainfall events resulted in short-duration wetted-front transport down to the water table of nitrate that had been stored in the soil column during periods of low infiltration. At times, nitrate concentrations in a day’s percolate of tens to a hundred or more mg/L N could pass a lysimeter sampling point.

The results of this study pointed to the need to take a significantly different approach toward assessing the potential for nutrients (and, for that matter, other pollutants) applied to the surface of soils to be transported to the water table and thereby pollute groundwaters. This transport can occur in a short period of time, primarily through preferential pathways that exist in the vadose zone.

Harter et al. (2005), associated with the University of California, Davis, published an article, “Deep vadose zone hydrology demonstrates fate of nitrate in eastern San Joaquin Valley,” which discussed the importance of considering preferential pathways for unsaturated (vadose) zone transport of pollutants. Such transport can lead to much more rapid groundwater pollution than is typically predicted based on uniform transport through the soil column.

The authors have encountered a situation associated with the University of California, Davis (UCD) Laboratory for Energy-related Health Research (LEHR) national Superfund site, where the US EPA (which has the lead on overseeing the work done by the responsible parties – the Department of Energy [DOE] and the University of California, Davis) is allowing average annual moisture content of the soil to be used to predict transport of pollutants in the upper part of the soil column to the water table, assuming uniform transport – i.e., ignoring preferential pathway transport. While the average annual moisture approach, which is based on a Lawrence Livermore vadose zone transport model, predicts hundreds of years for pollutants in the near-surface soil column associated with waste disposal practices to reach the water table, in fact, the transport can occur in a much shorter period of time as a result of wetted front and preferential pathway transport.

Another issue of concern in modeling the transport of pollutants through the vadose zone and saturated groundwater is the evaluation of the retardation of certain pollutants by soil sorption reactions. The typical approach of using pure solution distribution coefficients ($K_d$) and generic total organic carbon (TOC) to predict movement of pollutants derived from complex wastes can be in significant error due to the fact that the pure solution $K_d$ values are not applicable to the sorption/desorption reactions that occur on aquifer solid surfaces in the presence of a variety of organics derived from waste. Also of concern is the potential for cosolvent-assisted transport of pollutants, where small amounts of organic solvents dissolved in water can affect the distribution of a pollutant in the dissolved phase.

These issues are additional examples of the unreliable regulatory approaches that are occurring in the Central Valley in protecting groundwaters from pollution by waste disposal on land. A discussion of the unreliable approaches being used at the LEHR Superfund site for predicting rates of pollution of groundwater through vadose zone transport is presented in reports by Lee on the Davis South Campus Superfund Oversight Committee's (DSCSOC's) website (www.gfredlee.com/DSCSOC/DSCSOC.htm).

One of the issues of particular concern in the remediation of the LEHR site is the potential for chemicals in the vadose zone to migrate to the water table, and thereby cause groundwater pollution. It has been suggested that one way to evaluate whether chemicals in the vadose zone are being transported through the vadose zone to the water table is to establish vacuum cup lysimeters in the vadose zone, which sample the percolate that occurs in it. As described above, ceramic cup lysimeters which are properly placed in the vadose zone and operated to draw percolate into the cup by exerting a vacuum slightly greater than the soil moisture tension, can obtain a sample of the water that is percolating through the vadose zone. Particular attention should be given to collecting samples of this percolate during and immediately after rainfall events, when a wetted front of percolating water occurs. If the percolate collected during these conditions contains elevated concentrations of potential pollutants, then it is known that these pollutants are being transported to the water table.

Lee and Jones (1983) provided guidelines for sampling groundwaters, which discuss a number of factors that have to be considered in sampling groundwaters in order to assess the pollution of groundwater by waste disposal practices and agricultural activities. Some of the factors that need to be considered include the position of sampling wells and length of well screens relative to the distance from a potential pollutant source. Near a source of pollutants, the pollution of groundwaters will be manifested in the upper few feet of the saturated water at the water table. Monitoring wells with long screens could readily fail to detect this pollution, since, as part of the sampling of the wells, the polluted waters near the water table are mixed with waters without the pollution and therefore the concentrations of pollutants can be diluted below detectable limits. The sampling of groundwaters downgradient at some distance from a source may show no pollution of the waters right at the water table, due to infiltration of waters that do not contain the pollutants. At these locations the polluted waters would be at a lower level in the aquifer, but it is unlikely that they would be evenly distributed throughout the aquifer, except at considerable distances downstream from a pollution source.

**Waste Disposal in Landfills and Lagoons**

Over the years the authors have observed that the CVRWQCB allows dairies and other generators of wastes with high pollution potential to place their wastes in lined lagoons, where an upgradient and a downgradient monitoring well are installed to determine if the lagoon liner fails. Through our work on landfills and their potential to pollute groundwaters, we have become familiar with the properties of the plastic sheeting and/or clay liners that are used for these lagoons. In the 1970s G. F. Lee conducted a research project supported by the US EPA National Ground Water Research Laboratories (located in Ada, Oklahoma) to investigate the ability of various types of pond and landfill liners to contain wastes and thereby prevent groundwater pollution. Subsequently, he was supported by a university contract in his investigation of the ability of high-density polyethylene (HDPE) liners to serve as long-term barriers for containment of wastes in landfills and ponds. About a year and a half ago the authors developed a synthesis report of our almost 30 years of experience working on these types of issues, entitled "Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste." This report has been updated (Lee and Jones-Lee, 2007a). This "Flawed Technology" review summarizes what is known today about the ability of plastic sheeting HDPE liners and clay liners to function as effective barriers in landfills and waste disposal ponds for as long as the wastes in these areas are a threat to cause groundwater pollution. It is now generally recognized that these liner systems will ultimately fail to prevent groundwater pollution whenever long-term containment is needed.

Rowe et al. (2003) of the University of Western Ontario (Canada), in their report, "Evaluation of an HDPE Geomembrane after 14 Years as a Leachate Lagoon Liner," have reported on the failure of an HDPE lined leachate lagoon. They stated,

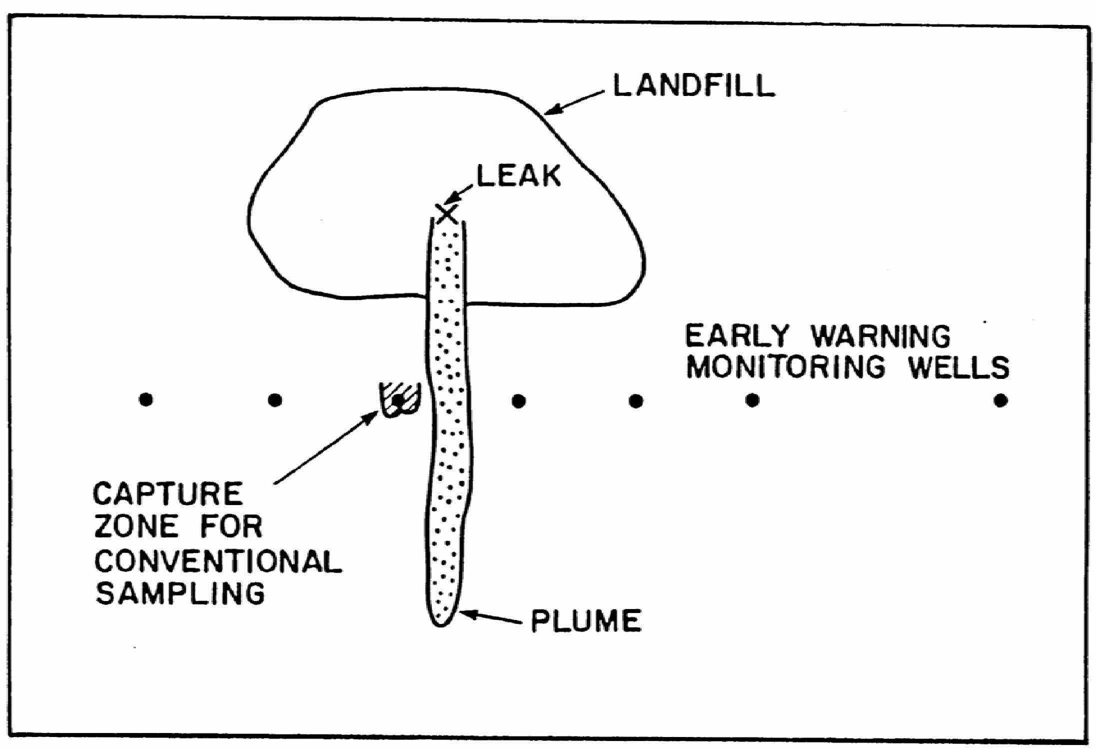
> *"A geomembrane – compacted clay composite liner system used to contain municipal solid waste (MSW) landfill leachate for 14 years is evaluated. Field observations of the geomembrane revealed many defects, including holes, patches, and cracks.*
>
> * * *
>
> *Contaminant modelling of the entire lagoon liner suggests that the geomembrane liner most likely stopped being effective as a contaminant barrier to ionic species sometime between 0 and 4 years after the installation."*

It is evident that in some situations there can be rapid failure of HDPE liners that are used in waste management lagoons.

**Unreliable Monitoring of Lagoon and Landfill Leakage**

Those developing/approving the monitoring well systems to monitor leakage from plastic sheeting lined lagoons and landfills assume that the leakage from the waste management unit will occur evenly across the bottom of the unit, and therefore any monitoring well placed downgradient from the unit should detect the polluted groundwater. The monitoring well array allowed by regulatory agencies such as Regional Boards ignores the fact that the initial leakage from such systems will occur through tears, punctures or points of deterioration in the plastic sheeting. As discussed by Cherry (1990) of the University of Waterloo in his paper, "Groundwater Monitoring: Some Deficiencies and Opportunities," such leakage will generate pollution plumes of limited lateral extent, as illustrated in Figure 1.

**Figure 1**
**Pattern of Landfill Leakage – Groundwater Contamination from Lined Landfills**
(after Cherry 1990)




The typical approach allowed by regulatory agencies for sampling monitoring wells involves removal of three borehole volumes of water from the well prior to taking the sample, in order to purge the well. This sampling approach leads to a zone of capture around the monitoring well of about one foot. A single or even a series of groundwater monitoring wells at a point of compliance downgradient from the waste disposal unit such as a landfill or lagoon has little possibility of detecting the initial leakage from the waste management unit before widespread offsite pollution occurs. These issues are discussed in a section of the Lee and Jones-Lee (2007a) "Flawed Technology" review. As discussed in this review, the best way to reliably monitor the eventual leakage of lagoons, landfills, etc., is through the use of a double composite lined system, with a leak detection system between the two liners. This is the approach that has been adopted by the state of Michigan for its municipal solid waste landfills.

Another problem with the monitoring of waste management units is that the monitoring wells are often screened for considerable distances through the aquifer. This approach assumes that any pollution that occurs of the groundwaters below the waste management unit will spread vertically throughout the saturated part of the aquifer within a short distance from the waste management unit. This would rarely occur. A monitoring well located downgradient of the waste management unit that is screened over a considerable distance of the aquifer can fail to detect pollution of the aquifer, since the pollutants in the upper part of the aquifer will be diluted below detection limits by the pollution-free water in the middle and lower parts of the aquifer. A better approach would be to develop a nested set of monitoring wells that can sample a narrow layer of the groundwater that can be polluted by the waste in the unit. This sampling should occur near the water table and, for those wastes which have a higher salt content (and therefore, typically, are denser than groundwater), at various depths in the saturated part of the aquifer.

An issue that occurs in some areas in the Central Valley and elsewhere is that agricultural and other pumping of the groundwaters can cause appreciable changes in the position of the water table between late summer and late winter. The variability of the depth of the water table needs to be considered in developing appropriately placed and screened monitoring wells, in order to reliably detect groundwater pollution just downgradient from a pollution source.

**Landfills and Groundwater Quality Protection in California**

In the early 1980s while G. F. Lee was teaching in the University of Texas system he was asked by the California State Water Resources Control Board landfill staff (Gil Torres) to review the draft Chapter 15 revised regulations governing the landfilling of municipal solid wastes. In 1984, at the request of the SWRCB staff, Dr. Lee participated in the SWRCB hearing where this regulation was adopted. At that time, the updated Chapter 15 was, in principle, one of the most protective landfilling regulations in the US for groundwater quality. Basically, this regulation established a minimum landfill liner design that could be used at locations where there is natural groundwater quality protection by the underlying hydrogeology. It also established that the Regional Water Quality Control Boards that administer these regulations were to conduct a site-specific evaluation of the landfill liner design and groundwater monitoring system in order to ensure that the landfill would not cause groundwater pollution for as long as the wastes in the landfill were a threat. As stated in Chapter 15, Article 4, Section 2540(c),

> *"Class III landfills shall have containment structures which are capable of preventing degradation of waters of the state as a result of waste discharges to the landfills if site characteristics are inadequate."*

Article 5, Section 2550(a) states,

> *"The siting, design, construction, and operation standards contained elsewhere in this subchapter and in Title 2 of this code are intended to prevent adverse impacts on water quality."*

Article 5, Section 2550(d) states,

> *"The regulations under this article apply during the active life of the waste management unit (including the closure period). After closure of the waste management unit, the regulations in this article apply during the post-closure maintenance period unless all waste, waste residues, contaminated containment system components, and contaminated geologic materials have been removed or decontaminated at closure."*

And Article 8, Section 2580(a) states,

> *"Classified waste management units shall be closed according to an approved closure and post-closure maintenance plan which provides for continued compliance with the applicable standards for waste containment and precipitation and drainage controls in Article 4 of this subchapter, and the monitoring program requirements in Article 5 of this subchapter, throughout the closure and post-closure maintenance period.* ***The post-closure maintenance period shall extend as long as the wastes pose a threat to water quality.****"* [emphasis added]

However, the way in which Chapter 15 was implemented by the Regional Boards assumed that the minimum landfill liner design of one foot of compacted clay with a permeability no greater than $10^{-6}$ cm/sec would be protective of all groundwaters located near landfills. This approach ignores the explicit requirements set forth in Chapter 15 cited above of a site-specific evaluation of the ability of landfills and their containment systems to protect groundwaters from pollution by waste constituents for as long as the wastes in the landfill will be a threat. A simple Darcy's Law calculation would have revealed that the Regional Boards' assumption is technically invalid, since one foot of $10^{-6}$ cm/sec compacted clay under the allowed one foot of leachate head can be penetrated within a few months. See Workman and Keeble (1989) for further discussion of this issue.

In 1989, when Dr. Lee held the position of Distinguished Professor of Civil and Environmental Engineering at the New Jersey Institute of Technology, he became a consultant to Metropolitan Water District of Southern California to assist in a review of the proposed expansion of the Azusa Landfill in the San Gabriel Basin in Southern California. In this position he had the opportunity to examine the approach that was being followed by the Regional Water Quality Control Boards and landfill consultants in implementing Chapter 15. A key provision of Chapter 15 was a site-specific evaluation of the protective nature of the underlying hydrogeology for a proposed landfill site. Much to Dr. Lee's surprise and over the objection of the SWRCB Chapter 15 staff, the staff of the Regional Boards, without public review, had adopted the position that the minimum allowed design for a landfill liner (one foot of clay with a permeability of $10^{-6}$ cm/sec) was appropriate for all landfills in the state, independent of the characteristics of the underlying hydrogeology for the landfill and its protective nature. The Regional Boards' staff assumed that a landfill like the Azusa landfill, located in a sand and gravel pit, should use the same liner as a landfill with several hundred feet of natural low-permeability clay. This approach is obviously technically invalid.

In 1984 the California legislature passed a law requiring the testing of water and air at all solid waste disposal sites. This program became known as the Solid Waste Assessment Test (SWAT) program. In 1995 Mulder and Haven (1995) presented a report on the results of the testing that had been done at 544 landfill sites in California. They reported that 72 percent of the sites tested had been found to have leaked waste constituents from the waste management unit. Only 14 percent were found to be not leaking, a finding that may reflect more the adequacy of the SWAT investigation than the lack of leakage. Another 14 percent was "undetermined" with respect to leaking leachate. Mulder and Haven (1995) concluded,

> *"Available data indicate no apparent correlation between the percentage of landfills which leaked and any of the different site-specific factors checked, including depth to ground water, average annual precipitation, waste acceptance rate, and rock type. Thus, information collected through the SWAT Program demonstrates that unlined or clay-lined landfills leak, regardless of factors such as climate or site-specific geology."*

This conclusion was applicable to landfills that had been developed based on the updated Chapter 15 requirements of a minimum liner design of one foot of $10^{-6}$ cm/sec clay, as well as those that were developed without a liner – i.e., those developed prior to 1984. This conclusion is in accord with the Darcy's Law predicted penetration of this type of liner.

The CVRWQCB recognized this situation, where, as stated in the CVRWQCB (1998) Basin Plan (page IV-5.00),

> *"Recent monitoring efforts under the State and Regional Water Boards' Title 23, CCR Division 3, Chapter 15; Title 27 CCR, Division 2, Subdivision 1; and SWAT programs have revealed that discharges of municipal solid wastes to unlined and single clay lined landfills have resulted in ground water degradation and pollution by volatile organic constituents (VOCs) and other waste constituents. VOCs are components of many household hazardous wastes and certain industrial wastes that are present within municipal solid waste streams. VOCs can easily migrate from landfills either in leachate or by vapor-phase transport. Clay liners and natural clay formations between discharged wastes and ground waters are largely ineffective in preventing water quality impacts from municipal solid waste constituents."*

In the early 1980s the US Congress, under pressure from environmental groups, adopted the "dry tomb" landfilling approach for hazardous and nonhazardous wastes (MSW), based on the concept of isolating the wastes from water that can generate leachate (garbage juice) that can in turn lead to groundwater pollution by constituents leached from the solid waste. In theory, since one of the primary problems of solid waste landfills that are used to manage municipal or industrial solid waste is the pollution of groundwater by leachate, if the waste could be isolated from water that leads to the formation of leachate, then groundwater pollution by landfills could be prevented. The dry tomb landfilling approach, however, leads to a situation where the wastes that are isolated from the environment in a compacted soil and plastic sheeting "tomb" will remain a threat, effectively forever, to cause groundwater pollution and to generate landfill gas. This is what Lee and Jones-Lee (2007a) have described as a fundamentally flawed approach for MSW landfilling, where liner systems that are used will deteriorate and become non-functional while the wastes in the landfill are still a threat to generate leachate that can pollute groundwaters.

In the early 1990s, with the implementation of US EPA Subtitle D national landfilling regulations, California was forced to abandon the minimum requirement for a landfill liner of one foot of $10^{-6}$ cm/sec clay and adopt the minimum US EPA Subtitle D requirement of a single composite liner consisting of an HDPE plastic sheeting layer and two feet of compacted clay with a maximum permeability of $10^{-7}$ cm/sec. In 1988 the US EPA had acknowledged that eventually a single composite lined landfill would pollute groundwaters underlying the landfill, associated with the eventual deterioration of the plastic sheeting layer in the composite liner. The Agency stated in the draft Subtitle D regulations (US EPA, 1988a),

> *"First, even the best liner and leachate collection system will ultimately fail due to natural deterioration, and recent improvements in MSWLF (municipal solid waste landfill) containment technologies suggest that releases may be delayed by many decades at some landfills."*

The US EPA (1988b) Criteria for Municipal Solid Waste Landfills stated,

> *"Once the unit is closed, the bottom layer of the landfill will deteriorate over time and, consequently, will not prevent leachate transport out of the unit."*

Lee and Jones-Lee (2007a) have discussed the political situation that occurred in the early 1990s, where, as a result of environmental group litigation against the Agency for failing to adopt regulations in accord with the Congressional deadline, the US EPA adopted Subtitle D municipal solid waste landfilling regulations that the Agency knew at the time would not be protective of groundwater resources for as long as the wastes in a "dry tomb"-type landfill would be a threat. However, efforts to adopt the more protective approach of a double composite lined system rather than a single composite lined system for MSW were opposed by the Administration under political pressure through the Office of Manpower and Budget (OMB) not to increase the cost of MSW landfilling. As discussed by Lee and Jones-Lee (2007a), the double composite lined system (which had been adopted in the 1980s in several states) is an approach that can lead to a highly protective landfill, since failure of the landfill cap and/or liner system is readily detectable before groundwater pollution occurs.

The double composite liner approach enables reliable evaluation of when the upper composite liner fails to collect the leachate produced in the landfill by detection of the presence of leachate between the two composite liners. Finding leachate in the leak detection zone between the liners allows the regulatory agencies and the landfill owner to take action to stop leachate production before groundwater pollution occurs. These issues are discussed by Lee and Jones-Lee (2007a) and have been recognized by a number of states which will not allow a US EPA minimum design Subtitle D single composite liner for MSW landfills.

While the California SWRCB Chapter 15 staff testified at the Subtitle D hearing that a more protective approach would be a double composite liner similar to that which had been adopted by about half a dozen states, the SWRCB rejected this approach and, under political pressure from public and private landfill owners, adopted the minimum design Subtitle D single composite liner as the standard for MSW landfills in California. The Regional Boards adopted the technically invalid approach of ignoring the eventual failure of a single composite liner to prevent leachate from penetrating into the groundwater underlying a proposed landfill, and assumed that a US EPA minimum design Subtitle D single composite liner would comply with the Chapter 15 (now Title 27) (SWRCB/CIWMB 2006) water quality protection performance standard of protecting groundwaters from pollution by landfill leachate for as long as the wastes in the landfill will be a threat. This is another of the fundamentally flawed approaches that the Regional Boards have adopted based on recommendations from their landfill staff with respect to protecting the state's groundwaters from pollution by landfill leachate.

As discussed below, this approach was followed by the CVRWQCB, even though its 1998 Basin Plan, on page IV-6.00, states,

> *"While a single composite liner of the type that can be approved under Subtitle D regulations is a significant improvement over past municipal solid waste containment systems, it should be noted, however, that single composite liners will not necessarily provide complete protection for ground water resources."*

***Unreliable Groundwater Monitoring.*** Another fundamentally flawed approach adopted by the Regional Boards is the allowed placement of a few downgradient groundwater monitoring wells at the point of compliance for groundwater monitoring. California Regional Boards continue to ignore the fact that the initial leakage from a plastic sheeting lined landfill will, as described by Cherry (1990), produce finger-like plumes of leachate that can readily pass by the point of compliance for groundwater monitoring without being detected by the groundwater monitoring wells (see Figure 1).

Previous US EPA Office of Solid Waste senior staff have acknowledged that there is a significant problem with the way in which states and some of the Agency's regional administrators are implementing the groundwater monitoring requirements of Subtitle D. These requirements mandate that the groundwater monitoring system utilized for a landfill be able to detect leachate-polluted groundwaters when they first reach the point of compliance for groundwater monitoring. As discussed by Lee and Jones-Lee (2007a), by allowing a groundwater monitoring well array at the point of compliance where the wells are spaced hundreds of feet apart and each well has a zone of capture of about one foot, states are ignoring one of the key provisions of Subtitle D regulations of being able to detect leachate-polluted groundwater when it first reaches the point of compliance for groundwater monitoring.

Lee and Jones-Lee have advocated that regulatory agencies require the landfill applicant and its consultants to reliably evaluate the potential for groundwater pollution to occur beyond the point of compliance for groundwater monitoring. They have suggested that at least a 95-percent probability of detecting leachate-polluted groundwaters that arise from initial leakage through any point in the liner associated with rips, tears, or limited-size points of deterioration be required for all landfills, especially those involving a US EPA minimum design single composite liner.

***Unreliable Vadose Zone Monitoring.*** In the early 1980s there was considerable interest in vadose zone monitoring under landfills and other waste disposal areas, as an early warning system to detect the potential for groundwater pollution before pollution occurs. A number of approaches were developed whereby percolate could be sampled from the vadose zone and analyzed. The SWRCB (1984) landfilling regulations required that vadose zone monitoring be accomplished under each new landfill or landfill cell. While, in principle, this approach could detect landfill liner failure before significant groundwater pollution occurs, in practice, as implemented by the Regional Boards, the vadose zone monitoring systems that have been developed are of limited reliability.

Basically, without analyzing the potential effectiveness of detecting limited-area leaks through the plastic sheeting layer in the liner by limited-dimension systems for vadose zone monitoring, the California Regional Water Quality Control Board staff have allowed landfill developers to use a variety of devices which will sample possibly one-half-foot to one-foot diameter areas under a several-hundred-acre landfill as complying with the need to establish a vadose zone monitoring system. This approach assumes that the plastic sheeting layer of the landfill liner will leak at all locations whenever leaks occur at any location. A proper analysis of the situation would have shown that initial leakage through the plastic sheeting layer will occur at limited areas of the landfill liner. This will produce finger-like plumes of leachate that will pass through the vadose zone to the water table. In order to detect these with any degree of potential reliability, it will be necessary to have a comprehensive set of vadose zone monitoring devices.

Keller (1991, 1992a,b) formerly of Science & Engineering Associates of Santa Fe, NM, developed several approaches for vadose zone monitoring that would have the potential of being a reliable early warning system of landfill liner failure under a single composite liner. As Lee and Jones-Lee (1993b) discussed, a possible approach for monitoring of the initial leakage of a landfill liner would be through the use of the SEAMIST™ system, in which, through horizontal drilling under the landfill liner, an array of vapor phase monitoring wells can be constructed and monitored to detect hazardous chemicals with an appreciable vapor pressure. While California Regional Water Quality Control Boards were made aware of these systems, they did not require that such systems be used, but continued to allow an unreliable approach for accomplishing vadose zone monitoring.

Information and an evaluation of the SEAMIST™ system is available from the US Department of Energy (US DOE, 1995) at http://web.em.doe.gov/plumesfa/intech/seamist/index.html. More recent information on the Flexible Liner Underground Technologies (FLUTe) (formerly SEAMIST™) monitoring approach is available at www.flut.com.

***Landfill Gas Pollution of Groundwaters.*** There is a potential for VOCs to pollute groundwaters through gas migration from the landfill through the soil. Prosser and Janechek (1995) have discussed that gaseous emissions from landfills are a threat to cause groundwater pollution that will not likely be detected by the groundwater monitoring wells, since gas migration can be in a direction different than down groundwater gradient. These gaseous emissions contain a variety of volatile hazardous chemicals that are a threat to cause cancer and other diseases in those living or using areas near a landfill.

Lee and Jones-Lee (2007a) have recently discussed the work of Richgels (2000), who has reported that municipal solid waste landfill gas production represents a more significant cause of groundwater pollution than leachate migration through the liner. Richgels has indicated that much greater attention should be devoted to effectively capturing all landfill gas emissions than is typically done today, in order to reduce the potential for groundwater pollution by landfill gas migration from the landfill.

***Health Effects of Landfill Airborne Emissions.*** While primary attention has been given over the years to the potential health effects associated with the pollution of groundwaters by leachate from landfills and other hazardous chemical sites, there is increasing evidence that airborne releases from landfills that are associated with landfill gas emissions contain hazardous chemicals that are adverse to the health of those within the sphere of influence of the landfill. While it has been known for many years that the populations living near landfills and Superfund sites tend to have higher incidences of various types of diseases, statistical data which would clearly establish this link has been lacking. This is a result of the fact that large databases are needed to use epidemiological approaches to establish health effects associated with airborne releases of hazardous chemicals.

This situation of the lack of data of health effects associated with landfills and other hazardous chemical sites has recently changed, where publications by Elliott et al. (2001) and Kouznetsova et al. (2007) have shown a correlation between adverse health effects and proximity to a landfill/hazardous chemical site. The Elliott et al. (2001) study showed an increased incidence of birth defects, while the Kouznetsova et al. (2007) study showed an increased incidence of hospitalization for diabetes. Lee and Jones-Lee (2007b) have developed a discussion of these papers, pointing out that if odorous compounds are detected in the air near a landfill, then the air of the area also likely contains hazardous chemicals that are a human health threat. The Agency for Toxic Substances and Disease Registry is aware of this situation and has stated (ATSDR 2006),

> *"Many of the typical landfill gases, notably the alkyl benzenes and the sulfur compounds (both organosulfides and acid gases), may present an odor problem that can cause adverse health effects such as mucous membrane irritation, respiratory irritation, nausea, and stress. If an individual has a pre-existing health condition (e.g., allergies, respiratory illness), these additional health impacts can be significant."*

***UCD Landfilling Issues.*** Since all of the minimum design Subtitle D landfills approved by the Regional Boards and the SWRCB will eventually pollute groundwaters with landfill leachate, where the pollution will often be first detected in offsite production wells, G. F. Lee initiated an effort to get the CVRWQCB and the SWRCB to critically examine this situation and take action to improve groundwater quality protection associated with the landfilling of municipal solid waste. Several times during the 1990s, he tried to get the Central Valley Regional Water Quality Control Board and SWRCB to recognize the eventual failure of the single composite liner in being protective of groundwater resources from pollution by landfill leachate.

Beginning in 1995, he became the US EPA Technical Assistance Grant (TAG)-supported advisor to the DSCSOC for the UCD/DOE LEHR national Superfund site located on the south campus of the University of California, Davis. DSCSOC is the representative for the public's interests in this site. Dr. Lee has the responsibility of reviewing the adequacy of site investigation and remediation conducted by UCD and DOE in protecting the public's interests. In the mid-1990s, he became aware that UCD had developed three campus landfills in the vicinity of LEHR. UCD also had developed a fourth campus landfill on the western part of the campus. While, typically, universities deposit their campus wastes in local municipal landfills, in order to save money, the UCD administration developed its own landfills for the campus, which received residential campus solid wastes and laboratory solid and liquid wastes. It was known at that time that the groundwaters in the Central Valley were vulnerable to pollution by landfill leachate, through studies that were conducted at the University of California, Berkeley. The results of these studies were incorporated into an American Society of Civil Engineers report entitled "Sanitary Landfill" (ASCE, 1959).

As expected, by the mid-1990s, all four of the UCD campus landfills had been found to be polluting groundwaters. Two of these had created chloroform plumes in the groundwater extending over a mile from the landfill. The chloroform was derived from its use on campus in veterinary medicine, where the waste chloroform was dumped into pits in the campus landfills. The LEHR site also had several disposal pits where low-level radioactive wastes were deposited associated with UCD's research involving feeding radium-226 and strontium-90 to dogs, in order to evaluate the health effects of low-level radiation exposure. By the early 1990s, it had been found that the LEHR site had widespread groundwater pollution from UCD's past waste disposal practices. This resulted in the LEHR site becoming listed on the National Priority List of Superfund sites. Ultimately, the cleanup of this site will cost the taxpayers of California and the US an estimated $50 million. While UCD saved a few dollars in waste disposal practices by constructing on-campus landfills, ultimately, far more funds will be needed to clean up the groundwater pollution from these landfills than were saved.

In the mid-1990s, UCD filed an application with the CVRWQCB to develop a fifth campus landfill adjacent to the fourth landfill on the western campus. This landfill was to meet minimum regulatory requirements of a single composite liner. Dr. Lee submitted a report to the CVRWQCB objecting to this approach, based on the fact that it was well known then that a single composite liner would not prevent groundwater pollution by landfilled wastes for as long as the wastes are a threat. Also of concern was the fact that landfill number four, which was immediately adjacent to the proposed landfill number five, was already polluting groundwaters, indicating that there was no natural protection of groundwaters at that location.

Through the 1990s, up through 2003, Dr. Lee presented reports and testimony at CVRWQCB hearings documenting why a single composite liner for the proposed UCD landfill number five should not be permitted. Information on these issues is presented in Lee and Jones-Lee (1994b) and Lee (1996a,b,c; 2000a,b; 2003b). These efforts were part of the unsponsored attempt by Dr. Lee to develop improved groundwater quality protection associated with developing MSW landfills in the Central Valley. At one of the CVRWQCB hearings, Dr. Lee, in accordance with hearing procedures, attempted to ask a number of questions of the CVRWQCB staff regarding whether the proposed UCD landfill number five would conform to the SWRCB performance standard of protecting groundwaters from pollution by landfill leachate for as long as the wastes in the landfill would be a threat. The staff admitted, in response to this question, that they had not made this evaluation. When Dr. Lee attempted to ask followup questions, the CVRWQCB attorney prevented the staff from responding, indicating that issues of this type should be taken to the SWRCB for review. Dr. Lee filed a complaint with the SWRCB Chief Counsel on the CVRWQCB attorney's action preventing him from asking questions of the CVRWQCB staff pertinent to their review of the proposed landfill. The SWRCB Chief Counsel, William Attwater, responded that the CVRWQCB attorney had violated Title 23 California Code of Regulations Section 649.5 and Government Code Sections 11125 and 11125.7 by denying the public the opportunity to ask appropriate questions relative to Chapter 15 requirements. According to the Chief Counsel's letter of May 14, 1997,

> *"In short, while cross-examination is required only when a hearing is held, notice, and opportunity to be heard and a questioning process are required."*

In accordance with the CVRWQCB attorney's instructions, Dr. Lee filed a petition (Lee 1996a,b,c) with the State Board for review of the CVRWQCB's approval of the proposed UCD landfill number five proposed design. After four years of no response by the SWRCB, Craig M. Wilson, Assistant Chief Counsel, informed Dr. Lee by certified letter dated April 27, 2000 (Wilson 2000),

> *"The State Water Resources Control Board's regulations on review of water quality petitions provide, in relevant part:*
>
> *'If formal disposition of the petition is not made by the state board within 270 days of the written notification provided for in Section 2050.5, the petition is deemed denied.' (Title 23, California Code of Regulations, Section 2052(d).)*
>
> *I am writing to inform you that this 270-day time period has elapsed in this matter."*

The subject line for his certified letter stated,

> "PETITION OF G. FRED LEE (WDR ORDERS 96-227 AND 96-228 FOR THE UNIVERSITY OF CALIFORNIA AT DAVIS CAMPUS LANDFILL GROUND WATER CLEANUP SYSTEM) CENTRAL VALLEY REGION: DISMISSAL."

Since the Petition was filed in the fall of 1996, it took the SWRCB four years to notify Dr. Lee that the Petition was dismissed without formal review since the SWRCB had not acted on it within 270 days of when it was filed.

It was subsequently learned that a State Board staff member, H. M. Schueller, in charge of the "Landfill Unit," had issued a memorandum indicating that the State Board, without public review, had adopted the position that the minimum design Subtitle D landfill liner system was, by definition, equivalent to the Chapter 15/Title 27 performance standard of protecting groundwaters from pollution by landfill leachate for as long as the wastes are a threat. Dr. Lee specifically asked the SWRCB, in a followup to his petition (Lee 1996b), for public review of this position. The SWRCB failed to act on Dr. Lee's request to review this issue. It became clear that the SWRCB and the CVRWQCB were unwilling to review the adequacy of a single composite liner in conforming to the Chapter 15/Title 27 performance standard.

It also became clear that the CVRWQCB and the SWRCB were not willing to adopt the double composite liner approach for landfilling of MSW, since this would increase the cost of landfill liner construction. This cost, however, amounts to less than a few cents per person per day for those who contribute waste to the landfill. In exchange for saving these funds, the Regional and State Boards are ignoring Chapter 15 (Title 27) requirements of protecting groundwaters from pollution by landfill leachate for as long as the wastes are a threat, by allowing the inevitable pollution of groundwaters by landfill leachate and the loss of these resources to future generations. Ultimately, the "Superfund"-like cleanup costs for the minimum design Subtitle D landfills will greatly exceed the funds saved. These costs, however, will have to be paid by future generations and not by those who produced the wastes.

At this time, several of the Regional Water Quality Control Boards in California, including the CVRWQCB, are finally, after more than 10 years, beginning to require double composite lined landfills for MSW (including part of the UCD landfill number five expansion), even though there is no regulatory requirement in California for this approach. There is need for the SWRCB to adopt a statewide policy of requiring double composite liners for all MSW landfills. The Lee and Jones-Lee (2007a) Flawed Technology review provides a detailed discussion, with extensive references to the literature, on why single composite lined MSW landfills are a fundamentally flawed technology for protecting groundwaters from pollution by MSW leachate for as long as the wastes in the "dry tomb"-type landfill will be a threat.

***Azusa Landfill Pollution of Groundwaters.*** In 1989, when Dr. Lee became a consultant to the Metropolitan Water District of Southern California on the proposed expansion of the Azusa Landfill, he examined the monitoring data that Browning-Ferris Industries (BFI) had been reporting to the Los Angeles Regional Water Quality Control Board on the characteristics of the groundwater downgradient from the landfill. He found that the existing landfill was already polluting groundwaters. Other studies had shown that a plume of groundwater pollution arising from this landfill extended several miles in the San Gabriel Basin. Dr. Lee testified at an SWRCB hearing in the fall of 1989 that the existing landfill was already polluting groundwaters, and that any proposed expansion of this landfill would also pollute groundwaters. His assessment of this situation was supported by the State Board staff. However, the SWRCB chose to ignore this situation and granted BFI permission to expand the landfill.

This caused the Metropolitan Water District of Southern California to organize a group of consultants, including Dr. Lee, to develop a detailed discussion of these issues, in which an effort was made to convince the Los Angeles Regional Water Quality Control Board that the existing Azusa Landfill was already polluting groundwaters, and that this Board should be requiring BFI to start remediation of the polluted groundwaters, in accordance with Chapter 15 regulations. Dr. Lee testified at several Los Angeles Regional Water Quality Control Board hearings on this issue, in which he presented the monitoring data that BFI had provided the Regional Board which clearly demonstrated that the existing landfill was polluting groundwater. Even though the evidence was obvious for this situation, the Los Angeles Board continued to ignore this pollution.

Several years later, the US EPA, as part of its efforts in addressing the San Gabriel Basin Superfund project involving cleanup of polluted groundwaters, examined the same data that Dr. Lee had previously discussed with the Regional and State Boards on the existing groundwater pollution (which had been ignored by both Boards), and concluded that the existing landfill was polluting groundwater. This led the US EPA to declare that the existing Azusa Landfill was contributing to the pollution of the San Gabriel Basin groundwaters by hazardous chemicals.

Of particular concern was the presence of vinyl chloride in the groundwater monitoring wells downgradient from the landfill. While there was no vinyl chloride in the Azusa Landfill leachate, there was trichloroethylene (TCE) in the groundwaters upgradient from the Azusa Landfill, associated with a Superfund site discharge from industrial facilities. It was found that, as the TCE-polluted groundwaters mixed with the leachate-polluted groundwaters from the Azusa Landfill, the TCE was, as expected, dechlorinated to form vinyl chloride. This is a well known reaction that occurs under anoxic (oxygen-free) conditions in the presence of an organic source. The US EPA concluded that the Azusa Landfill was, therefore, contributing to the vinyl chloride and other VOC pollution of the San Gabriel Basin and required that BFI take action to clean up the polluted groundwaters. It was clear from this situation that factors other than science were influencing the Los Angeles Regional Board's decisions on regulating the Azusa Landfill. Ultimately, through the efforts of the Metropolitan Water District and its consultants, the SWRCB required that BFI terminate its expansion of the Azusa Landfill.

***MSW Landfill Leachate Recycle.*** One of the issues of concern about the potential impacts of MSW landfills is the release/migration of landfill gas from the landfill. This landfill gas (methane and carbon dioxide) is a result of the bacterial fermentation of some of the organic components of the MSW. Landfill gas can cause explosions in offsite structures, and contains a variety of hazardous VOCs and odorous compounds. Typically, MSW sanitary landfills produce gas for 30 to over 40 years. Laboratory and field studies have demonstrated that the rate of landfill gas production from MSW is dependent on the moisture content of the wastes; therefore, adding moisture to the wastes by discharging MSW landfill leachate back into the landfill is a method that could be used to stimulate landfill gas production and thereby shorten the time for landfill "stabilization" with respect to gas production. This approach, called "leachate recycle," would also help with the disposal of leachate.

In the early 1980s there was considerable interest in exploring MSW leachate recycle, where a number of leachate recycle projects were conducted. However, some states such as New Jersey prohibited leachate recycle because the increased hydraulic loading of moisture to the landfill could lead to greater groundwater pollution.

In the early 1980s the US Army Construction Engineering Laboratory in Champaign, Illinois, issued a contract for support of G. F. Lee to evaluate the potential use of leachate recycle at "municipal" waste landfills at military bases. Based on the literature and the chemistry of the processes that take place in MSW landfills, Lee et al. (1985) reported that MSW leachate recycle could serve as a source of moisture that would increase the rate of landfill gas production, shorten the time that gas would be produced, and "stabilize" the landfill with respect to gas production and settlement of the wastes. However, the increased moisture from the recycled leachate could lead to greater groundwater pollution because of the increased hydraulic loading of the landfill. Lee et al. (1986) presented a summary of the results of the study and suggested approaches that could be used to recycle leachate without causing increased groundwater pollution, through appropriately designed landfills.

In the late 1980s the US EPA proposed the adoption of "dry tomb" type MSW landfills which prohibited the addition of water and leachate to the landfill. Basically this approach involves enclosing MSW in plastic sheeting and compacted clay liners in an effort to keep the wastes dry. The dry tomb landfilling approach led to the development of landfills that would continue to be a threat to produce gas and leachate, which could pollute the environment at some time in the future when the plastic sheeting and clay layer liners fail to prevent water from entering the landfill and fail to collect all the leachate generated in the landfill from such water.

Lee and Jones-Lee (1993c) published a paper, "Landfills and Groundwater Pollution Issues: 'Dry Tomb' vs F/L Wet-Cell Landfills," that provided guidance on how MSW landfills should be designed and operated in order to treat the wastes in the landfill and thereby produce a landfilled waste that would not be an *ad infinitum* threat to produce landfill gas and leachate. The Lee and Jones-Lee recommended approach involved a double composite lined landfill where the wastes to be deposited in the landfill would first be shredded to eliminate the presence of crushed plastic garbage-bagged wastes. Initially, MSW leachate would be recycled back into the landfill to stimulate gas production. When the gas production had essentially ceased, clean water would be added to the landfill to remove any leachable chemicals in the wastes. During this washing of the landfilled wastes, the leachate produced would not be recycled, but would be treated and disposed of offsite. Lee and Jones-Lee estimated that, following this approach, a stable, fermented and leached waste residual could be developed in 10 to 15 years.

Lee and Jones-Lee (1995a), Jones-Lee and Lee (2000) and Lee (2000c,d) have reviewed the problems of conducting MSW leachate recycle in minimum design US EPA Subtitle D landfills, a practice which is being supported by the US EPA and some state regulatory agencies. The interest in this approach stems from an effort to shorten the time that a dry tomb type landfill would be a threat. It also reduces the cost of leachate management. However, this approach could readily lead to increased groundwater pollution that would not be detected by the monitoring well systems allowed at such landfills. Jones-Lee and Lee point out that the US EPA and those who advocate this approach fail to discuss in their writings the potential problems with this approach of the increased potential for groundwater pollution. The Lee and Jones-Lee papers provide guidance on how leachate recycle should be practiced in order to produce a stable solid waste residue within about a decade that is little threat to cause environmental pollution.

***Heavy Metals.*** In recent years there has been considerable interest in the potential for electronic wastes (such as televisions, computers, mobile telephones, etc.) that are discarded in the municipal solid waste stream, to contribute heavy metals to MSW leachate that can pollute groundwaters. The Solid Waste Association of North America (SWANA) Applied Research Foundation released a report, "The Effectiveness of Municipal Solid Waste Landfills in Controlling Releases of Heavy Metals to the Environment" (SWANA 2004), that stated that the concentrations of heavy metals in MSW leachate do not represent a threat to cause groundwater pollution. Subsequently, O'Brien, Director of Applied Research for the SWANA Applied

Research Foundation, published a summary article on this report in *MSW Management* (O'Brien 2005). Lee (2004a) and Lee and Jones-Lee (2005a) provided a discussion of the unreliable information in the SWANA (2004) and O'Brien (2005) report/paper. As Lee and Jones-Lee discuss, the approach used by SWANA/O'Brien to conclude that heavy metals in MSW leachate are not a threat to cause groundwater pollution was not technically valid.

Examination of the US EPA Leach 2000 database (SAIC 2000), which was used by SWANA/O'Brien, shows that some of the landfills in this database had concentrations of heavy metals in leachate that were a threat to cause groundwater pollution in some aquifer systems. Of particular concern were aquifers that consist of sand and gravel, fractured rock or limestone. Lee and Jones-Lee also discussed the fact that SWANA/O'Brien's use of the hazardous waste classification Toxicity Characteristic Leaching Procedure (TCLP) regulatory limits, which are 100 times drinking water maximum contaminant levels (MCLs), is not a reliable basis for determining whether heavy metals in MSW leachate can cause groundwater pollution. O'Brien provided a set of comments in *MSW Management* "Elements 2007" (see Lee and Jones-Lee 2006a), in which he indicated that SWANA had used average concentrations of heavy metals in leachate to develop its conclusions, where, if the average concentration of a heavy metal was less than 100 times the drinking water MCL, it was considered to be not a threat to cause groundwater pollution. However, as Lee (2006a) pointed out, the SWANA/O'Brien approach of using average concentrations is not in accord with how drinking water heavy metals and other constituents are regulated. They are not regulated based on the average concentration, but on the maximum concentration.

In Lee's comments on the SWANA report and O'Brien paper (Lee 2006a), he indicated that there is need, as part of permitting landfills, to conduct a site-specific evaluation of whether the inevitable failure of the minimum design Subtitle D landfill liner system, which would allow leachate to pass into the underlying groundwater system, could lead to offsite pollution of groundwaters by leachate-associated pollutants. O'Brien, in his responses (see Lee 2006a), stated that the regulatory approach used in permitting landfills involves a site-specific evaluation of the hydrogeological characteristics of the aquifer underlying a proposed landfill. However, as Lee discussed in his comments on the O'Brien responses to his comments on the SWANA/O'Brien report/paper, in his review of over 75 landfills located throughout the US over the past 15 years, he has yet to find a single case where a regulatory agency conducted a site-specific evaluation to determine if there was a potential for the inevitable landfill liner failure to lead to offsite groundwater pollution. O'Brien's statements about how regulatory agencies conduct site-specific evaluations to determine if there is a potential problem for a landfill to cause groundwater pollution by heavy metals and other leachate-associated constituents do not represent current practices for permitting landfills.

Overall, it can be concluded that the SWANA/O'Brien assessment that heavy metals in MSW leachate do not represent a threat to cause groundwater pollution is based on an unreliable approach for evaluating this issue. There are landfills in which some heavy metals, such as lead, in the MSW leachate are present in sufficient concentrations so that when the single composite liner eventually fails to prevent leachate from passing through it, offsite groundwater pollution can, in some aquifer systems, be caused by heavy metals that are a threat to domestic water supply and, where groundwaters contribute to surface water, aquatic life and other beneficial uses of the surface water.

With respect to whether electronic wastes should be prohibited from being deposited in MSW landfills because of the potential to cause increased heavy metal concentrations in MSW leachate, Lee and Jones-Lee (2005a) have indicated that, at this time, it is unclear as to whether depositing electronic wastes in MSW landfills can significantly increase the concentrations of heavy metals in MSW leachate. The data on the characteristics of MSW leachate show that some landfills have high heavy metal content in their leachate. While it is possible that increasing the heavy metal content of the solid waste stream through allowing electronic wastes to be deposited in MSW landfills could increase heavy metal concentrations in MSW leachate, further studies are needed to define the potential magnitude of this increase. As Lee and Jones-Lee point out, it is prudent public health and environmental protection policy to limit the deposition of electronic wastes in MSW landfills in order to reduce the potential for increased heavy metal pollution of groundwaters by MSW landfill leachate.

**Lead as a Water Pollutant**

With respect to the potential for heavy metals in municipal landfill leachate to cause water pollution, lead is one of the chemicals of greatest concern. There are other situations where lead is the element of concern. Of particular concern is the lead in soils near streets and highways. The former use of lead as an additive in gasoline, coupled with the existence of natural lead in gasoline, as well as the use of lead as tire weights, has led to and currently contributes to elevated lead in the shoulder areas of streets and highways. While the primary concern of highway- and street-associated lead is surface water pollution and the pollution of soils that is a threat to children's health, there is a potential where some situations can lead to groundwater pollution by lead in highway and street runoff and in the soils near these areas. Lee and Taylor (1998) have reviewed this situation in connection with the state of California's regulation of highway construction that involves disturbing the shoulder soils that contain elevated lead. They have discussed the fact that in certain hydrogeological settings the lead in runoff from highways can cause groundwater pollution. Of particular concern are situations in which the underlying hydrogeology is sand or fractured bedrock.

*Stormwater Runoff Water Quality Newsletters* 8-7 and 9-9 (Lee 2005a, 2006b) provide information on lead as a water pollutant, as well as the California Department of Toxic Substances Control's current efforts to develop updated regulatory limits for lead in soils that become wastes with respect to their management as a hazardous waste. A condensed version of Newsletter 8-7 has been published in *Stormwater* (Lee and Jones-Lee, 2006b).

**Fractured Rock/Clay Aquifer Systems Underlying Landfills**

As discussed in several locations in this report, aquifer systems consisting of fractured rock or clay are particularly vulnerable to groundwater pollution. As discussed by Lee and Jones-Lee (2007a), fractured rock aquifer systems are essentially unmonitorable by conventional vertical monitoring wells with respect to detecting groundwater pollution from a waste management area before widespread pollution occurs. The presence of fractured bedrock, fissures, cavernous calcareous strata, and non-isotropic lenticular aquifers (such as former river beds) make the reliable prediction of flow paths from point-source leaks such as from lined landfills, waste ponds, etc., more difficult or even impossible and make the monitoring of groundwater for incipient leachate pollution highly unreliable and virtually impossible. Haitjema (1991) of the University of Indiana stated,

> *"An extreme example of Equation (1) (aquifer heterogeneity) is flow through fractured rock. The design of monitoring well systems in such an environment is a nightmare and usually not more than a blind gamble."*
>
> * * *
>
> *"Monitoring wells in the regional aquifer are unreliable detectors of local leaks in a landfill."*

Cherry, et al. (2006) has described the use of the FLUTe system for monitoring fractured rock aquifer systems. As discussed above, this system samples the vapor phase for volatile VOCs. The FLUTe approach offers promise in more reliably detecting the transport of pollutants through fractured rock.

***Campo Landfill.*** Recently G. F. Lee has reviewed the potential for the proposed Campo municipal solid waste landfill to cause offsite groundwater pollution. This landfill is proposed to be developed on the Campo Indian Reservation located in San Diego County near the US-Mexico border. The landfill is to be placed on lands that are elevated above surrounding areas. There is concern by nearby property owners about the potential for the pollution of their surface waters and groundwaters by the landfilled wastes. Ponce (2006) has provided a detailed review of the hydrogeology of this area. The hydrogeology of the area is based on a fractured rock aquifer system. He points out that there is considerable evidence for lineaments which can allow rapid transport of polluted groundwaters to adjacent properties' groundwater supply. His discussion of the situation is one of the most comprehensive that has been developed on this issue. It raises significant questions about the appropriateness of developing landfills situated above fractured rock aquifer systems.

G. F. Lee has encountered a number of other situations where landfills situated above fractured rock aquifer systems have the potential to cause offsite groundwater pollution without being detected by the groundwater monitoring systems typically employed. A summary of these situations is presented below.

***Gregory Canyon Landfill.*** One of these is the proposed Gregory Canyon landfill in north San Diego County. The Gregory Canyon landfill is proposed to be situated over a fractured rock aquifer system that is connected to a highly valuable alluvial aquifer system. As Lee and Jones-Lee (2000a) discussed, the detection of the inevitable failure of the landfill liner system that is proposed to be used to prevent leachate migration to the underlying groundwater system will be very difficult to achieve reliably.

***Grand Forks Landfill.*** A similar situation could occur for the Grand Forks (North Dakota) proposed landfill in Turtle River Township (see Lee and Jones-Lee, 2004a). In this case, the aquifer system (Lake Agassiz lakebed sediments) is fractured clay, which was shown to allow for rapid transport of water through the fractures. However, the proposed landfill developer, as part of the hydrogeological investigation of the site, estimated the permeability of the clay based on remolded samples. This approach missed the significant fractures that exist in the clay that would underlie the landfill should it be constructed at this site.

***Peoria Landfill.*** This same type of situation is projected to occur in the clay aquifer system underlying the Peoria Disposal Company's hazardous waste landfill in Peoria, Illinois. As discussed by (Lee 2006c,d), fractures in the clay layer underlying the landfill liner system could allow the transport of leachate that escapes from the landfill to the domestic water supply for Peoria. The Peoria County Board of Supervisors reviewed this situation and concluded that this landfill should not be allowed to continue to operate, because of the increased threat that it would represent to the Peoria domestic water supply.

***Adams Mine Site Landfill.*** In the 1990s the city of Toronto in Ontario, Canada, proposed to dispose of the city's municipal solid wastes at the Adams Mine site near Kirkland Lake, Ontario. This site was a former large open-pit iron ore mine situated in a fractured rock aquifer system. Lee (1995a) and Gallaugher and Lee (1997) reviewed this situation, pointing out that the fractured rock aquifer system would allow the transport of leachate to offsite groundwaters, rendering them unusable for domestic and many other purposes. The city of Toronto abandoned this plan to dispose of its municipal solid waste at this site because of the long-term groundwater pollution liability issues.

Subsequently, Toronto developed a contractual relationship with BFI to haul Toronto's garbage to Michigan. This inter-country transport of garbage from Canada to the US caused considerable controversy in Michigan. In an effort to control the characteristics of the solid waste deposited in Michigan's landfills, the state legislature adopted regulations that prohibited plastic bottles and tires from being deposited in its landfills. These regulations were challenged in the courts by the solid waste management associations that wanted to prevent any flow control of MSW from one area to another. In support of the Sierra Club, G. F. Lee prepared an affidavit (Lee 2004b) providing justification for Michigan's limiting the types of solid waste that may be deposited in its landfill. This position was based on the fact that Michigan has some of the most protective landfills in the US, in which double composite lined landfills are required for MSW. Prevention of the deposition of recyclable waste, such as plastic bottles and tires, would extend the lifetime of Michigan landfills. The judge reviewing this matter supported the state of Michigan, specifically citing G. F. Lee's affidavit as justification for his position.

Recently, Toronto has purchased the Green Lane Landfill in Ontario that will apparently meet its needs for MSW disposal for several years. This landfill is adjacent to the Oneida Nation of the Thames' property, and this Nation is attempting to prevent Toronto from depositing its municipal solid waste in this landfill because of the potential for increased environmental pollution associated with the deposition of Toronto's MSW at this landfill.

***Eagle Mountain Landfill.*** In the California desert near Joshua Tree National Park is a large, open-pit iron ore mine. This mine was proposed as an area that could take the Los Angeles area garbage for 100 years, where the garbage would be hauled by rail to the mine. There was considerable controversy about this approach, based on its potential adverse impacts on Joshua Tree National Park. Also of concern was the potential for the landfill to pollute the limited groundwater resources of the area. G. F. Lee provided several sets of comments on this situation, including Lee (1997a), in which he discussed that, with the ultimate failure of the landfill liner system that was proposed for this landfill, the fractured rock aquifer system associated with the mine would allow leachate-polluted groundwaters to pollute the groundwater resources of the area with a small probability of being detected by groundwater monitoring wells. The Regional Board for the area approved the development of this landfill, ignoring the long-term groundwater pollution problem that will occur as a result.

***Mesquite Landfill.*** The Mesquite Landfill was proposed to be developed in the Southern California desert. This landfill would occupy a former large open-pit gold mine. The hydrogeology of the area is fractured rock. Lee (1995b) commented on the potential for this landfill to pollute groundwaters, which could not be adequately monitored to detect the pollution before offsite pollution occurred. The Regional Board ignored this situation and approved the development of this landfill.

***Union Mine Landfill.*** The Union Mine Landfill is located in El Dorado County, California. A proposal was made to expand this landfill. There was concern, however, that the existing landfill, as well as any expansion, would lead to leachate pollution of groundwaters that would discharge to a nearby highly valued trout stream. Lee (1992) investigated this situation and concluded that the fractured rock aquifer system underlying the existing landfill and its proposed expansion could readily lead to pollution of the trout stream by landfill leachate.

***Campo Sur Landfill.*** A similar situation occurred on the south coast of Puerto Rico, where a private landfill developer proposed to construct the Campo Sur landfill over a volcanic fractured rock aquifer system. Lee (1997b) has discussed the potential for this landfill to cause groundwater pollution that would be a threat to the agricultural water supply of the region.

***Pottstown Landfill.*** The Pottstown Landfill Closure Committee of Pottstown, Pennsylvania, had G. F. Lee conduct a review of the potential threat of the privately owned Pottstown Landfill to cause groundwater pollution after closure of the landfill. Cole and Lee (2005), Lee (2005b,c) and Lee and Jones-Lee (2005b) developed several reports on this issue. This landfill is a large MSW landfill, most of which has been constructed with a single composite liner underlain by a leak detection layer consisting of a sand layer underlain by a plastic sheeting liner. The landfill is located over a fractured rock aquifer with groundwater monitoring wells located hundreds of feet apart around the perimeter of the landfill. One of the primary issues of concern was that the eventual failure of the landfill liner system and leak detection system would lead to offsite groundwater pollution that would not initially be detected by the groundwater monitoring system that has been allowed to be developed for the landfill.

A key aspect of the protection of groundwater from pollution at the Pottstown Landfill is the detection of leachate in the leak detection system underlying the landfilled wastes. When leachate is detected in this system, the owner of the landfill would be required to repair the failure of the landfill cover that was allowing moisture to enter the landfill, generating the leachate. While the private landfill owner could operate the landfill leachate collection system and leak detection system to detect when the composite liner fails, and maintain the integrity of the landfill cover when leachate is detected in the leak detection system, there is no assurance that this company will be able to fund postclosure monitoring and maintenance of this dry tomb type landfill for as long as the wastes in this landfill will be a threat – i.e., forever.

***Lava Cap Mine Superfund Site.*** As part of serving as US EPA-supported Technical Assistance Grant (TAG) advisors to the South Yuba River Citizens League (SYRCL), Lee and Jones-Lee became involved in evaluating the adequacy of US EPA's site investigation and remediation of the Lava Cap Mine national Superfund site located near Nevada City, California. They issued a series of reports, including Lee and Jones-Lee (2003a), on the deficiencies in the approach being used by the US EPA to investigate and remediate this Superfund site. Their reports are available at http://www.gfredlee.com/phazchem2.htm#lava.

Lava Cap Mine is a former gold mine, with an arsenopyrite ore. The extraction of gold from this ore produced large amounts of tailings (crushed ore) with high concentrations of arsenic. The tailings are present near the mine site and downstream, on land and in a lake developed for tailings disposal. The area is privately owned, low-density residential. The residents have domestic wells which are developed in the fractured rock aquifer system that exists throughout the area.

The major area of concern was the US EPA's approach of only capping the tailings pile, and then turning the so-called "remediated" tailings pile over to the California Department of Toxic Substances Control (DTSC) for monitoring and perpetual maintenance. While this approach is initially the least expensive, the long-term monitoring and maintenance, and the potential for additional remediation, could cost the state of California large amounts of funds over the infinite period of time that the tailings pile will be a threat to pollute groundwaters and surface waters of the area. Of particular concern is the potential for movement of high-arsenic leachate developed from water that percolates through the capped tailings pile, which penetrates into the fractured rock aquifer underlying it.

While, as part of remediation of the mine site and tailings pile area, a drain system was constructed at the toe of the tailings pile to capture the water that penetrates through it, which contains elevated arsenic leached from the tailings, there is a potential for some of the water penetrating through the pile to enter the fractured rock aquifer under the pile and therefore not be captured by the drain. It is also possible that water that enters the underlying fractured rock aquifer could become part of local streams, through groundwater discharges to the streams.

***Sydney Tar Ponds.*** Another example of the difficulties in attempting to prevent groundwater pollution associated with fractured rock aquifer systems occurs at the Sydney Tar Ponds located in Sydney, Nova Scotia. In May 2006 G. F. Lee became involved in the review of the proposed remediation of the Sydney Tar Ponds Canadian "Superfund" site in Sydney, Nova Scotia. This site is underlain by a fractured rock shallow groundwater aquifer system. G. F. Lee testified at a Joint Review Panel hearing on the technically invalid approach that the province of Nova Scotia's Sydney Tar Ponds Agency had proposed for remediation of the sediments in the Estuary which were contaminated with PCBs, PAHs and heavy metals derived from a former steel mill operation. Further, substantial amounts of untreated domestic wastewaters from the Sydney area were discharged to this Estuary. The "Superfund"-like remediation of this site is projected to cost $400 million. The province of Nova Scotia's Sydney Tar Ponds Agency has developed a proposed remediation approach (*in situ* mixing of the sediments with cement, and capping, basically creating a covered waste pile) that fails to address the long-term surface water and groundwater pollution problems associated with it. The site's shallow fractured bedrock aquifer system is projected to be a potential pathway for pollutants in the estuarine sediments to escape from the "remediated" area to the Estuary. These issues are discussed in Lee (2006e,f) and Lee and Jones-Lee (2006c).

***Overall.*** It is inappropriate to allow capped waste piles, other landfills, as well as MSW landfills with minimum design US EPA Subtitle D single composite liner systems and the typical groundwater monitoring systems, with monitoring wells spaced hundreds or more feet apart at the point of compliance for groundwater monitoring, overlying fractured rock/clay aquifer systems. There are also appropriate questions about allowing privately developed landfills with a double composite liner overlying fractured rock/clay aquifer systems. While the leak detection system in this type of landfill has the potential to assess when the upper composite liner fails, there are important questions about whether a private landfill developer will provide the funds needed to operate and maintain the leachate collection system and leak detection system over the very long (potentially infinite) period of time that the wastes in a dry tomb type landfill will be a threat. Under the current approach allowed for permitting subtitles C and D landfills, there is no assurance that private landfill developers will be able to provide the large amounts of funds needed during the postclosure period.

Lee and Jones-Lee (2007a) have provided a discussion of the significant deficiencies that exist in current landfilling regulations with respect to ensuring that the funds will be available that are needed to provide for postclosure monitoring and maintenance to adequately protect groundwaters from pollution by landfill leachate. The California Integrated Waste Management Board (CIWMB 2006) is in the process of developing approaches that can provide better assurance that adequate postclosure funding for landfill monitoring, maintenance, and groundwater remediation will be available for as long as the wastes in the landfill will be a threat. Lee and Jones-Lee (2007c) have reviewed the issue of the need for assured long-term funding for landfill postclosure monitoring and maintenance in support of CIWMB efforts to require the landfill owners to develop this funding.

### Construction and Demolition Waste Landfills

Over the years G. F. Lee has been involved in reviewing landfills that are permitted to accept only construction and demolition (C&D) wastes. These types of wastes arise from construction activities and the demolition of structures. In some areas these wastes are considered by regulatory agencies to be "inert." However, as discussed by Lee (2002; 2006g,h), studies by the US EPA and the Ohio EPA have found that typical C&D wastes produce leachate that is a significant threat to cause groundwater pollution. Such wastes should not be considered inert, and should be managed through disposal in double composite lined landfills, where there is a high degree of certainty that the eventual failure of the upper composite liner will be detected before offsite pollution occurs.

***Morrow County (Ohio) Landfill.*** In the review of a proposed construction and demolition waste landfill in Morrow County, Ohio, Lee (2006g) discussed the approach that should be used in providing a higher degree of public health and groundwater quality protection from pollutants in

C&D wastes. This site has a complex hydrogeology, with sandy lenses that could allow transport of leachate-polluted groundwaters to offsite areas. As typically occurs, the landfill applicant and its hydrogeologist consultants did not adequately define the potential pathways for leachate-polluted groundwaters to be transported from under the landfill to offsite properties. Lee (2006g) recommended that a plausible worst-case approach be used to evaluate the potential for leachate transport in complex groundwater aquifer systems where it is not possible to readily predict leachate-polluted groundwater flow paths. He also recommended that all existing and new water supply wells within several miles of the landfill be periodically monitored, in perpetuity, for the purpose of detecting incipient groundwater pollution by landfill leachate. This program should be funded by the private landfill developer. This approach should be applied to all landfills and other waste management areas where it is not possible to reliably monitor for groundwater pollution before offsite pollution occurs. This is a prudent public health and groundwater quality protection strategy.

***Old Gentilly Landfill.*** The city of New Orleans, with permission by the Louisiana Department of Environmental Quality (LDEQ), is allowing the demolition wastes associated with cleanup of the hurricane Katrina impacts on the city to be disposed of on top of a closed unlined municipal landfill, at the rate of 20,000 tons per day, with a proposal to increase that rate to 50,000 tons per day. LDEQ assumed that these C&D wastes were inert without any evaluation of the potential for components in the wastes to leach pollutants. Lee (2006h,i,j) has discussed that this approach can readily lead to significant groundwater and environmental pollution associated with the New Orleans C&D Katrina-caused wastes.

***Recommended Approach.*** As discussed by Lee and Jones-Lee (2007a), construction and demolition wastes should be carefully evaluated for potential pollutants and placed in properly sited, designed, operated, closed, monitored and maintained (in perpetuity) landfills. Lee and Jones (1982) discussed a risk assessment approach for evaluating the potential for solid wastes to be adverse to public health and the environment through migration of waste components from the area of deposition. This approach requires an understanding of the potential for waste components to be released from the waste source, be transported to a location of concern, and impact public health and the environment at that location.

Lee and Jones-Lee (2007a) recommend that an evaluation procedure similar to "The Designated Level Methodology for Waste Classification and Cleanup Level Determination," developed by Marshack (1989), of the California Central Valley Regional Water Quality Control Board, be conducted to determine if C&D waste components have the potential to be leached and thereby pollute groundwaters. This methodology involves appropriately conducted leaching tests, an evaluation of the potential for transport of the leached pollutants from the waste deposition area to a location of concern (such as an offsite groundwater at the property line), and an evaluation of the potential for any pollutants transported offsite to be adverse to public health and/or the environment.

### Enhanced Groundwater Recharge

With the difficulties of constructing new surface water storage reservoirs to store water that can be used during periods of drought, increased attention is being given to enhanced groundwater recharge, where surplus surface waters are infiltrated or injected into an aquifer, and recovered as needed. This approach can be cost-effective for enhancing water supply storage capacity, especially in those areas where the water table has been drawn down, through pumping. Many areas of California have considerable potential for storing additional water in the unsaturated part of aquifers.

There are two basic approaches that are used. One is based on the construction of infiltration basins, where surface waters are allowed to infiltrate through the soil column into the aquifer. The other approach, which is gaining increased popularity, is aquifer storage and recovery (ASR), where surface waters are pumped into the aquifer through an injection well. The infiltration basin approach, in which water is allowed to percolate through the upper parts of the soil column, has considerable advantages in removing a variety of pollutants, including TOC, in the near-surface soil (vadose zone) from the recharged surface waters. The ASR approach, however, injects all of the chemicals in the recharge water into the saturated zone of the aquifer. As discussed by Lee and Jones-Lee (2005c), this can lead to significant water quality and aquifer quality problems.

G. F. Lee has been active in evaluating the use of enhanced groundwater recharge, with particular reference to potential problems that can develop when pollutants are present in the recharged surface waters that have the potential to contaminate the aquifer and thereby adversely impact the quality of the recovered waters, as well as the ability of the aquifer to serve as a water storage area (aquifer quality). Lee was a member for many years of the American Society of Civil Engineers (ASCE) Managed Aquifer Recharge Standards Committee. This Committee developed a report, "Standard Guidelines for Artificial Recharge of Ground Water" (ASCE, 2001).

Lee and Jones-Lee have published a number of papers and reports on these issues, which are available on their website, at http://www.gfredlee.com/plandfil2.htm#gwrecharge. In the spring of 2005, in connection with the CVRWQCB's review of the city of Tracy's proposed injection of the city's treated domestic water supply into the aquifer underlying the city as part of an ASR project, they submitted comments to the Regional Board, "Water/Aquifer Quality Issues That Need to Be Considered in Enhanced Groundwater Recharge Projects" (Lee and Jones-Lee 2005c). They pointed out that the current regulatory approaches allow chemicals such as TOC in drinking water used for domestic purposes, which can have significant adverse impacts on water quality and aquifer quality. There is a lack of understanding regarding the fact that a water that is judged to be suitable for domestic consumption (i.e., meets all the current drinking water maximum contaminant levels) is not necessarily suitable for injection into the groundwater as part of an ASR project. Lee and Jones-Lee (2005c) have discussed these issues, pointing out that there are a variety of reactions that can occur in groundwaters with ASR injected chemicals that can be adverse to groundwater quality and aquifer quality.

At this time the CVRWQCB is taking a case-by-case approach in reviewing proposed enhanced groundwater recharge projects, especially those involving ASR.

One of the issues of greatest concern to the CVRWQCB staff with respect to injecting treated domestic water supplies into the aquifer as part of an ASR project is the presence of trihalomethanes (THMs) in the treated water. These chemicals arise from disinfecting surface waters, where there is an interaction between a disinfectant, such as chlorine, and the total organic carbon in the water, to produce chloroform-like chemicals (THMs). Chloroform and the other THMs are regulated as carcinogens. Their injection into a groundwater is a violation of the CVRWQCB Basin Plan.

Recently there have been reviews on water quality aspects of ASR, which provide additional information on the fate/persistence of THMs and other pollutants associated with groundwater recharge, with particular reference to ASR projects. These include Dillon and Toze (2005) and Dillon and Malloy (2006). Their reports include some information on the potential for TOC and other pollutants in the injected surface waters to damage the ability of the aquifer to store surface waters for later recovery.

***Incidental Groundwater Recharge.*** A number of streams, rivers and other waterbodies in the Central Valley and elsewhere are "losing" waterbodies with respect to groundwater recharge – i.e., waters in the waterbody are contributing to groundwater recharge. Lee and Jones-Lee (1993d, 1995b) have discussed the potential for constituents in streams that incidentally recharge groundwaters to cause groundwater pollution. A situation of this type occurs in Putah Creek, downstream from where the University of California, Davis, discharges its domestic wastewaters to the creek. Putah Creek has been found to contribute water and pollutants to groundwaters. The UCD/DOE LEHR Superfund site has polluted several of the aquifers underlying and to the east of the site with chloroform and other VOCs. Studies on the sources of the VOCs and, particularly, chloroform in groundwaters near Putah Creek have shown increased concentrations compared to those a distance away from the creek, indicating that the recharge of Putah Creek water, which contains chloroform derived from the UCD campus wastewater treatment plant, to the groundwaters is polluting the groundwaters with chloroform.

Lee (1997c) provided detailed comments on the deficiencies in the CVRWQCB draft National Pollutant Discharge Elimination System (NPDES) permit for UCD's wastewater treatment plant, in which he discussed the need to restrict the allowed discharges from this treatment plant which are causing pollution of Putah Creek. One of the areas of concern is the presence of chloroform in the UCD campus wastewater discharges to the creek, which pollutes groundwaters through Putah Creek incidental recharge to groundwater. The CVRWQCB did not incorporate into the UCD wastewater treatment plant NPDES permit restrictions on constituents in the wastewater treatment plant discharge to the creek that could cause groundwater pollution through incidental groundwater recharge. All NPDES wastewater discharge permits should include an evaluation of the potential to pollute groundwaters by constituents in the wastewaters discharged to waterbodies that recharge groundwater.

### Stormwater Infiltration

The infiltration of urban area and highway stormwater runoff as a best management practice (BMP) is used as a means of reducing the stormwater-runoff-associated pollutant load to surface waters. Lee et al. (1998) and Taylor and Lee (1998) have reviewed the issues that need to be considered in using stormwater infiltration as a means of surface water pollution control.

Based on a literature review, there can be significant problems with infiltrating urban area and highway stormwater runoff into aquifers, which can lead to groundwater pollution. There is a basic problem with stormwater infiltration as a BMP, in that those situations where the unsaturated part of the aquifer will accept large amounts of infiltrating water (such as sand and gravel systems) are the systems that have the poorest ability to remove pollutants through sorption on the aquifer solids. Lee et al. (1998) recommend that any stormwater infiltration that is practiced as part of BMP development/implementation be accompanied by comprehensive proactive groundwater monitoring to determine if the infiltrating stormwater has the potential to pollute groundwaters. Situations such as that allowed by the CVRWQCB, where Modesto, California, has for years been allowed to dispose of its stormwater in dry wells, without monitoring to determine if groundwater pollution is occurring, should not be allowed.

**Shallow Water (Class V) Injection Wells**

The US EPA has the responsibility for regulating injection wells. In 1998 the Agency proposed rules for regulating Class V injection wells, which are shallow wells that are used for infiltrating stormwater or surface waters into near-surface aquifer systems. Lee (1998), as a member of a review panel for the US EPA, provided comments on the need for the Agency to develop a comprehensive approach toward regulating shallow Class V injection wells, in order to protect groundwater quality. The Agency, in its final promulgation of the Class V injection well regulations, did not provide for adequate monitoring of such injection wells to protect groundwaters from pollution by contaminants in the injected surface waters.

**Deep Well Injection**

Deep well injection of wastewaters can cause groundwater pollution. While current regulatory approaches are somewhat improved in protecting groundwater from near-term pollution by the injected wastewaters, there are potential long-term problems that can occur where the injected wastewaters pollute groundwaters when the injection containment system no longer maintains its protective character. Information on these issues is provided in discussions of deep well injection on the Internet (e.g., http://www.frtr.gov/matrix2/section4/4-54.html).

**Septic Tanks**

Individual wastewater disposal systems (septic tanks) used in rural and in some developing urban areas can be a source of pollutants for groundwaters. A review of the SWRCB website reveals that there are a number of areas in California where domestic septic tanks have polluted groundwaters. The CVRWQCB Basin Plan makes several references to septic tank systems as a source of groundwater pollution. There is confusion, however, about the "failure" of a septic tank system, with respect to groundwater pollution. Typically, a septic tank is said to "fail" when wastewaters discharged to the septic tank come to the surface. While the presence of septic tank effluent on the surface of the soil in the vicinity of the system is a failure of the septic tank wastewater disposal system to prevent land surface pollution, this situation is independent of groundwater pollution by septic tank systems. In fact, septic tank system wastewaters that do not come to the surface are, therefore, transporting pollutants in the wastewaters to the local groundwater system, which can cause groundwater pollution. This pollution can represent an isolated situation in areas of low residential development, although even there, an individual residential well can be polluted by the household septic tank. In areas of intense residential development, large-scale pollution of groundwaters can occur.

There were situations in the 1960s in the sandy areas of Wisconsin where there was intense residential development, involving the use of septic tanks for wastewater disposal. The household residents used to complain about the fact that, on Tuesday and Wednesday, their residential water supply wells produced water that had a foam on it. It was determined that, since many of the households washed clothes on Monday, the non-biodegradable detergents used at that time were demonstrating that there was a direct connection between groundwater polluted by a septic tank wastewater disposal system, and the domestic water supply well. The solution adopted to solve this problem was to ban the use of non-degradable detergents. While this approach did not eliminate the problem of wastewaters from septic tanks being connected to a source of domestic water supply, it did eliminate the evidence of this, since the foaming problem disappeared.

While teaching and conducting research at the University of Wisconsin, Madison, G. F. Lee became involved in investigating the potential for septic tank wastewater disposal systems to contribute pollutants to nearby waterbodies. Of particular concern was the siting of new developments on the shores of a new reservoir or other waterbody, where the septic-tank-associated wastewaters transported pollutants to the waterbody through subsurface flow. The constituents of greatest interest were nitrogen and phosphorus compounds in the household wastewaters that, upon entering a surface water, would stimulate excessive growths of aquatic plants. At the time of these studies it was well established that the ammonia and, to some extent, organic nitrogen present in household wastewaters would, upon contact with oxygen in the vicinity of the septic wastewater disposal system tile field, be nitrified and thereby contribute nitrate, which would move with the groundwater.

There was uncertainty, however, about the potential for phosphorus transport in groundwater systems. Ordinarily, phosphorus is not transported in groundwaters. Phosphorus tends to precipitate on the aquifer solids for those systems that have elevated calcium carbonate (hard water). However, in quartz sand aquifer systems, which do not have significant iron oxide coatings on the sand, the phosphorus sand particles do not precipitate/sorb phosphorus, with the result that the phosphorus is transported from septic tank wastewater disposal systems in groundwaters to surface waters, leading to excessive fertilization of the waterbody. Jones and Lee (1977, 1979) have discussed these issues and provided details on the study of the transport of phosphorus in a sand aquifer system associated with a septic tank wastewater disposal system.

**Shallow Groundwater and Surface Water Interaction**

There are a number of situations where pollutants in groundwaters can cause pollution of surface waters. These are associated with shallow groundwater systems that discharge to surface waters. Of particular concern is the use of subsurface drains in irrigated agriculture to lower the water table. Also of concern is the disposal of domestic wastewaters on land, which can pollute shallow groundwaters.

***Subsurface Drains.*** In the Grasslands Bypass area of the Mud and Salt Slough watersheds in the Central Valley of California, subsurface drains have been constructed to lower the water table, associated with irrigated agriculture. A number of pollutants are present in the subsurface drain waters, such as nitrate, salts, selenium, boron, etc., that pollute the surface waters where the drains discharge. As discussed by Lee and Jones-Lee (2003b), the subsurface drain waters from the Grasslands area are rich in nitrogen and phosphorus, which stimulate prolific growths of algae in the drainage ditches receiving the subsurface drain water. The algae that develop from the subsurface drain water nutrients become the seed algae that lead to high concentrations of planktonic algae that are present in the discharges of Mud and Salt Sloughs to the San Joaquin River. These discharges are the initial source of algae that continue to develop along the San Joaquin River, ultimately dying and decomposing in the San Joaquin River Deep Water Ship Channel, leading to the problem of low dissolved oxygen in the channel.

***Wastewater Discharges to Land.*** There are several examples in the San Joaquin River watershed where the CVRWQCB restricts municipalities from discharging their domestic wastewaters to tributaries of the San Joaquin River during the low-flow summer months. During these times the municipalities discharge their wastewaters to the land surface. Pollutants in the wastewaters, such as nitrogen compounds that are converted to nitrate, and salts, pollute the shallow groundwater. The shallow groundwater, in turn, discharges to nearby surface waters, contributing the pollutants to the surface water system. Lee and Jones-Lee (2000b, 2003b) have discussed these issues with respect to Modesto, Merced and several other communities in the San Joaquin River watershed. Their discharges of wastewaters to the land are polluting shallow groundwater that, in turn, pollutes nearby tributaries of the San Joaquin River. This, in turn, contributes to the pollutant load that is contributing to the water quality problems in the San Joaquin River and the Stockton Deep Water Ship Channel.

In addition to the potential for polluting shallow groundwater (discussed above), land disposal of domestic wastewaters can (and, in fact, usually does) lead to deeper groundwater pollution in the Central Valley by nitrates, salts and potentially other chemicals. The rapid urbanization of the areas south of Stockton, California, is causing increased concern about groundwater pollution associated with the on-land disposal of domestic wastewaters. W. Jennings of the California Sportfishing Protection Alliance (CalSPA 2006) has recently reviewed this issue with respect to the city of Lathrop's proposal for wastewater reclamation. All land disposal of domestic and industrial/commercial wastewaters should include a critical review of the potential for land disposal of wastewaters to lead to groundwater pollution. Further, a comprehensive monitoring program should be required that is designed to detect incipient groundwater pollution before widespread pollution occurs.

McHenry (pers comm., 2006) of the CVRWQCB has indicated that land application of domestic wastewaters is one of the most widely used wastewater management/disposal approaches in the Central Valley of California. G. F. Lee has been involved in reviewing the potential surface water and groundwater impacts of land application of domestic wastewaters in various parts of the US since the 1960s. While teaching at the University of Wisconsin, Madison, where he was Director of the Water Chemistry Program, he was involved in reviewing the potential impacts of the Corps of Engineers' proposal to stop treating the city of Madison's wastewaters by conventional primary and secondary treatment, and instead spread the wastewaters on agricultural lands. This approach was not adopted because of the potential adverse impacts to both surface waters and groundwaters. Lee (1976) discussed the "Potential Problems of Land Disposal of Domestic Wastewaters." Jones and Lee (1978) presented an invited paper, "Chemical Agents of Potential Health Significance for Land Disposal of Municipal Wastewater Effluents and Sludges," which discusses some of the potential environmental problems of hazardous chemicals in domestic wastewaters and their sludges. Lee and Jones (1986) provided a discussion of a hazard assessment approach for evaluating potential environmental impacts of treated domestic wastewaters.

In the 1990s Lee and Jones-Lee published several papers on the potential public health and environmental problems associated with land application of reclaimed wastewaters. These are listed and available from their website, at http://www.gfredlee.com/preclaim2.htm. They point out that the degree of treatment of domestic wastewaters that is allowed in California (and, for that matter, many other areas) does not eliminate the potential for surface water and groundwater pollution associated with the use of the reclaimed wastewaters for shrubbery irrigation, parks, golf courses, etc. These uses can lead to both surface water and groundwater pollution with hazardous chemicals and pathogens. Jones-Lee and Lee (2001) presented a paper, "Evaluation of Inorganic and Organic Nutrient Source Impacts in Nutrient TMDLs." The focus of this paper was on the aquatic plant nutrients (nitrogen and phosphorus compounds) in domestic wastewater sludges (so-called "biosolids") as a potential cause of surface water and groundwater pollution.

Based on past and current NPDES permit adoptions, the CVRWQCB is allowing municipalities to discharge/dispose of their domestic wastewaters to land without requiring that comprehensive studies be conducted of existing groundwater quality prior to disposal. Based on the characteristics of the domestic wastewaters that are allowed to be managed by land disposal and the hydrogeological characteristics of the Central Valley aquifer system, as well as the past history of vulnerability of the Central Valley aquifer to pollution by land disposal of wastes, the CVRWQCB currently-allowed practice of land disposal of domestic wastewaters has a significant potential for groundwater pollution, in violation of the Basin Plan. G. F. Lee has found that the current CVRWQCB review of the potential impacts of disposal of domestic wastewaters on land is significantly deficient compared to that needed to properly evaluate the potential for land disposal to lead to groundwater pollution by treated wastewater components. As part of obtaining an NPDES permit for disposal of domestic wastewaters, studies should be conducted that would provide a reliable, in-depth assessment of the potential for the proposed land disposal of municipal, commercial and industrial wastewaters to lead to violations of the CVRWQCB Basin Plan for protection of groundwater quality.

With the shift away from landfilling of green wastes, such as yard trimmings, where these types of wastes are composted and used as a soil amendment, there is need to evaluate the potential for various types of pollutants, including nitrogen compounds, in compost to lead to surface water and groundwater pollution. Further, various chemicals, such as pesticides/herbicides, that can be present in composted yard waste can cause surface water and groundwater pollution. Gintautas et al. (1992) reported finding a phenoxyalkanoic acid herbicide in municipal landfill leachate which had not been previously reported. They concluded that the chlorinate 2-phenoxypropionic herbicides are ubiquitous in MSW landfill leachates in the US. These herbicides are used on residential lawns for control of broadleaf plants (dandelions). These same compounds and others are likely present in composted yard waste. While not normally done, any compost should be evaluated with respect to the presence of commonly used pesticides and herbicides, to determine if they are present in the compost.

Overall, the land application of domestic wastewaters and/or their sludges is a potentially significant source of surface water and groundwater pollution that needs to be carefully evaluated and monitored associated with this method of wastewater/sludge management/disposal. In the Central Valley of California, such monitoring is likely to show that significant groundwater pollution is occurring from such activities.

***Lake Tahoe Water Quality Issues.*** G. F. Lee first became involved in Lake Tahoe water quality issues in the 1960s, when he served as a member of a team of consultants examining water quality management issues in the Tahoe Keys. Here, the primary issue was excessive growths of algae in the channels associated with the Tahoe Keys, in which nutrients, likely derived from fertilization of the lawns near the channel, drained into the Keys channels, leading to excessive growths of algae. During the mid-1970s, G. F. Lee was selected by the US EPA to develop a synthesis report covering the water quality characteristics of the waterbodies that were included in the international Organization for Economic Cooperation and Development (OECD) eutrophication studies. These studies represented a $50-million, five-year effort, involving 22 countries in western Europe, North America, Japan and Australia. The focus of the studies was to examine the relationship between aquatic plant nutrient loads to waterbodies and their eutrophication-related water quality. The US part of these studies, involving 34 waterbodies, included having various investigators provide information in a standard format on nutrient loads and eutrophication response for their waterbody. G. F. Lee had the responsibility of developing a synthesis report from the US OECD waterbody studies. This report (Rast and Lee 1981) was presented to the US EPA. A summary of this report was published as Lee et al. (1978).

Lake Tahoe was one of the waterbodies included in the US OECD studies. University of California, Davis, faculty (Goldman) was responsible for developing the background information on nutrient sources and lake characteristics. Rast and Lee (1981) found that the estimates of nutrient loads for Lake Tahoe did not include the atmospheric and groundwater sources. In 1989, while Dr. Lee held the position of Distinguished Professor of Civil and Environmental Engineering at the New Jersey Institute of Technology, he became involved in a study of the impacts of residential development on Lake Tahoe water quality. At that time, California and the Tahoe region were experiencing a significant drought. As a result, the water levels in Lake Tahoe were below normal, where there were considerable previously underwater areas of the lake's near-shore environment that were above the waterline. Examination of the near-shore areas of the lake revealed numerous locations where there were seeps of groundwater discharged to the now-exposed lake sediments. Many of these seep areas had prolific growths of algae associated with them, indicating that the groundwaters being discharged, now above the lake level, were rich in nutrients.

In a number of locations it was possible to relate nearby land use to a potential source of the nutrients that were being transported to the lake. These included residential and commercial lawns for lakeshore property, including golf courses, that were being fertilized. Lee and Jones (1992) developed a report, "Role of Vehicular Exhaust NOx and Lawn-Shrubbery Fertilizers as a Cause of Water Quality Deterioration in Lake Tahoe," discussing this situation. They pointed out that, with ordinary Lake Tahoe water levels, the nutrients added to the lake via shallow groundwater transport from nearby properties would not have been detected. They also pointed out that both nitrogen and phosphorus were being transported in the shallow groundwaters, since both would be needed to stimulate the growth of algae observed in the near-shore environment of the lake. This situation is indicative of the shallow groundwater aquifer solids having little or no ability to remove phosphorus.

Lee and Jones-Lee (1994c) presented a review of Lake Tahoe nutrient sources, pointing out that one of the most likely significant sources of nitrogen for Lake Tahoe was vehicular traffic in the Lake Tahoe watershed. Also, a potentially significant source of nitrogen and phosphorus for Lake Tahoe was the shallow groundwater transport from areas of the lake's watershed that formerly utilized septic tanks for wastewater disposal. In the 1960s the regulatory agencies developed a sewerage system for the Lake Tahoe watershed, in which all domestic wastewaters generated in the watershed were collected and pumped out of the watershed. This meant that all of the household septic tank systems were no longer being used.

While this approach stopped the loading of the groundwaters by nutrients and other pollutants from septic tank systems, it did not prevent the legacy of polluted groundwaters from being a source of nutrients for the lake. As discussed by Lee and Jones-Lee (1994c), there will be a long-term addition of nutrients to Lake Tahoe from the legacy of septic-tank-derived nutrients in the shallow groundwater that is moving to the lake and likely discharging below the lake surface. In order to stop this source of pollution there is need to investigate the nutrient characteristics of the shallow groundwater entering the lake from those areas that were formerly served by a septic tank, and then determine if it is possible to intercept the shallow groundwater before it enters the lake, and remove nutrients from it.

There are many other examples of shallow groundwater being polluted by waste management activities, which in turn leads to surface water pollution. One of these is the Royal Mountain King Mine located in Calaveras County The owners of this mine constructed a lagoon to collect polluted waters associated with former mining activity. It became evident that this unlined lagoon was polluting groundwaters, which, a short distance downgradient, were surfacing in a local stream. These types of situations are fairly common, especially in mountainous areas.

***Pollution of Surface Waters by Deeper Groundwaters.*** There is the potential for groundwaters that do not naturally come to the surface, to pollute surface waters through irrigation pumping of polluted groundwaters. This pumping can bring pollutants that ordinarily would not be on the land surface, to the surface and thereby adversely affect public health and/or the environment. An example of this type of situation occurs at the University of California, Davis, LEHR Superfund site, where past UCD waste disposal practices have polluted substantial areas of groundwaters underlying adjacent properties that are used for irrigated agriculture. The pumping of this polluted groundwater brings to the surface chloroform and other pollutants in the groundwater that would not normally be present in the agricultural fields.

DSCSOC (2006), as part of its efforts to evaluate the adequacy and reliability of the human health and ecological risk assessment for the LEHR Superfund site investigation/remediation, has raised this issue in connection with discussing the significant deficiencies in the approach that UCD was allowed to follow in conducting the ecological risk assessment for the LEHR Superfund site. It was DSCSOC's position that this situation should be evaluated and discussed. Unfortunately, the regulatory agencies at the federal and state level did not require that UCD make this evaluation. Without such an evaluation at this site and other sites where polluted groundwaters are used for irrigated agriculture, it is unknown whether the pollutants brought to the surface through crop irrigation are having an adverse impact on public health and/or the environment.

**Dust Suppressants**

A groundwater quality protection issue of concern in those areas where dirt roads or lands under development are treated to reduce dust is the potential for the dust suppressants to cause surface water and groundwater pollution. Of particular concern is that some of the dust suppressants used are chemicals, including wastes. This was the situation that led to the Times Beach, Missouri, pollution of soils with dioxins, where chemical wastes containing dioxins were used as dust suppressants.

In 2002 the US EPA organized an expert panel to review the issues of the potential for various types of dust suppressants to cause surface water and groundwater pollution. This panel's report (US EPA 2004) is available at http://epa.gov/esd/cmb/pdf/dust.pdf. G. F. Lee, as a member of this panel, developed a report (Lee and Jones-Lee 2004b) discussing the approach that can be used to evaluate whether the chemicals/wastes used as dust suppressants have the potential to cause surface water or groundwater pollution.

**Natural Attenuation**

Several years ago the SWRCB issued a contract to Lawrence Livermore Laboratory to develop guidance for implementing natural attenuation, through dilution and transformation, associated with the remediation of gasoline pollution of groundwater from leaking underground storage tanks. The Lawrence Livermore modeling effort focused on the disappearance of benzene, toluene and xylene (BTX) as a measure of adequate natural attenuation. Lee (1997d), in response to a request for comments by the SWRCB on the Lawrence Livermore modeling approach, pointed out that there are a wide variety of other components besides BTX in gasoline, including degradation products, that can pollute groundwaters. As a result, any assessment of natural attenuation must be based on the fate and persistence of the full range of chemicals in gasoline, including their transformation products. Following the Lawrence Livermore natural attenuation modeling approach could grossly underestimate the potential for leaking underground gasoline storage tanks to cause groundwater pollution beyond the area where benzene, toluene and xylene are persistent. The inappropriateness of the Lawrence Livermore/SWRCB proposed approach for assessing the adequacy of natural attenuation has subsequently been demonstrated by the widespread pollution of groundwaters by MTBE, a gasoline additive. MTBE persists in groundwaters to a much greater degree than BTX compounds.

**Unrecognized Pollutants**

There is increasing concern about pharmaceuticals and other unregulated chemicals from confined animal facilities (CAFs), domestic wastewaters and municipal landfills to cause water quality problems in surface waters and groundwaters. The current approach for monitoring potential pollutants is significantly deficient in that it considers only a hundred or so chemicals of the many tens of thousands of chemicals that are discharged to waters from urban and agricultural sources. Daughton (2002, 2004) of the US EPA has indicated that there are over 22 million organic and inorganic substances, with nearly 6 million commercially available. The current water quality regulatory approach focuses on "Priority Pollutants" and other conventional pollutants, which represent less than 200 of these chemicals. A group of these unregulated chemicals is pharmaceuticals and personal care products (PPCPs). These chemicals have the potential to have adverse effects on organisms at very low concentrations. According to Daughton, *"Regulated pollutants compose but a very small piece of the universe of chemical stressors to which organisms can be exposed on a continual basis."*

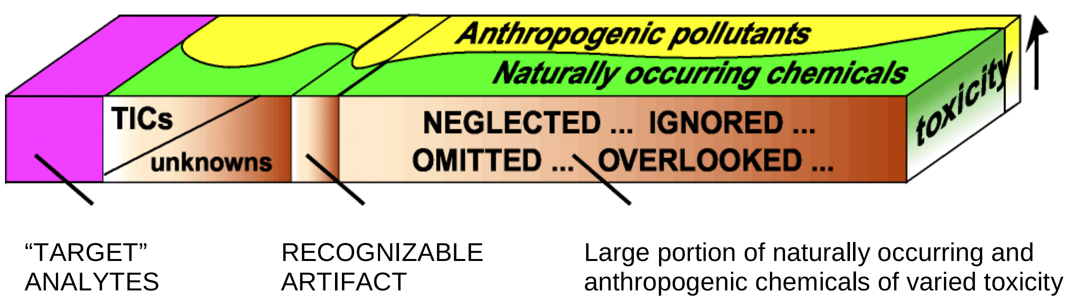
Daughton has indicated that one of the routes of environmental exposure to PPCPs is through trash placed in municipal solid waste landfills. He specifically singles out *"leaching from municipal landfills"* as an origin of PPCPs in the environment. He characterizes municipal landfills as "*pollution postponement*." MSW landfills receive substantial amounts of pharmaceuticals and other unregulated/unmonitored chemicals that become present in landfill leachate. In addition to being present in surface waters and groundwaters polluted by landfill leachate near the landfill, the disposal of MSW leachate in POTWs (municipal wastewater treatment plants) contributes to the pollution of the environment through discharges of "treated" wastewaters to surface waters. Additional information on PPCPs is available at www.epa.gov/nerlesd1/chemistry/pharma/index.htm.

Daughton has discussed the inadequacies of the current approach for monitoring water quality compared to the vast arena of chemicals discharged to the environment that are a potential threat to water quality. The inadequacy of current regulatory programs in defining hazardous chemicals has been discussed by Daughton in his presentation, "Overview of Science Involved with Pharmaceuticals," that was made in August 2005 at a Las Vegas US EPA workshop. Daughton stated in one of his PowerPoint slides,

> *"Further Truisms Regarding Environmental Monitoring*
> - *What one finds usually depends on what one aims to search for.*
> - *Only those compounds targeted for monitoring have the potential for being identified and quantified.*
> - *Those compounds not targeted will elude detection.*
> - *The spectrum of pollutants identified in a sample represent but a portion of those present and are of unknown overall risk significance."*

His diagram of this situation is presented in Figure 2.

**Figure 2**
**Chemical Analysis Output for a Typical Environmental Sample**



This figure is from the following web page:
Daughton, C. C., “The Critical Role of Analytical Chemistry,” July (2002)
http://www.epa.gov/nerlesd1/chemistry/pharma/critical.htm

Daughton’s presentation at the Las Vegas workshop is available at
http://es.epa.gov/ncer/publications/meetings/8-23-2005/Daughton_0915_d1.pdf.
While this presentation focused on pharmaceuticals, as Daughton has discussed in other presentations and his writings, it is applicable to the full arena of hazardous chemicals that are not adequately identified, monitored and regulated.

Perchlorate is a chemical that has been recently recognized as a cause of groundwater pollution. Perchlorate is a component of some rocket fuels that has, in some areas, contaminated surface waters and groundwaters in sufficient concentrations to be adverse to human health. The situation that developed at the Aerojet-General Corporation, located near Sacramento, California, is an example of how dischargers and regulatory agencies’ narrow scope of defining potential pollutants can readily fail to detect significant pollution by unrecognized, unregulated pollutants. According to a document on the CVRWQCB (2006b) website,

> *“Aerojet-General Corporation operates a rocket-testing and chemical manufacturing facility in eastern Sacramento County. Past practices at the facility has led to pollution of the groundwater on and off the Aerojet property.”*

Initially the CVRWQCB required that Aerojet pump and treat (air-strip) polluted groundwaters to remove volatile organic compounds (VOCs) and 1,4-dioxane. The CVRWQCB allowed Aerojet to re-inject the air-stripped groundwaters into the aquifer. Subsequently it was found that the extracted groundwaters contained perchlorate and several other chemicals as unrecognized pollutants. Aerojet is now having to pump the groundwaters it had re-injected, to more adequately clean up the pollution than was originally required

Perchlorate from other sources, such as nitrate fertilizers derived from Chile, is also being found as a cause of groundwater pollution. The recently held international conference on “The Future of Agriculture: Science, Stewardship and Sustainability” included a session on perchlorate pollution of the environment. Abstracts of papers on this issue presented at this conference are available at http://www.dce.k-state.edu/dce/conf/ag&environment/AbstractBook.pdf. The papers will be available in the proceedings of the conference, which are expected to be available in 2007.

Areas that contain TOC/DOC in groundwaters near waste disposal areas that have received complex mixtures of wastes are areas that could readily contain unrecognized pollutants. Situations of this type should be recognized as areas that may need further remediation as the components of the TOC/DOC are identified in future studies.

Lee (2005d) and Lee and Jones-Lee (2005d) have provided additional information on unrecognized pollutants. As the scope of water quality monitoring programs is expanded to better characterize water quality impairment, additional pollutants will be found, some of which have the potential to cause groundwater pollution.

**Sealing of Wells**

A commonly accepted practice for abandoning wells, for attempting to prevent surface water from entering the well and/or for attempting to prevent inter-aquifer transfer of water along the well casing is to use cement and/or bentonite clay to "seal" the well. Virtually every state and some local groundwater jurisdictions require/allow the sealing of wells with bentonite clay. While this practice is accepted as standard practice, a critical review of its long-term potential reliability shows that significant problems can develop in the seal, due to cracking. Cement is well known to crack. Sodium bentonite clay can also develop cracks due to ion exchange shrink-swell properties.

Bentonite is a montmorillonite expandable lattice clay, in which the spacing between the lattice layers is determined by the cation on the ion exchange sites. In the sodium form, where sodium is the cation at the exchange sites, the clay is in a swollen state. However, in contact with water which has higher calcium and magnesium than sodium, the calcium and magnesium will occupy the exchange sites, and the clay will shrink. This shrinkage can lead to cracking of a clay layer. It should therefore be understood that so-called "sealed" wells may lose their seal over time. DWR (1991), in their "California Well Standards," on page 19 states,

> *"Bentonite seals may have a tendency to dry, shrink and crack in arid and semi-arid areas of California where subsurface moisture levels can be low. Bentonite clay seals can be adversely affected by subsurface chemical conditions, as can cement-based materials."*

No information is provided by DWR, however, on the conditions that can lead to the failure of a bentonite-based seal. Lapham et al. (1997) with the USGS, in their report, "Guidelines and Standard Procedures for Studies of Ground-Water Quality: Selection and Installation of Wells, and Supporting Documentation," have included a detailed discussion of the potential problems with cement- and bentonite-based well sealants. This discussion includes (on page 69) Table 24, presented below.

Lapham et al. (1997) recommend that, in high-calcium-magnesium waters, a calcium bentonite clay be used, rather than sodium bentonite.

**Table 24.** *Characteristics of bentonite and cement as annular seals*[1] (From Lapham et al. 1997)

[Information from Claassen (1982), Gillham and others (1983), Driscoll (1986), Aller and others (1989), Hardy and others (1989), and ASTM (1992); ~, approximately]

**BENTONITE**

(A hydrous aluminum silicate composed primarily of montmorillonite with pH ranging from 8.5 to 10.5)

**Advantages:**

- Readily available and inexpensive.
- Several options for placement of the bentonite exist. The best method, however, is as a slurry made from a quick-setting powder, which is pumped into the annular space through a tremie pipe.
- If it remains saturated, it remains plastic and will not crack.
- Expands 10 to 15 times the dry volume when hydrated.
- Low hydraulic conductivity (about $1 \times 10^{-7}$ to $1 \times 10^{-9}$ centimeters per second).

**Disadvantages:**

- Effectiveness of seal is difficult to assess.
- Complete bond to casing is not assured.
- If it is not pumped into the annulus as a slurry, bentonite can stick to the walls of the annulus and bridge the annulus because of rapid hydration.
- Because of desiccation, bentonite generally is not an effective annular seal in the unsaturated zone (and is a poor surface seal).
- Can affect the chemistry of the surrounding ground water by cation exchange of Na, Al, K, Mg, Ca, Fe, and Mn from the bentonite with other cations in the ground water.
- Sets with a pH between 8.5 and 10.5, which can affect the chemistry of surrounding ground water that differs in pH.
- Most bentonites contain about 4-6 percent organic matter, which could affect the concentration of some organic constituents in ground water.
- Bentonite can react with high-salinity ground water and not set properly, resulting in a poor annular seal.

**CEMENT**

(Composed of calcium carbonate, alumina, silica, magnesia, ferric oxide, and sulfur trioxide with pH ranging from 10 to 12)

**Advantages:**

- Readily available and inexpensive.
- Can assess continuity of placement using temperature or acoustic-bond logs.

**Disadvantages:**

- Requires mixer, pump, and tremie pipe for placement.
- Generally, cleanup required exceeds that required for bentonite.
- Contamination can be introduced to borehole by the pump.
- Failure of the cement to form a seal can occur because of premature or partial setting, insufficient column length, voids or gaps in the column, or excessive shrinkage.
- Neat cement (cement and water) will shrink during the curing process, which could result in a poor seal between the cement and the casing or the borehole wall (Aller and others, 1989, p. 196).
- Heat of hydration during curing can deform or melt thermoplastic casing such as PVC in a 2-inch (~5 centimeter) annulus filled with cement as temperature rises to about 35-45°F (Smith, 1976; Driscoll, 1986, p. 324).
- Additives to the cement that compensate for natural shrinkage can cause an increase in pH, dissolved solids, and temperature of the ground water during the curing process. The increased pH can cause precipitation of calcium and bicarbonate ions from ground water that has a pH less than that of cement.
- Soluble salts in the cement can be leached by the ground water, thereby increasing the concentrations of calcium and bicarbonate in the ground water.
- Cement can cause unusually high values of pH in ground-water-quality samples.
- Most cement will react with high-sulfate ground water and deteriorate.

[1]Native materials at the site or cuttings returned from the borehole during drilling are commonly used as annular seals but are not recommended because they might be contaminated and likely would not have the properties required to seal the annulus adequately.

While the potential problems with cement and/or bentonite clays serving as a reliable long-term sealant for wells have been well known and discussed in the literature for over 40 years, these problems are largely ignored by regulatory agencies and others when they allow sealing of wells by bentonite clays and cement. From a groundwater quality protection point of view, it should be understood that many of the wells that have been "sealed" may, in time, allow for pollution of groundwaters by surface waters or the transfer of pollutants from one aquifer layer to another along the well casing.

**Chlorinated Solvents**

In the early 1970s G. F. Lee held the position of Professor of Engineering and Director of the Center for Environmental Studies at the University of Texas at Dallas. In this position he was involved in cooperative studies with the US EPA National Groundwater Research Center in Ada, Oklahoma. At that time, chlorinated solvents such as trichloroethylene (TCE), perchlorethylene (PCE), carbon tetrachloride ($CCl_4$) chloroform ($CHCl_3$), etc., were being found in groundwater-based domestic water supplies. These solvents are widely used by industry under conditions where wastes are produced that require disposal. On behalf of the US EPA, G. F. Lee conducted a review of the approach being used across the US to manage waste chlorinated solvents at industrial facilities. It was found that there were no national regulations on the management of waste solvents. Most states had no regulations governing waste solvent disposal. Several states allowed the disposal of waste solvents in lagoons. These clay-lined lagoons were used to store the solvents where they were allowed to evaporate. Some of the solvents were polluting groundwaters in the vicinity of the lagoon.

***Impact of Solvents on Clay Liners.*** It was found that the permeability of the lagoon clay liners was being evaluated using distilled water. Since the movement of solvents through clay liners would be expected to be different than distilled water, G. F. Lee initiated research on the penetration of packed clay columns that were similar to the clay liners being used in waste solvent lagoons. It was found (see Green et al. 1981, 1983, 1984) that solvents would cause packed clay columns to develop cracks.

While chlorinated solvents in water are immiscible (do not mix), small amounts of water do dissolve into a chlorinated solvent. The cracking of the clay layer is associated with dry solvents' removing from the packed clay the water that was used to achieve optimum moisture density. This dehydration of the packed clay leads to shrinking and cracking. However, if the solvent contains small amounts of water dissolved in it, the shrinkage/cracking does not occur. Since it would be unlikely that a waste solvent would be completely dry (i.e., contain no water), the effects of solvents on packed clays is not likely a significant factor in influencing the ability of packed clay liners to serve as a retardant for waste solvents. The rate of solvent movement through a packed clay liner is generally that of the rate of water penetrating through the clay liner.

***Pollution of Groundwaters by Solvents.*** According to Parmelee (2006), Editor of the American Water Works Association *E-Mainstream*, the US Geological Survey (USGS) has published a report (Carter et al. 2006) that finds that low-level VOC contamination of aquifers is widespread. Parmelee (2006) states, *"Volatile organic compounds (VOCs) were detected in 90 of 98 aquifers in a US Geological Survey study, with the most frequent detection occurring in California, Nevada, Florida, and the New England and Mid-Atlantic states."*

* * *

*The good news is that concentrations of VOCs found in domestic and public wells were mostly below the levels of human health concerns. Domestic wells in the study represented 61 percent and public supply wells 15 percent of wells with VOCs.*

*Almost 20 percent of the samples contained VOCs at a level of 0.2 µg/L and more than 50 percent of a smaller set of samples contained VOCs at a level of 0.02 µg/L. Samples were taken before any treatment or blending.*

*'VOC contamination in aquifers may be more prevalent than previously reported in monitoring programs that used analytical methods with higher reporting levels,' the report found. However, generally the total concentrations were less then 1 µg/L, which the agency defines as 'low.'*

*'Many of the nation's aquifers are vulnerable to low-level VOC contamination, indicating a need to include VOCs in groundwater monitoring programs,' concluded the report. The USGS also recommended continued control of VOC sources to track the trend of low-level VOC contamination."*

The top 10 VOCs found by the USGS (Carter et al. 2006) in groundwater were listed as

- Chloroform
- PCE
- MTBE
- Trichloroethene
- Toluene
- Dichlorodifluororomethane
- 1,1,1-Trichloroethane
- Chloromethane
- Bromodichloromethane
- Trichlorofluoromethane
- Bromoform
- Dibromochoromethane
- trans- 1,2-Dichloroethene
- Methylene chloride
- 1,1-Dichloroethane

According to Parmelee (2006),

*"Only about 2 percent of the public water supply wells tested in the USGS study had VOCs at levels above human health concerns. VOC detection in public wells is associated with utility size: VOC detection occurs more frequently and in greater concentration in larger community water systems, according to data from the US Environmental Protection Agency.*

*This may be because larger utilities pump larger quantities from an aquifer than smaller systems or domestic wells and therefore are affected by a larger area of the aquifer.*

*The USGS tested for 55 VOCs, and found 42 in the aquifer samples tested. The most frequently occurring VOC was chloroform, which was 'attributed, in part, to the recycling of chlorinated waters to aquifers.' Perchloroethene (PCE) and methyl tert butyl ether (MTBE) were the second and third most frequently detected compounds.*

*The publication of the study, Volatile Organic Compounds in the Nation's Ground Water and Drinking-Water Supply Wells, is part of the USGS National Water Quality Assessment Program. The USGS analyzed samples from more than 2,500 wells, which was augmented by VOC data from another 1,700 wells, including data from other USGS studies and from other agencies."*

***Chloroform in Groundwaters.*** The USGS finding of trihalomethanes (THMs), such as chloroform, bromoform and the chloro-bromo compounds, as common groundwater pollutants is of concern since it means that there is pollution of groundwaters by THMs derived from domestic water supplies and domestic wastewaters. This is an additional indication that domestic wastewaters are a source of groundwater pollution in some areas of the US.

The chloroform pollution of groundwaters at the University of California, Davis, LEHR Superfund site (discussed elsewhere in this report) is an example of the potential for chlorinated solvents to cause widespread groundwater pollution. These solvents are persistent in groundwaters (i.e., do not readily degrade) and travel with the water (i.e., have little or no retardation).

***PCE.*** The use of perchloroethylene (PCE) by dry cleaning establishments leads to some waste PCE that cannot be recovered. This waste PCE has caused groundwater pollution at a number of locations. G. F. Lee served as an advisor to the Yolo County Attorney General on a situation in Woodland, California, where the dry cleaning establishment dumped the waste PCE down a dry well outside the establishment. This led to groundwater pollution of that area.

The groundwaters underlying a number of California Central Valley cities, especially Lodi, are polluted by PCE. It is believed that the dry cleaning establishment owners/managers in these cities dump the waste PCE in the sewer. Since domestic sewerage systems frequently leak sewage to the groundwater, the PCE in the sewage pollutes the groundwaters of the area. The city of Lodi has entered into an agreement with the California Central Valley Regional Water Quality Control Board (CVRWQCB 2005) to undertake cleanup of PCE-polluted groundwater. Leaking sewers can also be a source of pollution of groundwaters by other constituents.

***Sacramento Rail Yard Site.*** In 1989, when G. F. Lee returned to California and became a full-time consultant, one of the first projects he undertook was on behalf of the city of Sacramento Planning Department. The City Council was concerned about the adequacy of California Department of Toxic Substances Control's oversight of the Southern Pacific (SP) Transportation Company's remediation of the rail yard located in downtown Sacramento. Subsequently, Union

Pacific Railroad Company acquired the rail yard from Southern Pacific and is now responsible for the site.

The issue of concern to the City Council was that the city required any redevelopment projects of this type to include some low-income housing. At that time, DTSC had proposed to allow SP to remediate areas where low-income housing was to be located with only two feet of clean soil overlying soils that had been polluted by lead, waste oil, petroleum hydrocarbons and other contaminants. Lee and Jones-Lee were issued a contract to review this situation. As part of this review, they concluded that two feet of clean soil was inadequate to prevent children in low-income housing from being exposed to lead and other pollutants that could be brought to the surface at some time in the future through construction or other activities. Lee (1993a,b; 1994) and Lee and Jones-Lee (1993e,f) prepared a series of reports pertinent to the SP site remediation issues. Ultimately, DTSC agreed with Lee and Jones-Lee, that two feet of clean soil on top of the highly polluted soil was not sufficient to prevent the polluted soil from coming to the surface where it could be a threat to public health and the environment. DTSC modified the remediation to include at least five feet of clean soil.

The issue of rail yard site remediation pertinent to this report is the pollution of groundwaters by TCE. TCE was extensively used at the site as part of degreasing of the locomotive parts. This TCE was allowed to infiltrate the groundwater. In the early 1990s a TCE/vinyl chloride plume, which originated at the SP site, extended south beyond Capitol Mall. The vinyl chloride arose from the bacterial dehalogenation of the TCE associated with utilizing organics derived from the SP site as a source of energy for removal of chlorine from the TCE. The formation of vinyl chloride is of particular concern since it is a known human carcinogen with one of the lowest maximum contaminant levels (MCLs). It is also very stable in groundwaters. There was concern about the potential threat that this plume represented to future groundwater users in the area. Also at the rail yard site, SP was found to have been disposing of waste battery sulfuric acid down a dry well. This caused localized pollution by the acid and sulfate.

P. Carpenter (pers. comm., 2006), current DTSC Rail Yard Site project manager, has indicated that low-income housing is no longer an issue at the site. There are still discussions about the amount of clean soil needed to cover contaminated soils, since this is dependent on how an area of the site will be developed. He also indicated that a source control extraction of TCE and other pollutants, as well as a downgradient pump-and-treat system of the TCE vinyl chloride plume, has been implemented. The most recent information on soil cleanup at this site is available on the DTSC website at http://www.dtsc.ca.gov/SiteCleanup/Projects/Sac_Rail_Yard.cfm.

***Toxicity of TCE.*** TCE is one of the most common causes of groundwater pollution. The Pentagon is reported by AWR (2006) to have 1,400 TCE-contaminated sites. TCE is a pollutant at about 60 percent of the worst Superfund sites. Currently the US EPA has established a TCE drinking water MCL of 5 µg/L. The National Academy of Sciences (NAS 2006) has reported that,

> *"The committee found that the evidence on carcinogenic risk and other health hazards from exposure to trichloroethylene has strengthened since 2001* [when the draft report was issued]. *Hundreds of waste sites are contaminated with trichloroethylene, and it is*

*well documented that individuals in many communities are exposed to the chemical, with associated health risks."*

The NAS report could become the impetus for reduction of the US EPA drinking water MCL for TCE, which could lead to even more sites that need remediation due to TCE pollution of groundwater.

**Underground and Aboveground Leaking Tanks and Spills**

The pollution of soils and groundwaters by leaking underground storage tanks is a well known problem. The widespread pollution of groundwaters by MTBE (a gasoline additive) has demonstrated the common occurrence of the leaking of underground storage tanks causing groundwater pollution. MTBE is more persistent, and therefore travels further, than BTX compounds.

The SWRCB has established a "GeoTracker" website (https://geotracker.waterboards.ca.gov/), which provides information on regulated facilities that have caused groundwater pollution in California. According to this website,

> *"GeoTracker is a geographic information system (GIS) that provides online access to environmental data. GeoTracker is the interface to the Geographic Environmental Information Management System (GEIMS), a data warehouse which tracks regulatory data about underground fuel tanks, fuel pipelines, and public drinking water supplies.*
>
> * * *
>
> *Now, GeoTracker contains well, tank, and pipeline data from all of California. This makes it an important resource to both regulators and the public."*

According to C. Condon (pers. comm., 2006) of the CVRWQCB, while the problems associated with the leaking of liquids from underground storage tanks have diminished, it has been found in several areas of the state that vapor releases from these tanks and their associated pipelines are a source of pollution. It is estimated that about 70 percent of the underground storage tanks are causing pollution near the tanks through vapor releases.

There is also a problem with aboveground storage tanks that develop leaks or spills. The State Water Resources Control Board and the Regional Boards have programs that specifically work on these problems.

With respect to aboveground storage tanks, the California legislature has developed legislation that requires that the State and Regional Water Quality Control Boards develop programs that focus on pollution prevention. Of particular concern are storage tanks for petroleum.

In October 2005 the SWRCB developed regulations governing underground storage tanks. Article 2 section 2620(a) of these regulations states,

> *"The regulations in this chapter are intended to protect waters of the state from discharges of hazardous substances from underground storage tanks. These regulations*

*establish construction requirements for new underground storage tanks; establish separate monitoring requirements for new and existing underground storage tanks; establish uniform requirements for unauthorized release reporting, and for repair, upgrade, and closure of underground storage tanks; and specify variance request procedures."*

**Protection of All Aspects of Groundwater Quality**

The authors have been involved in a number of situations where the regulatory agencies only consider some aspects of groundwater quality protection. For example, during the 1980s, the authors served as advisors to EBASCO Services in Lindhurst, New Jersey, on the REM III Superfund contract. This contract was a US EPA $200-million effort designed to prepare preliminary RI/FS's for national Superfund sites east of the Mississippi River. Lee and Jones served as consultants to the EBASCO site manager's staff on a variety of issues at various Superfund sites. One of the issues of particular concern was the approach that is used to remediate Superfund sites with respect to apparently nonhazardous pollutants. Some US EPA regions were interpreting Superfund regulations to focus the remediation only on so-called "Priority Pollutants," while ignoring other pollutants that would render the groundwater unusable for domestic and other purposes.

An example of this type of situation occurred in the work that the authors did on behalf of the US Army Construction Engineering Research Laboratory in Champaign, Illinois. They assisted the laboratory staff in conducting an investigation of the national Superfund site located at Fort Dix, New Jersey. The problems arose from pollution of groundwater by TCE and other chlorinated solvents associated with a former municipal landfill at the military base. In that investigation, they found that the US EPA focused the remediation on chlorinated solvent removal, while ignoring the vast arena of other chemicals in the groundwater that were not on the Priority Pollutant list. It became clear that the removal of TCE from the groundwater to meet drinking water MCLs would not restore the groundwater so that it could be used for domestic water supply purposes, due to taste- and odor-causing and other compounds that had polluted the groundwater.

A similar situation is occurring now at the UCD LEHR national Superfund site, where the focus of the US EPA's investigation and remediation is on chlorinated solvents (chloroform), radioactivity, TDS and nitrate. (The TDS and nitrate are included because of state of California requirements for remediation of polluted groundwaters.) However, the CVRWQCB (1998) Basin Plan requires that groundwaters be protected from pollution by taste- and odor-producing compounds, as well as toxicity. The Basin Plan states on page III-10.00,

*"**Tastes and Odors***

*Ground waters shall not contain taste- or odor-producing substances in concentrations that cause nuisance or adversely affect beneficial uses.*

***Toxicity***

*Ground waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life associated with designated beneficial use(s). This objective applies regardless of* *whether the toxicity is caused by a single substance or the interactive effect of multiple substances."*

DSCSOC has pointed out to the LEHR site regulatory agencies (RPMs) that, in order to fulfill the Basin Plan requirements, there is need to test the groundwaters for tastes and odors, and toxicity. However, thus far the RPMs have chosen to not require this testing. There can be little doubt that, since many of the groundwaters that are polluted by chemicals which are the focus of the current investigation/remediation program (so-called "constituents of concern") contain elevated concentrations of total organic carbon derived from waste management units at the LEHR site, there could readily be taste- and odor-producing compounds, as well as toxicity. This is another example of the regulatory agencies' choosing to ignore part of the requirements for fully investigating and then restoring groundwaters polluted at Superfund sites.

**Differences in the Pollution of Groundwaters versus Surface Waters**

There are some significant differences in the potential for some pollutants to impair the beneficial uses of surface waters versus groundwaters that should make regulatory agencies be more protective of groundwater quality. The most important difference between surface waters and groundwaters is that in surface waters, typically (but not for all chemicals) there can be fairly rapid recovery, once the source of the pollution is controlled. Processes of degradation/ transformation and dilution that occur in surface waters greatly aid the restoration of water quality. The exception to this is for persistent bioaccumulatable substances, such as the organochlorine legacy pesticides. For many surface water situations, chemicals which are toxic to aquatic life are rapidly diluted to nontoxic levels. Another factor is that in surface waters, photodegradation can play a major role in transforming a pollutant to a non-pollutant. However, in groundwaters, the slow rates of movement (from a few tenths of a foot per year to a few feet per day), coupled with the limited mixing that occurs in groundwater systems, greatly inhibits the ability of dilution/mixing to restore the quality of polluted aquifers.

For groundwaters, the restoration of groundwater quality upon controlling the source of pollution may be difficult, if not impossible to achieve. Where groundwaters are polluted by complex mixtures of chemicals, such as in landfill leachate, domestic and some industrial wastewaters, once a part of an aquifer is polluted, that part, even after so-called "remediation" (such as by pump-and-treat), should never be assumed to be usable again. The US EPA (1988a,b), as part of developing Subtitle D regulations governing municipal landfills, concluded that, once a part of an aquifer is polluted by municipal landfill leachate, any wells drawing water from that area must be abandoned, and a new well constructed in a non-polluted area. Similar situations exist for other types of pollution, where even if the primary target for remediation is controlled below a drinking water MCL, there still can readily be present in the aquifer unrecognized, unregulated pollutants, as well as transformation products of the original pollutant of concern.

In addition, for groundwaters situated in complex hydrogeological settings, it is difficult and expensive to reliably monitor groundwater quality. Overall, the current approach of primarily focusing water quality regulatory programs on surface water situations, while limiting or neglecting groundwater quality protection, needs to be significantly changed. Much greater attention needs to be given to protection of groundwater quality than is being done by regulatory agencies at the federal, state and local level.

**Non-Protective Regulations and Inadequate Implementation of Regulations**

While, as discussed above, Porter-Cologne is explicit in requiring groundwater quality protection in the state of California, there are situations where regulatory agencies/boards allow the potential pollution of groundwater based on the situation that federal and other state regulations do not adequately protect groundwater quality. An example of this type of situation recently occurred where the CVRWQCB concluded that since the NPDES regulations governing stormwater runoff from urban areas do not explicitly require groundwater quality protection from pollutants in the runoff, the recharge of a mixture of treated domestic wastewaters and stormwater was allowed. Under these types of situations, the Board could have applied Porter-Cologne requirements for groundwater quality protection.

Federal regulations do not limit the ability of states to implement more protective regulations. The federal regulations with respect to protecting groundwater quality are well known to be weak and largely ineffective in protecting the nation's groundwater quality. The weak federal regulations covering groundwater quality protection, as well as the inadequate implementation of California's Porter-Cologne regulations, represent a situation where those responsible for developing/implementing regulations do not want to cause those who conduct land surface activities that pollute groundwaters to have to pay the price for groundwater quality protection. This approach leads to permitting cheaper-than-real-cost land surface activities (such as waste disposal, irrigated agriculture, dairies) at the expense of future generations' loss of groundwater resources. Further, future generations will have to pay the costs of trying to remediate groundwater pollution that has been allowed by current regulatory practices.

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More information on groundwater quality protection issues is available at http://www.gfredlee.com/plandfil2.htm#gwprotection. If there are questions about this report, please contact G. F. Lee at gfredlee@aol.com. It is hoped that the information contained in this report can be used to improve groundwater quality protection associated with irrigated agriculture and on-land disposal of wastes, as well as other land-use activities that can lead to groundwater pollution.

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# Appendix A

**Dilemma: Managing Ground Water Quality and Irrigated Agriculture**
*by John Letey*

# DILEMMA: MANAGING GROUND WATER QUALITY AND IRRIGATED AGRICULTURE[1]

**JOHN LETEY[2]**

Agricultural activities occur at the land surface and aquifers are tens to hundreds of feet below the land surface. Yet, agricultural activities affect water quality in aquifers. By what means are surface activities connected to ground water quality and by what means can the negative consequences of surface activities on ground water quality be mitigated? The first part of this paper will review those physical-biological processes (water flow, chemical transport, and chemical transformation) that constitute the causative link between surface activities and ground water quality. An understanding of these processes is necessary to identify agricultural management strategies which reduce the risks of ground water degradation. A latter part of the paper will identify the dilemma in achieving the dual goal of high agricultural productivity and low ground water degradation. Finally, a set of guiding principles will be proposed to manage ground water quality and irrigated agriculture.

## PHYSICAL-BIOLOGICAL PROCESSES

Water Flow. The physical connection between agricultural activities and ground water quality is water flow from the surface to ground water which can transport potential pollutants. In the absence of water flow, agricultural activities are disconnected from ground water and the activities do not affect the water quality.

Water below the root zone flows largely in response to gravitational forces. Distance of water movement during a given time period is approximated by dividing the amount of water which passed the root zone (hereafter referred to as deep percolation) by the volumetric water content ($\theta$) of the strata below the root zone. The volumetric water content is the fraction of the total soil volume that is water. The value of $\theta$ is variable depending on soil properties and can range from approximately 0.20 to 0.45, with the lower value being associated with very coarse-textured strata.

For example, assume that irrigation is such that 6 inches of deep percolation occurs each year and $\theta$ has a value of 0.33. This water would move 18 inches per year toward ground water (6 divided by 0.33). Reliance on this estimate must be tempered because of variability of water application across the field. Calculation of amount of water flow below the root zone is usually made on a field basis and represents an average for the field. As will be discussed in more detail later, deep percolation can be much higher or lower in some parts of the field than the average value. Variability of flow can also be manifest at the microscale where water flows more rapidly in larger soil pores. This phenomenon has been referred to as preferential flow and has implications for transport of chemicals.

An understanding of these processes is necessary to identify agricultural management strategies which reduce the risks of ground water degradation.

Transport of Chemicals. Chemicals dissolved in water move with the flowing water. However, many chemicals interact with the soil particle surfaces. Clay and organic matter in soil have electric charges which are usually negative and interact with charged chemicals. Positively-charged chemicals are electrostatically attracted and negatively-charged chemicals are repelled by negatively-charged surfaces. Chemical composition of water can change as water flows through the soil because of exchange between elements in water and those on charged particulate surfaces. For example, calcium and magnesium are

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more strongly attracted than sodium to the negative clay surfaces, so there can be an exchange with sodium becoming more concentrated and calcium or magnesium becoming less concentrated in the solution as it passes through the soil.

Organic molecules such as those that are pesticides can also become attached to particulate surfaces via adsorption even though no electrostatic attraction is involved. This phenomenon can be observed by measuring the concentration of an organic chemical in solution before and after adding soil to the solution. The organic chemical concentration decreases after exposure to the soil. If these measurements are made with solutions of differing concentrations, an approximate linear relationship is often found between concentration of adsorbed chemical and the equilibrium concentration in solution. The slope of this curve is referred to as the adsorption coefficient ($K_d$), with larger $K_d$ representing higher adsorption. The numerical value of $K_d$ is dependent on chemical and soil properties. Increasing organic matter and/or clay content increases $K_d$ for a given chemical. Different chemicals have different $K_d$ values for a given soil.

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In the absence of water flow, agricultural activities are disconnected from ground water and the activities do not affect the water quality.

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As solution containing organic chemicals flows through the soil, the movement of the chemical is retarded by adsorption and moves less rapidly than water. The retardation factor (R) is numerically equal to $K_d$ times the bulk density of the soil (β) and divided by the volumetric water content and then adding 1 ($R = K_d\beta/\theta + 1$). The depth of organic chemical movement is approximated by dividing the depth of water penetration by R. As mentioned above, water may flow through different pores at different velocities. Thus, the transport of organic chemical in each pore is determined by dividing the water flow in each pore by R. The net effect is that most of the organic chemical concentration is where the average water flow penetration is divided by R, but some organic chemical is distributed both deeper and shallower than the computed value.

The transport of organic chemicals through soil by water will be illustrated using data for DDT, an insecticide which has been banned in the U.S. for several years, and TCE, a widely used industrial product. Typical $K_d$ values are 2,400 $cm^3/g$ for DDT and 1.4 $cm^3/g$ for TCE. Assume a soil with bulk density of 1.4 $g/cm^3$ and volumetric water content of 0.4. The retardation factor is 8,401 for DDT and 5.9 for TCE. If irrigation and precipitation resulted in 1 ft of deep percolation each year, that water would move to the water table at a rate of 30 in/yr (12 divided by 0.4). The average rate of chemical flow would be 0.004 in/yr for DDT and 5.1 in/yr for TCE. These values explain why DDT is not found in aquifers whereas TCE has been identified.

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. . . elimination of a chemical source will not be reflected in improved ground water quality for years.

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From this illustration, one can draw a few conclusions. First, water serves as the transporting medium, and irrigation and precipitation that penetrate below the root zone contribute to this flow. Second, adsorption of chemical to soil serves as a retardation factor and the higher the adsorption, the greater the retardation. Since transport is a rate factor, the time dimension is important. The impact of any land surface activity on ground water quality is delayed, usually for years. Any activity which initiates water flow and introduces a chemical which can be transported will not affect ground water quality for years, depending on the depth of ground water and other factors. Likewise, elimination of a chemical source will not be reflected in improved ground water quality for years.

Chemical Transformations. Significantly, many chemicals undergo transformations in the soil. They may be transformed to a chemical which is more or less toxic, and more or less mobile in the soil. Knowledge of transformation is important in assessing the impact of an agricultural activity on ground water quality, particularly those activities which include chemical applications. Many transformations are the result of microbial activity. Organic chemicals are classified as being biodegradable if they are broken down to innocuous forms in a relatively short time by microorganisms. Microbial activity is most rigorous in the upper part of the root zone where the microbes have a good supply of nutrients, energy source, and oxygen. Microbial activity decreases dramatically below the root zone where natural soil organic compounds which serve as an energy source may be limited. Very low rates of microbial transformations occur in the aquifer because the environment is not conducive to bacterial activity.

Detailed analysis of all the potential chemical transformations goes well beyond the scope of this paper. Each chemical must be analyzed separately. The main point is that chemical transformations do occur and the transformations have significant effects on the consequences of agricultural activity on ground water quality. A few examples will be given to illustrate the point.

Very low rates of microbial transformations occur in the aquifer because the environment is not conducive to bacterial activity.

DDT is an insecticide with a chemical form that is very resistant to degradation by bacteria. Therefore, the chemical is very persistent in the environment. However, as detailed above, DDT has a very high adsorption coefficient to soil so it is very immobile. Thus, it does not migrate to ground water. DDT is a hazard to surface water quality because it remains near the soil surface and is subject to transport to the stream by erosion.

Glyphosphate (Roundup™) is an extensively used herbicide. Roundup is readily decomposed to innocuous forms by soil microbes and additionally has a relatively high adsorption coefficient which reduces its mobility. These two factors greatly reduce the probability that Roundup will migrate to ground water.

Nitrogen serves as a good example of the consequences of chemical transformation on mobility and threat to ground water quality. Nitrogen in dead plant or animal material, manure, or sewage sludge is in an organic form which is neither mobile nor available for plant use as a nutrient. The same is true for commercially produced organic forms of nitrogen. Organic nitrogen is transformed by microbial activity into ammonium ($NH_4^+$) by a process referred to as mineralization. The rate of $NH_4^+$ formation is initially high and decreases logarithmically with time, the rate of which depends on the type of organic material to be decomposed and soil conditions.

Ammonium is available to plants and is not very mobile because the positive charge allows it to be electrostatically attracted to negatively-charged soil particulates. Ammonium is susceptible to rapid transformation to nitrate ($NO_3^-$) through a microbial process referred to as nitrification. Thus, the presence of $NH_4^+$ is transitory. Nitrate is available for plant use, but because it is electrostatically repelled by negatively-charged particulates, it is very mobile. Nitrate moves wherever water moves and at the same rate. The retardation factor for nitrate is equal to zero.

The reason that $NO_3^-$ is frequently observed at elevated concentrations in ground water is obvious. Nitrogen is a plant nutrient required in relatively large amounts for good crop production. All forms of applied N undergo transformations which lead to the formation of $NO_3^-$. Nitrate is completely mobile whereby it can be transferred to ground water with the flow of water.

For completeness of presentation, $NO_3^-$ can, under proper conditions, be microbially transformed to harmless $N_2$ gas which goes to the atmosphere. This transformation is called denitrification. Denitrification occurs when there is energy for microbial activity and oxygen is not available. This condition occurs when soil is very wet and is most common in soils which have clay layers which restrict downward flow of water. To be effective in promoting denitrification, the restricting layers can not be too deep because the energy source for microbes decreases with depth. Very little denitrification occurs in aquifers because energy supplied for microbes is essentially absent.

## AGRICULTURAL MANAGEMENT STRATEGIES

Irrigation. Water flow, which is the physical linkage between agricultural activities and ground water quality, is a function of precipitation and irrigation. Proper irrigation management is therefore critical, not only for crop production but also for ground water protection. Deep percolation is not useful for crop production, except for controlling salinity, and constitutes the means by which chemicals can be transported to ground water. In principle, the amount of irrigation should only restore the water lost to evapotranspiration (ET) between irrigation events. Application of this principle requires knowledge of the amount lost to ET and a means of accurately controlling the amount of applied water.

Estimates of crop ET are made by multiplying reference ET from weather data provided by the California Irrigation Management Irrigation System (CIMIS) by an appropriate crop coefficient. Crop coefficient values are determined from empirical studies and vary among crops, time of season, and relative plant growth. Crop coefficients for a specific case are subject to uncertainty. Nevertheless, this procedure, along with periodic field checks on soil water status, is the best available practice for determining the amount of water to apply during a given irrigation.

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Proper irrigation management is therefore critical, not only for crop production but also for ground water protection.

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The ability to precisely apply a desired amount of water at each irrigation depends on the irrigation system. Surface irrigation, where water is applied at one end of the field and is allowed to flow across the field in furrows or borders, is the most widely used irrigation system in California. The farmer has control of the time period water is discharged on the field and the length of the furrow or border. To some extent, the rate of water delivery at the top end of the field can be controlled. The rate and ultimately the amount of water which infiltrates the soil are highly dependent on soil properties, over which the farmer has limited control. The infiltration rate varies among locations in the field because of soil variability and also varies with time of year in the same location in the field. At a given location, the infiltration rate is usually high during the first irrigation following tillage, and decreases with subsequent irrigations. Water is on the field longer at the upper end than at the lower end of the field, so has the opportunity for infiltration is greater at the upper end of the field. All of these factors contribute to nonuniform infiltration across the field and lack of control on the precise amount of infiltrated water at a given irrigation.

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The ability to precisely apply a desired amount of water at each irrigation depends on the irrigation system.

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Whereas the farmer may know the amount of water discharged onto the field and thus the average depth of water applied to the field, the farmer does not know the depth of infiltrated water at a given location in the field. If the average applied depth is equal to the estimated ET from the last irrigation, some parts of the field have water greater than ET resulting in deep percolation for chemical transport to ground water; and some parts of the field have less than ET resulting in water deficit and yield reduction. With nonuniform irrigation, both excess and deficient irrigation may occur at the same time. If increased yield is desired, it comes at the cost of added deep percolation from additional water. If reduction in deep percolation is desired, it comes at the cost of reduced yields.

Pressurized irrigation systems deliver water in pipes under pressure and the water is released to various type of orifices such as sprinklers, nozzles, or drip emitters. The amount of water applied can be precisely controlled by the time the valve is opened allowing water flow. Uniformity of water application is a function of system design, over which some control can be imposed. Sprinkler systems, where water patterns can be affected by wind, do not allow precise control over uniformity. In principle, a system with uniform irrigation allows application to meet ET requirement without deep percolation for the entire field. Physically, a perfectly uniform irrigation system is not possible, but the selection, design, and maintenance of proper irrigation systems can achieve a high level of uniformity.

Conversion from surface to pressurized irrigation systems is impeded by the high initial capital costs for the pressurized systems. This investment is not always recouped by economic benefits of the system, particularly if costs such as ground water degradation associated with deep percolation are not assessed to the farmer.

Dilemma: Irrigation leading to zero deep percolation is technically impossible. The technological ability to decrease deep percolation decreases as the salinity of the irrigation water increases. Thus, regulations stipulating zero degradation are incompatible with physical realities. Shifts in irrigation management to greatly reduce deep percolation will frequently entail costly investment in new irrigation systems.

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If increased yield is desired, it comes at the cost of added deep percolation from additional water. If reduction in deep percolation is desired, it comes at the cost of reduced yields.

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Chemical use. Fertilizers and pesticides are the type of chemicals most commonly applied during agricultural operations. Synthetic pesticides are the only chemicals whose source in soil is strictly due to application. All plant nutrients are present in soil at some level, and fertilizer application only increases the amount present in the soil. Land disposal of organic waste products such as sewage sludge or irrigation with sewage effluent may introduce chemicals to the soil which must be accounted for.

Pesticides vary widely in their properties and each must be evaluated individually as to the trade-off between beneficial use and potential ground water degradation. The toxicity, transformations and mobility are critical factors in determining a chemical's potential for ground water degradation. Rapid transformation to innocuous chemicals and high adsorption coefficient decrease the probability that the chemical will migrate to the ground water. The level of toxicity identifies the hazard associated with the chemical that does migrate to the aquifer. Since the adsorption coefficient is dependent on soil type as well as chemical structure, the mobility of the pesticide varies with soils. Sandy soils with low organic matter content have lowest adsorption coefficients, so these soils represent the areas of greater hazard for pesticide use.

Nitrogen, phosphorus, and potassium are the plant nutrients required in highest amounts by plants and are the fertilizer elements most commonly applied. Phosphorus and potassium have very low mobility in soil, and thus application as fertilizer does not usually pose a hazard to ground water degradation. Nitrogen is subject to transformations with nitrate usually being the resultant form of nitrogen regardless of type of nitrogen applied. Nitrate is very mobile, so it represents a threat to ground water quality. Nitrogen management, therefore, is one of the most critical agricultural activities that affects ground water quality.

Nitrogen management options include time, amount and type of nitrogen to apply. Before commercial fertilizer production became common, farm operations were more diversified to include both crop and animal production on the same farm. Nitrogen was usually made available for a crop by a combination of crop rotation and application of manure. Crop rotation included a crop capable of fixing nitrogen from the atmosphere and storing it in plant tissue including the roots. This crop used available nitrogen in the soil before fixing atmospheric nitrogen so that the inorganic nitrogen in the soil was depleted. As plants were decomposed in subsequent years, the nitrogen was released and made available for the succeeding crop. As crop decomposition is a gradual and continual process, nitrogen was slowly released and large quantities of inorganic nitrogen were never present in the soil for leaching. Nevertheless, release of nitrogen from the organic to the inorganic form usually extended beyond the subsequent crop season so that inorganic nitrogen was released to the soil after crop uptake ceased.

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Shifts in irrigation management to greatly reduce deep percolation will frequently entail costly investment in new irrigation systems.

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Use of a crop rotation for nitrogen management may not be economically optimum. The nitrogen-fixing crop may not be as profitable as a crop which does not fix nitrogen. Furthermore, the rate of nitrogen release from organic forms is not perfectly matched time-wise with plant uptake during the growing crop. Thus, crop yields may be lower than could be achieved by using commercial inorganic forms of nitrogen. If organic nitrogen is applied in high enough levels to achieve very high yields, much of the applied nitrogen is released after crop use, and thus available for leaching.

The most prevalent nitrogen fertilizer practice is application of commercial fertilizer. Reduction of amount applied would appear to be the obvious approach to reduce nitrate moving to ground water. The consequence of reduced nitrogen input depends on the present level of fertilization by a given farmer. One perception is that farmers apply nitrogen in excess of what is necessary for maximum production. Obviously, if an excess of nitrogen is applied that extra amount could be eliminated with no consequence on yields. However, if excess fertilizer is not being presently applied, reduction in application results in reduced yields as well as the expected reduced ground water degradation. Furthermore, unless adjustments are made in irrigation, reduction of nitrogen application induces more leaching. Crop ET is proportional to plant growth for most crops. If plant growth is reduced by lack of nutrients or pest damage, ET is reduced so more percolation results from the same irrigation. Deep percolation serves as the transporting medium to ground water, so any practice which increases deep percolation enhances ground water pollution potential. Therefore, unless fertilizer and irrigation management are coordinated, reduced nitrogen input could result in reduced yield with possibly very little, if any, benefits to ground water quality, particularly if chemicals other than nitrate are being transported.

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Use of a crop rotation for nitrogen management may not be economically optimum. The nitrogen-fixing crop may not be as profitable as a crop which does not fix nitrogen.

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Uniformity of water application affects fertilizer management as well as irrigation management. Areas of the field receiving excess water are subject to deep percolation and subsequently have a potential for large amount of nitrogen being leached from the root zone. Fertilizers are usually applied uniformly over the field. However, nonuniformity of fertilizer status in the root zone can result from nonuniform irrigation. Farmers may learn from experience that higher amounts of nitrogen must be applied to get high field-wide yields because of leaching caused by nonuniform irrigation on parts of the field. This factor may account for why farmers often apply higher rates of fertilizer than recommended by scientists doing research on crop fertility. Research is usually done on small plots with carefully controlled uniform irrigation. The consequences of nonuniform irrigation are not reflected in the experimental results, but are reflected in the yields the farmer observes.

Precision farming is a modern approach to conserving resources. Nonuniformity of field soils is widely recognized. Prescription farming would uniquely treat each part of the field subject to site-specific conditions. For example, larger quantities of fertilizer would be applied to areas of the field where soil has low amounts of fertilizer and less fertilizer would be applied to areas where the soil is higher in fertility. This approach represents efficient fertilizer use from a crop production point of view, but may not be an efficient practice for ground water quality. If low soil nitrogen is associated with areas of high leaching and high soil nitrogen is associated with areas of low leaching, the prescription calls for higher nitrogen application to areas with highest leaching. High chemical application, coupled with high water flow to the water table, can have negative impact on ground water quality.

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Precision farming is as modern approach to conserving resources.

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Dilemma: Attempts to reduce ground water degradation caused by fertilizers and pesticides by imposing regulations restricting their application may be counterproductive if they result in significant crop production loss. Reduced crop production leads to less evapotranspiration which leads to more deep percolation which accelerates the transport of pollutants to the ground water. Furthermore, reduced profits resulting from reduced production limits the capability to invest in irrigation technology which is prerequisite to drastically reducing the transport of pollutants. Conversely, reduced application in some cases decreases the amount which may potentially be transported to ground water.

Waste disposal. Disposal of organic wastes such as sewage sludge and/or sewage effluent on agricultural lands may become more prevalent as the urban sector is seeking opportunities to dispose waste to land. The consequence of applying waste to agricultural lands on ground water quality is related to the types of chemicals or organisms associated with the waste. The chemical composition of sewage sludge is variable, depending upon its source. However, zinc, chromium, copper, nickel, lead, and cadmium are found in most sludges. None of these chemicals is mobile, so their addition to the soil should not pose a threat to ground water quality but may have other consequences. Organic wastes contain nitrogen which can be transformed to nitrate, which is mobile. The consequence of organic matter application to land must be analyzed using the principles enumerated above as related to nitrogen management.

Attempts to reduce ground water degradation caused by fertilizers and pesticides by imposing regulations restricting their application may be counterproductive if they result in significant crop production loss.

Human pathogens such as bacteria, viruses, and parasites might be applied with sewage sludge or sewage effluent and thus serve as a potential source of ground water contamination. The hazards of these pathogens to ground water contamination are related to the same principle as other entities - transformation and mobility.

Bacteria are relatively large (0.2 – 10 μm) and tend to aggregate to effectively further increase their size. These aggregates tend to be sieved out by small soil pores, and the bacteria also tend to be sorbed by particulate surfaces. As such, they are not very mobile. Bacteria which are harmful to humans are not competitive with other bacteria in the soil environment and do not tend to survive long. As such, they might be considered to be "transformed" to an innocuous state.

Viruses are about 1/50 the size of bacteria. Viruses are basically protein material around a nucleic acid molecule. Enteric (living in the intestine) viruses replicate only in the living host. Outside the host, they can be considered to be a chemical rather than "living" matter. As such, they are subject to the same reactions as other organic chemicals and can be transformed to innocuous decay products. The rate of transformation is a function of soil properties such as temperature and pH. Viruses are also sorbed by soil particles such as other organic chemicals and thus their movement is retarded relative to water flow. The reported sorption coefficients for viruses are highly variable. Quantitative information on basic factors affecting virus transport to ground water is not sufficiently extensive to allow general conclusions concerning the threat of soil-applied viruses to ground water contamination.

Disposal of urban wastes such as sewage sludge and sewage effluent on agricultural lands has . . . positive effects, [and] negative effects.

Parasites range in size from 2 to 60 μm with most being in the 10-30 μm range. Because of their relatively large size they tend to be filtered out by small soil pores, but the smallest sizes may possibly move through very coarse-textured media. The chief hazard associated with parasites is that they are long-lived because they exist in a cyst or "resting stage" which is very resistant to inactivation.

Dilemma: Disposal of urban wastes such as sewage sludge and sewage effluent on agricultural lands has the positive effects of utilizing water, organic matter, and nutrients associated with these wastes but has the negative effects of potentially introducing toxic chemicals and organisms to the food chain or ground water.

## MONITORING

Quantitative measurement of pollutant transport from land surface to aquifers is virtually impossible. The amount of pollutant transported to the aquifer in a time period is equal to the concentration of pollutant in the water times the amount of water flow subject to retardation factors for specific pollutants. Earth samples can be taken and analyzed for the concentration of pollutant, but an accurate measurement of the water flow is not possible. Interpretation of quantitative (or even qualitative) pollutant transport toward ground water based on the concentration alone can lead to erroneous conclusions.

Large amounts of excess irrigation water leads to high subsurface water flow rates. The large quantity of water also dilutes the dissolved pollutant chemicals. Thus a condition can be imposed leading to high ground water degradation with a deceptively low concentration of pollutant in the soil-water. For example, several years ago I monitored the water discharge rate and nitrate-nitrogen concentration from several agricultural tile drainage systems throughout California. I found no correlation between the total amount of nitrate discharged and the concentration of nitrate in the water. As representative of extreme results, farm A had an average nitrate-nitrogen concentration equal to 45 mg/L in the tile effluent and an annual discharge of that chemical equal to 18 kg/ha; whereas farm B had a concentration of 15 mg/L and an annual discharge of 336 kg/ha. Thus system B, with one-third the nitrate concentration, was discharging 19 times more nitrate to the environment than system A.

Dilemma: The effectiveness of altered agricultural management practices designed to protect ground water cannot be determined by monitoring. Indeed, efforts to monitor by measuring subsurface concentrations of various pollutants could lead to erroneous conclusions. The effectiveness of management practices or regulations for protecting ground water can only be evaluated by analyses of the physical-biological processes that constitute the causative link between surface activities and ground water quality - the results of which may be subject to dispute.

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The effectiveness of altered agricultural management practices designed to protect ground water cannot be determined by monitoring.

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## GUIDING PRINCIPLES

Elimination of all pollutant migration from agricultural lands to ground water is technically impossible. However, the rate and amount of migration are governed by physical-biological processes which are subject to manipulation by management. I propose the following guiding principles for the quest to reduce ground water degradation potential while maintaining high agricultural productivity.

1. Water flow from the root zone to the aquifer transports the pollutants and is the most crucial process to control. Failure to reduce water flow results in failure to protect ground water quality regardless of other actions. If water flow is restricted, the consequences of other actions are less critical. Irrigation systems and management which provide the most control on uniformity and amount of water application contribute to this goal.

2. Crop ET is a function of climate, type of crop and crop growth. Reduced crop growth leads to reduced ET which leads to increased deep percolation. Regulations or practices which greatly impact crop production may be counterproductive from two aspects. First, reduced crop production will induce more deep percolation with its associated consequences. Second, the farmer's income is reduced which reduces the resources which could be invested in upgrading irrigation management. High agricultural crop production is compatible with maintaining ground water quality if water flow is controlled.

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. . . the rate and amount of [pollutant] migration are governed by physical-biological processes which are subject to manipulation by management.

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3. Regulations on chemical application should be chemical-specific and site-specific based on chemical and soil properties related to toxicity, transformations, and mobility.

4. Reliance on chemical concentration in the subsoil solution to quantify potential ground water degradation is not appropriate and can be counterproductive. Low concentrations can be achieved by massive water application leading to high transport and consequent aquifer degradation.

# Appendix B

**Probabilistic modeling for risk assessment of ground water contamination by pesticides**

*DPR Memorandum to John Sanders from John Troiano and Murray Clayton*

MEMORANDUM

Mary-Ann Warmerdam
*Director*

Arnold Schwarzenegger
*Governor*

Terry Tamminen
*Secretary, California Environmental Protection Agency*

TO: John Sanders, Ph.D.
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DATE: December 2004

SUBJECT: Probabilistic modeling for risk assessment of ground water contamination by pesticides.

**Background**

During registration of an active ingredient, the Environmental Monitoring Branch (EM) receives requests from the Pesticide Registration Branch to evaluate the potential for groundwater contamination by the pesticide. Such evaluations are typically conducted based on concerns about the physical-chemical properties of new active ingredients or new use patterns of older active ingredients.

Previous evaluations by EM staff were primarily based on procedures prescribed in the Pesticide Contamination Prevention Act (PCPA) of 1985. The PCPA required the California Department of Pesticide Regulation (DPR) to establish thresholds for six physical-chemical properties that characterize environmental fate: water solubility, organic carbon normalized soil adsorption coefficient (Koc), hydrolysis half-life, aerobic and anaerobic soil metabolism half-lives, and field dissipation half-life. The methodology derived by Wilkerson and Kim (1986) was based on comparing distributions of environmental fate variables between two groups of pesticides: those that were ground water contaminants and those that were classified as non-contaminants. If a significant difference was found between the distributions, then a cut-off value for inclusion in the contaminant group was determined as the estimated 90th percentile of the respective environmental fate variable for the contaminant group. This procedure has been named the Specific Numerical Values (SNV) procedure; the SNVs were revised by Johnson in 1988 and lastly in 1989 (Johnson, 1988 and 1989). The purpose of the SNV process was to provide a method to determine whether or not pesticides were potential ground water contaminants. If environmental fate variables indicated a potential to move offsite and if specific use conditions were met, then the active ingredient was placed on the 6800(b) list and DPR was required to provide ground water monitoring.

Two potential limitations with the SNV process are:

1. It is a univariate approach. The tests were derived separately for each environmental variable, ignoring potential relationships between variables.
2. Information on variability of environmental fate characteristics for individual active ingredients is not included. When multiple data existed for each variable, the mean was obtained and used to represent the environmental fate of each pesticide. Since the profile for each pesticide was set in a deterministic manner, information on the variance for each variable was not included.

One approach to address the first limitation is to use a model for pesticide fate. Since models simultaneously simulate different environmental fate processes, they provide a method to determine the joint effect of physical-chemical properties on potential for offsite movement and subsequently can produce estimates for contamination potential. Although use of modeling determines the joint effects of environmental fate variables, the prevalent modeling methodology is to use a deterministic approach where, similar to the SNV process, a single set of input variables is used to represent the environmental fate of an active ingredient.

An approach to address the second limitation is to use probabilistic methods. Advances in computer technology have allowed development of computationally intensive probabilistic modeling techniques where a distribution of outcomes is estimated. A distribution of the modeling output is generated from repetitious model simulations, each representing a different combination of input values. The potential combinations and number of computer simulations can be extremely large when the input variables themselves are described by distributions. In this case, sets of input values for each parameter are derived through random sampling of input distributions. The outcomes from the repetitive model simulations provide a distribution that, when expressed as a cumulative function, can be used to provide a range in expectations of the outcome or, when described by a mean and variance, can be used in a statistical test.

**Basis for Determination of Leaching Potential Using Probabilistic Based Modeling**

Studies conducted by the Environmental Monitoring Branch have enabled development of a probabilistic modeling approach to determine the leaching potential of pesticides. The LEACHP model, a module of the Leaching Estimation and Chemistry Model (Hutson and Wagenet, 1992) has been used by EM in a probabilistic Monte Carlo study that investigated the effects of irrigation management on leaching of known California groundwater contaminants: namely atrazine, bromacil, diuron, hexazinone, norflurazon, and simazine (Spurlock, 2000). The objective of that study was to produce a distribution of ground water contaminant concentrations for different irrigation management strategies and to base comparisons on those distributions. Soil data for the modeling scenario were obtained from a field study that determined the effect of method and amount of irrigation water application on atrazine movement in a coarse, loamy-sand soil in Fresno County (Troiano et al., 1993). This site was vulnerable to leaching of pesticides because the soil was coarse-textured, freely draining, and low in organic carbon content. The irrigation study of Troiano et al. (1993) measured water and pesticide movement at different amounts of water applications. These data were used to calibrate the leaching model in the Monte Carlo study.

In conducting the Monte Carlo study, field dissipation half-life and organic carbon normalized soil adsorption coefficient (Koc) were compiled for the six ground water contaminants. The combined data from all contaminants consisted of 52 field dissipation half-lives and 56 Koc values, producing over 2900 potential paired values for substitution into the model. Because the study involved comparing a number of different irrigation scenarios, computing time was minimized by randomly choosing a smaller but representative subset of paired environmental fate values for each scenario. One conclusion was that reductions in the amount of water that percolates during the growing season is effective in restricting pesticide movement, consequently, irrigation management was identified as a method to reduce concentrations in ground water to levels below the current DPR reporting limit of 0.05 $\mu g \cdot L^{-1}$ (0.05 ppb). Reducing the amount of percolating water during irrigation requires increased management because crop water demand or soil water depletion must be monitored, and these results related to the frequency and volume of irrigations.

**Procedure for a Probabilistic Approach to Determining Leaching Potential of Pesticides**

The probabilistic approach is based on the procedure developed by Spurlock (2000). In Spurlock’s study, data for Koc and terrestrial field dissipation were collected for 5 pesticides, resulting in 56 values for Koc and 52 values for terrestrial field dissipation half-life. In contrast to Spurlock’s study, data for individual pesticides are sparse. A recent evaluation of employing Monte Carlo methods to determine pesticide fate has recommended use of statistical distributions for input variables, such as normal or lognormal functions, when there are sufficient data (Dubus et al., 2002). In most cases, data will be insufficient to test for the specific distributions. When data are sparse, use of an empirical triangular distribution is recommended. Thus, the set of data for Koc and terrestrial field dissipation half-life to be input into the modeling will be based on sampling from a triangular distribution. In addition, the output distributions of the known leachers generated by Spurlock (2000) will be redefined with the input data set based on sampling from a statistical distribution that best fits the distribution for Koc and terrestrial field dissipation half-life data sets. The data set from the resulting benchmark distribution will be used for comparison of leaching potential of candidate pesticides.

The following procedure will be used to determine the leaching potential of a candidate pesticide.

1. Data for terrestrial field dissipation half-life and Koc physical-chemical properties will be collected for a candidate pesticide.
2. An output distribution of estimated residue concentrations for the candidate pesticide below 10 feet will be produced from repetitive simulations using the previously calibrated LEACHP model. In anticipation of a sparse data set for Koc and terrestrial field dissipation half-life, an empirical triangular frequency distribution will be constructed. Parameterization of the distribution will utilize the median of the data set for the peak while the upper and lower bounds will reflect those values derived from percentiles (%) given by 100*(2N-1)/(2N) and 100/(2N), respectively, where N is the number of values in the data set. Sampling for input values from a subsequent cumulative probability distribution will utilize Latin Hypercube methodology, as discussed by Dubus *et al* (2002).
3. The output distribution for the candidate pesticide will be compared to the redefined distribution for known ground water contaminants, as based on the data sets collated by Spurlock (2000). Distributions from two irrigation conditions will be developed and compared as follows:
    a. Over-Watered Condition: First, a distribution of the candidate pesticide will be generated using test parameters that mimic an over-watered condition where a large portion of the applied water is lost to deep percolation. This was referenced as 160% irrigation efficiency in Spurlock (2000). This output distribution will be used to reflect the potential for the candidate pesticide to leach under California agronomic conditions where irrigation is not managed.
    b. Managed Irrigation Condition: Secondly, the candidate pesticide distribution will be generated using test parameters that mimic controlled irrigation where the amount of percolating water is reduced. This was referenced as 133% irrigation efficiency in Spurlock (2000). Since that study, a better understanding of the appropriate method to input crop evapotranspiration has been determined through discussion with one of the developers of the model (John Hutson, personal communication). The target irrigation efficiency has been revised down to 125% based on updated modeling results. This output distribution will be used to determine whether or not a high potential to leach can be mitigated using efficient irrigation management practices.
4. When there is no overlap of distributions between the candidate and the benchmark distributions, the conclusions are straightforward. Under the over-watered condition of 3a, no overlap between the candidate and benchmark distributions would indicate that the candidate pesticide possesses either a lesser or greater potential to leach compared to current ground water contaminants. Furthermore, if the candidate pesticide's distribution from the managed irrigation condition of 3b exceeds the distribution for current ground

water contaminants, this result would indicate that efficient irrigation might not adequately mitigate the potential for contamination.

5. When there is overlap of distributions, a statistical test will be required to determine if the candidate pesticide's distribution is significantly different from the benchmark distributions. The appropriate test will be based on whether or not the distributions conform to t-test assumptions. When they are not normally distributed or when the variances are not homogeneous then a nonparametric test such as a Wilcoxon Rank Sum test will be used to determine similarity of the candidate and benchmark distributions. Otherwise, a standard t-test will be used. Significant differences will be determined at a 95% probability level.
6. When application rates are lower than the range for the current ground water contaminants, then the distribution for proportion of chemical leached would be compared in addition to concentration. This distribution of proportion should be considered for rates lower than 1 lb/acre.

In contrast to the SNV approach, which relies upon a test of five determinate variables, this approach uses only two variables, Koc and terrestrial field dissipation half-life but it incorporates information on the variability associated with these variables. Reasons for varying these two variables instead of all five from the SNV process are:

1. Values for water solubility and hydrolysis half-life usually exhibit much smaller variability so varying their values would have a small effect on the outcome of the model. Water solubility and hydrolysis half-lives are two variables from the SNV process that are used for the LEACHM modeling procedure. In many cases there may be only one submitted value for these variables. When there is more than one submitted value, they are usually very similar and the coefficients of variation are small. Owing to the small range in variability, the means, when they exist, should be entered for water solubility and hydrolysis half-life.
2. Other investigators have developed modeling approaches using only data for soil adsorption and half-life. A ground water screening model developed by US E.P.A. staff denoted SCIGROW employs data for Koc and aerobic soil half-life (U.S. EPA, 2001). Another screening model developed by Gustafson (1989) denoted the GUS index is based on only soil adsorption and field half-life data. This indicates that there is general consensus that soil adsorption and half-life data are key determinants to describe mobility and persistence of pesticide active ingredients.

**Summary**

In order to estimate the potential of a pesticide to leach to groundwater, DPR will utilize probabilistic modeling approaches, such as Monte Carlo procedures, as opposed to deterministic approaches for two reasons. First, in contrast to deterministic approaches, which normally use a single set of estimates, probabilistic modeling includes information on variability that is observed in multiple measurements of environmental variables. Second, a distribution of outcomes is produced which enables estimations of risk assessment across a continuous scale of scenarios and which can also be the basis for statistical testing.

The procedure to compare leaching potential of a candidate pesticide is based on a Monte Carlo approach developed by Spurlock (2000). That study produced distributions of concentrations of known groundwater contaminants under varied irrigation management treatments applied to a coarse soil located in Fresno County. These distributions will be recomputed and the updated distributions will serve as benchmarks against which distributions derived from the candidate pesticide will be compared.

There are some situations that might require a different approach. For example, the LEACHP model does not include anaerobic conditions, so special cropping scenarios such as rice culture may require using the SNV procedure.

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# Appendix C

## Findings and Recommendations from
## “California’s Groundwater – Bulletin 118, Update 2003”
## Department of Water Resources

(http://www.dpla2.water.ca.gov/publications/groundwater/bulletin118/Bulletin118-Findings.pdf)

# Major Findings

1. **Groundwater provides about 30% of the State's water supply in an average year, yet in many basins the amount of groundwater extracted annually is not accurately known.**
   - In some regions, groundwater provides 60% or more of the supply during dry years.
   - Many small- to moderate-sized towns and cities are entirely dependent on groundwater for drinking water supplies.
   - 40% to 50% of Californians rely on groundwater for part of their water supply.
   - In many basins, groundwater use is indirectly estimated by assuming crop evapotranspiration demands and surveying the acreage of each crop type.

2. **Opportunities for local agencies to manage their groundwater resources have increased significantly since the passage of Assembly Bill 3030 in 1992. (Water Code § 10750 et seq.). In the past several years more agencies have developed management programs to facilitate conjunctive use, determine the extent of the resource, and protect water quality.**
   - The act provides the authority for many local agencies to manage groundwater.
   - The act has resulted in more than 200 local agencies adopting groundwater management plans to date.
   - The act encourages regional cooperation in basins and allows private water purveyors to participate in groundwater management through memoranda of understanding with public agencies.
   - Many local agencies are recognizing their responsibility and authority to better manage groundwater resources.

3. **Agencies in some areas have not yet developed groundwater management plans.**
   - Concerns about cooperative management, governance, and potential liabilities have kept some agencies from developing management plans.
   - Development of management programs to maintain a sustainable groundwater supply for local use has not been accomplished throughout the State.

4. **A comprehensive assessment of overdraft in the State's groundwater basins has not been conducted since Bulletin 118-80, but it is estimated that overdraft is between 1 million and 2 million acre-feet annually.**
   - Historical overdraft in many basins is evident in hydrographs that show a steady decline in groundwater levels for a number of years.
   - Other basins may be subject to overdraft in the future if current water management practices are continued.
   - Overdraft can result in increased water production costs, land subsidence, water quality impairment, and environmental degradation.
   - Few basins have detailed water budgets by which to estimate overdraft.
   - While the most extensively developed basins tend to have information, many basins have insufficient data for effective management or the data have not been evaluated.
   - The extent and impacts of overdraft must be fully evaluated to determine whether groundwater will provide a sustainable water supply.
   - Modern computer hardware and software enable rapid manipulation of data to determine basin conditions such as groundwater storage changes or groundwater extraction, but a lack of essential data limits the ability to make such calculations.
   - Adequate statewide land use data for making groundwater extraction estimates are not available in electronic format.

5. **Surface water and groundwater are connected and can be effectively managed as integrated resources.**
   - Groundwater originates as surface water.
   - Groundwater extraction can affect flow in streams.
   - Changes in surface water flow can affect groundwater levels.
   - Legal systems for surface water and groundwater rights can make coordinated management complex.

6. **Groundwater quality and groundwater quantity are interdependent and are increasingly being considered in an integrated manner.**
   - Groundwater quantity and groundwater quality are inseparable.
   - Groundwater in some aquifers may not be usable because of contamination with chemicals, either from natural or human sources.
   - Unmanaged groundwater extraction may cause migration of poor quality water.
   - Monitoring and evaluating groundwater quality provides managers with the necessary data to make sound decisions regarding storage of water in the groundwater basin.
   - State agencies conduct several legislatively mandated programs to monitor different aspects of groundwater quality.
   - California Department of Water Resources (DWR) monitors general groundwater quality in many basins throughout the State for regional evaluation.

7. **Land use decisions affecting recharge areas can reduce the amount of groundwater in storage and degrade the quality of that groundwater.**
   - In many basins, little is known about the location of recharge areas and their effectiveness.
   - Protection and preservation of recharge areas are seldom considered in land use decisions.
   - If recharge areas are altered by paving, channel lining, or other land use changes, available groundwater will be reduced.
   - Potentially contaminating activities can degrade the quality of groundwater and require wellhead treatment or aquifer remediation before use.
   - There is no coordinated effort to inform the public that recharge areas should be protected against contamination and preserved so that they function effectively.

## Additional Important Findings

8. **Funding to assist local groundwater management has recently been available in unprecedented amounts.**
   - Proposition 13 (Water Code, § 79000 et seq.) authorized $230 million in loans and grants for local groundwater programs and projects, almost all of which has been allocated.
   - The Local Groundwater Management Assistance Act of 2000 (Water Code, § 10795) has resulted in more than $15 million in grants to local agencies in fiscal years 2001, 2002, and 2003.
   - Proposition 50 (Water Code, § 79500 et seq) will provide funding for many aspects of water management, including groundwater management and groundwater recharge projects.
   - Funding for the California Bay-Delta program has provided technical and facilitation assistance to numerous local groundwater planning efforts.

9. **Local governments are increasingly involved in groundwater management.**
   - Twenty-four of the 27 existing county groundwater management ordinances have been adopted since 1990.
   - Most ordinances require the proponents of groundwater export to demonstrate that a proposed project will not cause subsidence, degrade groundwater quality, or deplete the water supply before the county will issue an export permit.
   - While the ordinances generally require a permit for export of groundwater, most do not require a comprehensive groundwater management plan designed to ensure a sustainable water resource for local use.
   - Some local governments are coordinating closely with local water agencies that have adopted groundwater management plans.
   - Many local governments are monitoring and conducting studies in an effort to better understand groundwater resources.

10. **Despite the increased groundwater management opportunities and activities, the extent of local efforts is not well known.**
    - There is no general requirement that groundwater management plans be submitted to DWR, so the number of adopted plans and status of groundwater management throughout the State are not currently known.
    - There are no requirements for evaluating the effectiveness of adopted plans, other than during grant proposal review.
    - No agency is responsible for tracking implementation of adopted plans.
    - Unlike urban water management plans, groundwater management plans are not required to be submitted to DWR, making the information unavailable for preparing the California Water Plan.

11. **Despite the fact that several agencies often overlie each groundwater basin, there are few mechanisms in place to support and encourage agencies to manage the basin cooperatively.**
    - Some local agencies have recognized the benefits of initiating basinwide and regional planning for groundwater management and have recorded many successes.
    - Regional cooperation and coordination depends on the ability of local agencies to fund such efforts.
    - There is no specific State or federal program to fund and support coordination efforts that would benefit all water users in a region and statewide.

12. **The State Legislature has recognized the need to consider water supplies as part of the local land use planning process.**
    - Three bills—Senate Bill 221[1], SB 610[2], and AB 901[3]—were enacted in 2001 to improve the assessment of water supplies. The new laws require the verification of sufficient water supply as a condition for approving certain developments and compel urban water suppliers to provide more information on the reliability of groundwater as an element of supply.
    - The Government Code does not specifically require local governments to include a water resources element in their general plans.

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1 Business and Professions Code Section 11010, Government Code Sections 65867.5, 66455.3, and 66473.7.
2 Public Resources Code Section 21151.9, Water Code Sections 10631, 10656, 10657, 10910-10912, 10915.
3 Water Code Sections 10610.2, 10631, 10634.

13. **The need to monitor groundwater quality and contamination of groundwater continues to grow.**
    - As opportunities for developing additional surface water supplies become more limited, subsequent growth will increasingly rely on groundwater.
    - Human activities are likely the cause of more than half the exceedances of maximum contaminant levels in public water supply wells.
    - New contaminants are being regulated and standards are becoming more stringent for others, requiring increased monitoring and better management of water quality.

14. **Monitoring networks for groundwater levels and groundwater quality have not been evaluated in all basins to ensure that the data accurately represent conditions in the aquifer(s).**
    - Groundwater levels are monitored in about 10,000 active wells including those basins where most of the groundwater is used.
    - Groundwater levels are not monitored in approximately 200 basins, where population is sparse and groundwater use is generally low.
    - Groundwater quality monitoring networks are most dense near population centers and may not be representative of the basin as a whole.
    - Many of the wells being monitored are not ideally constructed to provide water level or water quality information that is representative of a specific aquifer.
    - Many wells are too deep to monitor changes in the unconfined (water table) portion of basins.

15. **The coordination of groundwater data collection and evaluation by local, State, and federal agencies is improving.**
    - The State Water Resources Control Board (SWRCB) recently formed the Groundwater Resources Information Sharing Team (GRIST) consisting of several State and federal agencies with groundwater-related programs.
    - DWR established a website in 1996 that has provided water-level data and hydrographs for more than 35,000 active and inactive wells monitored by DWR and cooperating agencies.
    - DWR collects and maintains water level data in part through partnerships with local agency cooperators.
    - DWR staff collaborated with many local, State, and federal agencies in developing this update of Bulletin 118.
    - SWRCB recently formed an interagency task force to develop a comprehensive groundwater quality monitoring program for assessing every groundwater basin in the State as required by the Groundwater Quality Monitoring Act of 2001 (AB 599; Water Code, § 10780 et seq.).
    - Water purveyors have concerns about balancing public access to data with water supply security.

16. **Boundaries of groundwater basins have been determined using the best available geologic and hydrologic information. These boundaries are important in determining the availability of local water supplies.**
   - Basin boundaries were derived primarily by identifying alluvial sediments on geologic maps using the best available information, but are subject to change when new information becomes available.
   - The Water Code requires the use of basin boundaries defined in Bulletin 118 in groundwater management plans and urban water management plans.
   - The location of basin boundaries will become more critical as the demand for water continues to increase.
   - Subbasin boundaries may be delineated for management convenience rather than based on hydrogeologic conditions.

17. **Little is known about the stream-aquifer interaction in many groundwater basins.**
   - Groundwater and surface water are closely linked in the hydrologic cycle.
   - The relationship between streamflow and extraction of groundwater is not fully understood in most basins and is generally not monitored.
   - Groundwater extraction in many basins may affect streamflow.
   - Interaction of groundwater flow and surface water may affect environmental resources in the hyporheic zone.
   - An understanding of stream-aquifer interaction will be essential to evaluating water transfers in many areas of the State.

18. **Although many new wells are built in fractured rock areas, insufficient hydrogeologic information is available to ensure the reliability of groundwater supplies.**
   - Population is increasing rapidly in foothill and mountain areas in which groundwater occurs in fractured rock.
   - The cumulative effect of groundwater development may reduce the yield of individual wells, lower the flow of mountain streams, and impact local habitat.
   - Characterization of groundwater resources in fractured rock areas can be very expensive and complex.
   - Many groundwater users in these areas have no other water supply alternatives.
   - Recent dry years have seen many wells go dry in fractured rock areas throughout the State.
   - Groundwater management in these areas is beginning, but there is insufficient data to support quantitative conclusions about the long-term sustainable yield.

19. **When new wells are built, drillers are required to file a Well Completion Report with DWR. That report contains a lithologic log, the usability of which varies considerably from driller to driller.**
   - The Well Completion Reports are confidential and not available to the public, as stipulated by the Water Code, unless the owner's permission is obtained.
   - The usefulness of the information in Well Completion Reports varies but is not fully realized.
   - Public access to Well Completion Reports would increase understanding of groundwater conditions and issues.
   - There is no provision in the Water Code that requires submission of geophysical logs, which would provide an accurate log of the geologic materials within the aquifer.
   - Geophysical logs would provide a greatly improved database for characterization of aquifers.

# Major Recommendations

1. **Local or regional agencies should develop groundwater management plans if groundwater constitutes part of their water supply. Management objectives should be developed to maintain a sustainable long-term supply for multiple beneficial uses. Management should integrate water quantity and quality, groundwater and surface water, and recharge area protection.**
   - Groundwater management in California is a local agency responsibility.
   - In basins where there is more than one management agency, those agencies should coordinate their management objectives and program activities.
   - A water budget should be completed that includes recharge, extraction and change in storage in the aquifer(s).
   - Changes in groundwater quality should be monitored and evaluated.
   - Stakeholders should be identified and included in development of groundwater management plans.

2. **The State of California should continue programs to provide technical and financial assistance to local agencies to develop monitoring programs, management plans, and groundwater storage projects to more efficiently use groundwater resources and provide a sustainable supply for multiple beneficial uses. DWR should:**
   - Post information about projects that have successfully obtained funding through various grant and loan programs.
   - Provide additional technical assistance to local agencies in the preparation of grant and loan applications.
   - Continue outreach efforts to inform the public and water managers of grant and loan opportunities.
   - Participate, when requested, in local efforts to develop and implement groundwater management plans.
   - Continue to assess, develop, and modify its groundwater programs to provide the greatest benefit to local agencies.
   - Develop grant criteria to ensure funding supports local benefits as well as Statewide priorities, such as development of the California Water Plan and meeting Bay-Delta objectives.

3. **DWR should continue to work with local agencies to more accurately define historical overdraft and to more accurately predict future water shortages that could result in overdraft.**
   - A water budget should be developed for each basin.
   - The annual change in storage should be determined for each basin.
   - The amount of annual recharge and discharge, including pumping, should be determined.
   - Changes in groundwater quality that make groundwater unusable or could allow additional groundwater to be used should be included in any evaluation of overdraft.

4. **Groundwater management agencies should work with land use agencies to inform them of the potential impacts various land use decisions may have on groundwater, and to identify, prioritize, and protect recharge areas.**
   - Local planners should consider recharge areas when making land use decisions that could reduce recharge or pose a risk to groundwater quality.
   - Recharge areas should be identified and protected from land uses that limit recharge rates, such as paving or lining of channels.

- Both local water agencies and local governments should pursue education and outreach to inform the public of the location and importance of recharge areas.
- DWR should inform local agencies of the availability of grant funding and technical assistance that could support these efforts.

5. **DWR should publish a report by December 31, 2004 that identifies those groundwater basins or subbasins that are being managed by local or regional agencies and those that are not, and should identify how local agencies are using groundwater resources and protecting groundwater quality.**
   - Such information will be necessary to confirm whether agencies are meeting the requirements of SB 1938 (Water Code Section 10753.7).
   - Collection and summary of existing groundwater management plans will provide a better understanding of the distribution and coordination of groundwater management programs throughout the State.
   - Successful strategies employed by specific local agencies should be highlighted to assist others in groundwater management efforts.
   - Similarly, the impact of groundwater management ordinances throughout the State should be evaluated to provide a better understanding of the effect of ordinances on groundwater management.

6. **Water managers should include an evaluation of water quality in a groundwater management plan, recognizing that water quantity and water quality are inseparable.**
   - Local water managers should obtain groundwater quality data from federal, state, and local agencies that have collected such data in their basin.
   - Local agencies should evaluate long-term trends in groundwater quality.
   - Local agencies should work closely with the SWRCB and DWR in evaluating their groundwater basins.
   - Local agencies should establish management objectives and monitoring programs that will maintain a sustainable supply of good quality groundwater.

7. **Water transfers that involve groundwater (or surface water that will be replaced with groundwater) should be consistent with groundwater management in the source area that will assure the long term sustainability of the groundwater resource.**

8. **Continue to support coordinated management of groundwater and surface water supplies and integrated management of groundwater quality and groundwater quantity.**
   - Future bond funding should be provided for conjunctive use facilities to improve water supply reliability.
   - Funding for feasibility and pilot studies, in addition to construction of projects will help maximize the potential for conjunctive use.
   - DWR should continue and expand its efforts to form partnerships with local agencies to investigate and develop locally controlled conjunctive use programs.

9. **Local, State, and federal agencies should improve data collection and analysis to better estimate groundwater basin conditions used in Statewide and local water supply reliability planning. DWR should:**
   - Assist local agencies in the implementation of SB 221, SB 610, and AB 901 to help determine water supply reliability during the local land use planning process.
   - Provide and continue to update information on groundwater basins, including basin boundaries, groundwater levels, monitoring data, aquifer yield, and other aquifer characteristics.

- Identify areas of rapid development that are heavily reliant on groundwater and prioritize monitoring activities in these areas to identify potential impacts on these basins.
- Evaluate the existing network of wells monitored for groundwater elevations, eliminate wells of questionable value from the network, and add wells where data are needed.
- Work cooperatively with local groundwater managers to evaluate the groundwater basins of the State with respect to overdraft and its potential impacts, beginning with the most heavily used basins.
- Expand DWR and local agency monitoring programs to provide a better understanding of the interaction between groundwater and surface water.
- Work with SWRCB to investigate temporal trends in water quality to identify areas of water quality degradation that should receive additional attention.
- Estimate groundwater extraction using a land use based method for over 200 basins with little or no groundwater budget information.
- Integrate groundwater budgets into the California Water Plan Update process.

10. **Increase coordination and sharing of groundwater data among local, State, and federal agencies and improve data dissemination to the public. DWR should:**
    - Use the established website to continually update new groundwater basin data collected after the publication of California's Groundwater (Bulletin 118-Update 2003).
    - Publish a summary update of Bulletin 118 every five years coincident with the California Water Plan (Bulletin 160).
    - Publish, in cooperation with SWRCB, a biennial groundwater report that addresses current groundwater quantity and quality conditions.
    - Coordinate the collection and storage of its groundwater quality monitoring data with programs of SWRCB and other agencies to ensure maximum coverage statewide and reduce duplication of effort.
    - Make groundwater basin information more compatible with other Geographic Information System-based resource data to improve local integrated resources planning efforts.
    - Compile data collected by projects funded under grant and loan programs and make data available to the public on the DWR website.
    - Encourage local agency cooperators to submit data to the DWR database.
    - Maximize the accuracy and usefulness of data and develop guidelines for quality assurance and quality control, consistency, and format compatibility.
    - Expand accessibility of groundwater data by the public after considering appropriate security measures.
    - State, federal and local agencies should expand accessibility of groundwater data by the public after considering appropriate security measures.
    - Local agencies should submit copies of adopted groundwater management plans to DWR.

## Additional Important Recommendations

11. **Local water agencies and local governments should be encouraged to develop cooperative working relationships at basinwide or regional levels to effectively manage groundwater. DWR should:**
    - Provide technical and financial assistance to local agencies in the development of basinwide groundwater management plans.
    - Provide a preference in grant funding for groundwater projects for agencies that are part of a regional or basinwide planning effort.
    - Provide Proposition 50 funding preferences for projects that are part of an integrated regional water management plan.

12. **Groundwater basin boundaries identified in Bulletin 118 should be updated as new information becomes available and the basin becomes better defined. DWR should:**
    - Identify basin boundaries that are based on limited data.
    - List the kind of information that is necessary to better define basin boundaries.
    - Develop a systematic procedure to obtain and evaluate stakeholder input on groundwater basin boundaries.

13. **Improve the understanding of groundwater resources in fractured rock areas of the State.**
    - DWR, in cooperation with local and federal agencies, should conduct studies to determine the amount of groundwater that is available in fractured rock areas, including water quality assessment, identification of recharge areas and amounts, and a water budget when feasible.
    - Local agencies and local governments should conduct studies in their areas to quantify the local demands on groundwater and project future demands.
    - The Legislature should consider expanding the groundwater management authority in the Water Code to include areas outside of alluvial groundwater basins
    - DWR should include information on the most significant fractured rock groundwater sources in future updates of Bulletin 118.

14. **Develop a program to obtain geophysical logs in areas where additional data are needed.**
    - DWR should encourage submission of geophysical logs, when they are conducted, as a part of the Well Completion Report.
    - The geophysical logs would be available for use by public agencies to better understand the aquifer, but would be confidential as stipulated by the Water Code.
    - DWR should seek funding to work with agencies and property owners to obtain geophysical logs of new wells in areas where additional data are needed.
    - Geophysical logs would be used to better characterize the aquifers within each groundwater basin.

15. **Educate the public on the significance of groundwater resources and on methods of groundwater management.**
    - DWR should continue to educate the public on statewide groundwater issues and assist local agencies in their public education efforts.
    - Local agencies should expand their outreach efforts during development of groundwater management plans under AB 3030 and other authority.
    - DWR should develop educational materials to explain how they quantify groundwater throughout the State, as well as the utility and limitations of the information.
    - DWR should continue its efforts to educate individual well owners and small water systems that are entirely dependent on groundwater.

# Appendix D

## Summary of G. F. Lee and Anne Jones-Lee's Expertise and Experience in Groundwater Quality Investigation/Protection

# Drs. G. Fred Lee and Anne Jones-Lee's Background Pertinent to Groundwater Quality Protection

Dr. G. Fred Lee is President of G. Fred Lee & Associates, which consists of Dr. G. Fred Lee and Dr. Anne Jones-Lee (Vice President) as the principals in the firm. This discussion of groundwater quality protection issues is based on G. Fred Lee's academic background and professional experience, which includes a BA degree in environmental health sciences from San Jose State College in 1955, a Master of Science in Public Health focusing on water quality issues from the University of North Carolina in 1957, and a PhD in environmental engineering/ environmental science from Harvard University in 1960. Beginning in 1960 for a period of 30 years he held university graduate-level professorial teaching and research positions at several major US universities, including the University of Wisconsin, Madison, the University of Texas system, and Colorado State University. In 1989 he retired from university teaching and research as a Distinguished Professor of Civil and Environmental Engineering at the New Jersey Institute of Technology, where he also held the position of Director of the Site Assessment and Remediation division of a multi-university hazardous waste research center. For a several-year period, he also held the position of Director of the Water Quality Program for the State of New Jersey Sea Grant Program. During his 30-year university teaching and research career he conducted in excess of five million dollars of research and published over 500 papers and reports on these efforts. This research included several masters theses and PhD dissertations on groundwater quality issues, including a PhD dissertation on transport of pesticides in groundwaters.

Dr. Anne Jones-Lee was a university professor for a period of 11 years in environmental engineering and environmental sciences. She has a BS degree in biology from Southern Methodist University and obtained a PhD in Environmental Sciences in 1978 from the University of Texas at Dallas, focusing on water quality evaluation and management. At the New Jersey Institute of Technology she held the position of Associate Professor of Civil and Environmental Engineering with tenure. She and Dr. G. F. Lee have worked together as a team since the mid-1970s.

In 1989, Dr. Lee retired from university teaching and research and expanded the part-time consulting activities that he conducted while a university professor into a full-time activity. While living in New Jersey he became involved in three different consulting jobs in California, one of which was concerned with Delta water quality issues. Another was concerned with Lake Tahoe water quality, and the third was on behalf of the Metropolitan Water District of Southern California, on groundwater quality protection in the San Gabriel Basin. It was at that time that Dr. Anne Jones-Lee and he moved from New Jersey to El Macero, which is adjacent to Davis, California, about 11 miles from Sacramento. Since 1989 they have maintained a two-person specialty consulting firm, working on water supply water quality, water and wastewater treatment, water pollution control for both fresh and marine surface waters, and solid and hazardous waste impact evaluation and management, with particular emphasis on groundwater quality protection. They have continued to be active in publishing the results of their studies, where in the last 17 years they have added another 600 papers and reports covering work they have done in their various areas of activity. One of the major areas is groundwater quality evaluation and management.

G. F. Lee first became involved in investigating groundwater quality in 1960 at the University of Wisconsin, Madison, where he held the position of Professor of Water Chemistry and Director of the Water Chemistry Program. Beginning in the early 1960s Dr. Lee initiated studies on the role of agricultural activities (row crops, dairies) in a lake's watershed in contributing nutrients to the lake through surface runoff and groundwater discharges to the lake.

Dr. Lee became involved in investigating the potential role of municipal solid waste (MSW) landfills as a cause of groundwater pollution at the University of Wisconsin, Madison. In the 1970s Dr. Lee became involved in US Environmental Protection Agency (EPA)-sponsored research on the ability of various types of landfill and waste lagoon liners to effectively prevent groundwater pollution by waste-derived constituents.

In the 1980s Dr. Anne Jones (now Jones-Lee) and he, as part of their university graduate-level teaching and research, worked together on a variety of groundwater pollution issues at various locations in the US and in several other countries. Particular emphasis in their investigations was on protecting groundwaters from pollution that could impair their use as a domestic water supply. A summary of many of these activities is included in the text of this report.

Dr. G. Fred Lee's work on hazardous chemical site and municipal/industrial landfill impact assessment began in the mid-1950s while he was an undergraduate student in environmental health sciences at San Jose State College in San Jose, California. His course and field work involved review of municipal and industrial solid waste landfill impacts on public health and the environment. The focus of his masters degree work at the University of North Carolina was on water quality evaluation and management with respect to public health and environmental protection from chemical constituents and pathogenic organisms. As part of his PhD degree work at Harvard, he obtained further formal education in the fate, effects and significance and the development of control programs for chemical constituents in surface and ground water systems. An area of specialization during his PhD work was aquatic chemistry, which focused on the transport, fate and transformations of chemical constituents in aquatic (surface and ground water) and terrestrial systems as well as in waste management facilities.

His work on the impacts of hazardous chemical site and municipal/industrial solid waste landfills began in the 1960s when, while directing the Water Chemistry Program in the Department of Civil and Environmental Engineering at the University of Wisconsin, Madison, he became involved in the review of the impacts of municipal solid waste landfills on groundwater quality. His research included, beginning in the 1970s, the first work done on the impacts of organics on clay liners for landfills and waste piles/lagoons. In the 1970s, while he was Director of the Center for Environmental Studies at the University of Texas at Dallas, he was involved in the review of a number of municipal solid and industrial (hazardous) waste landfill situations, focusing on the impacts of releases from the landfill on public health and the environment.

In the early 1980s, while holding a professorship in Civil and Environmental Engineering at Colorado State University, he served as an advisor to the town of Brush, Colorado, on the potential impacts of a proposed hazardous waste landfill on the groundwater resources of interest to the community. Based on this work, he published a paper in the Journal of the American

Water Works Association discussing the ultimate failure of the liner systems proposed for that landfill in preventing groundwater pollution by landfill leachate. In 1984 this paper was judged by the Water Resources Division of the American Water Works Association as the best paper published in the journal for that year.

In the 1980s, he conducted a comprehensive review of the properties of HDPE liners of the type being used today for lining municipal solid waste and hazardous waste landfills with respect to their compatibility with landfill leachate and their expected performance in containing waste-derived constituents for as long as the waste will be a threat.

In the 1980s while he held the positions of Director of the Site Assessment and Remediation Division of a multi-university consortium hazardous waste research center and Distinguished Professor of Civil and Environmental Engineering at the New Jersey Institute of Technology, he was involved in numerous situations concerning the impact of landfilling of municipal solid waste on public health and the environment. He has served as an advisor to the states of California, Michigan, New Jersey and Texas on solid waste regulations and management. He was involved in evaluating the potential threat of uranium waste solids from radium watch dial painting on groundwater quality when disposed of by burial in a gravel pit in New Jersey. The public in the area of the proposed disposal site objected to the State's proposed approach. Dr. Lee provided testimony in litigation, which caused the judge reviewing this matter to prohibit the State from proceeding with the disposal of uranium/radium waste at the proposed location.

Dr. Lee's expertise includes surface and ground water quality evaluation and management. This expertise is based on academic course work, research conducted by Dr. Lee and others and consulting activities. He has served as an advisor to numerous governmental agencies in the US and other countries on water quality issues. Further, he has served on several editorial boards for professional journals, including *Ground Water*, *Environmental Science and Technology*, *Environmental Toxicology and Chemistry*, etc. Throughout his over-45-year professional career, he has been a member of several professional organization committees, including chairing the American Water Works Association national Quality Control in Reservoirs Committee and the US Public Health Service PCBs in Drinking Water Committee. For a number of yours he was a member of the ASCE Groundwater Committee and the ASCE Groundwater Recharge Committee. G. F. Lee was responsible for spearheading the development of the Groundwater Resources Association.

Beginning in the 1960s, while a full-time university professor, Dr. Lee was a part-time private consultant to governmental agencies, industry and environmental groups on water quality and solid and hazardous waste and mining management issues. His work included evaluating the impacts of a number of municipal and industrial solid waste landfills. Much of this work was done on behalf of water utilities, governmental agencies and public interest groups who were concerned about the impacts of a proposed landfill on their groundwater resources, public health and the environment.

In 1989, when he retired after 30 years of graduate-level university teaching and research, he expanded the part-time consulting that he had been doing with governmental agencies, industry and community and environmental groups into a full-time activity. A principal area of his work since then has been assisting water utilities, municipalities, industry, community and environmental groups, agricultural interests and others in evaluating the potential public health and environmental impacts of proposed or existing hazardous, as well as municipal solid waste landfills. He has been involved in the review of approximately 85 different landfills and waste piles (tailings) in various parts of the United States and in other countries, including 12 hazardous waste landfills, eight Superfund site landfills and five construction and demolition waste landfills. He has also served as an advisor to a hazardous waste landfill developer and to IBM corporate headquarters and other companies on managing hazardous wastes.

Dr. Anne Jones-Lee (his wife) and he have published extensively on the issues that should be considered in developing new or expanded municipal solid waste and hazardous waste landfills in order to protect the health, groundwater resources, environment and interests of those within the sphere of influence of the landfill. Their over 120 professional papers and reports on landfilling issues provide guidance not only on the problems of today's minimum US EPA Subtitle D landfills, but also on how landfilling of non-recyclable wastes can and should take place to protect public health, groundwater resources, the environment, and the interests of those within the sphere of influence of a landfill/waste management unit. They make many of their publications available as downloadable files from their web site, www.gfredlee.com.

Their work on landfill issues has particular relevance to Superfund site remediation, since regulatory agencies often propose to perform site remediation by developing an onsite landfill or capping waste materials that are present at the Superfund site. The proposed approach frequently falls short of providing true long-term health and environmental protection from the landfilled/ capped waste.

In the early 1990s, Dr. Lee was appointed to a California Environmental Protection Agency's Comparative Risk Project Human Health Committee that reviewed the public health hazards of chemicals in California's air and water. In connection with this activity, Dr. Jones-Lee and he developed a report, "Impact of Municipal and Industrial Non-Hazardous Waste Landfills on Public Health and the Environment: An Overview," that served as a basis for the human health advisory committee to assess public health impacts of municipal landfills.

In 2004 Dr Lee was selected as one of two independent peer reviewers by the Pottstown (PA) Landfill Closure Committee to review the adequacy of the proposed closure of the Pottstown Landfill to protect public health, groundwater resources and the environment for as long as the wastes in the closed landfill will be a threat.

In addition to teaching and serving as a consultant in environmental engineering for over 40 years, Dr. Lee is a registered professional engineer in the state of Texas and a Diplomate in the American Academy of Environmental Engineers (AAEE). The latter recognizes his leadership roles in the environmental engineering field. He has served as the chief examiner for the AAEE in north-central California and New Jersey, where he has been responsible for administering examinations for professional engineers with extensive experience and expertise in various aspects of environmental engineering, including solid and hazardous waste management.

His work on landfill impacts has included developing and presenting several two-day short-courses devoted to landfills and groundwater quality protection issues. These courses have been presented through the American Society of Civil Engineers, the American Water Resources Association, and the National Ground Water Association in several United States cities, including New York, Atlanta, Seattle and Chicago, and the University of California Extension Programs at several of the UC campuses, as well as through other groups. He has also participated in a mine waste management short-course organized by the University of Wisconsin-Madison and the University of Nevada. He has been an American Chemical Society tour speaker, where he is invited to lecture on landfills and groundwater quality protection issues, as well as domestic water supply water quality issues throughout the United States.

Throughout Dr. Lee's 30-year university graduate-level teaching and research career and his subsequent 17-year private consulting career, he has been active in developing professional papers and reports that are designed to help regulatory agencies and the public acquire technical information on environmental quality management issues. Drs. Lee and Jones-Lee have provided a number of reviews on issues pertinent to the appropriate landfilling of solid wastes. Their most comprehensive review of municipal solid waste landfilling issues is what they call the "Flawed Technology of Subtitle D Landfilling of Municipal Solid Waste," which was originally developed in 1992, and redeveloped and updated in the fall of 2004. Between the two versions they have published numerous invited and contributed papers that provide information on various aspects of municipal solid waste landfilling, with emphasis on protecting public health and the environment from waste components for as long as they will be a threat. The "Flawed Technology" review has been periodically updated, including the most recent update in March 2006, which can be found on their website at http://www.members.aol.com/apple27298/SubtitleDFlawedTechnPap.pdf.

This review provides a comprehensive, integrated discussion of the problems that can occur with minimum-design Subtitle D landfills and landfills developed in accord with state regulations that conform to minimum Subtitle D requirements. The "Flawed Technology" review contains a listing of the various reviews that Drs. Lee and Jones-Lee have developed, as well as peer-reviewed literature. Over 40 peer-reviewed papers are cited in "Flawed Technology" supporting issues discussed in this review.

## SUMMARY BIOGRAPHICAL INFORMATION

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DATE & PLACE OF BIRTH:
July 27, 1933
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## EDUCATION

Ph.D. Environmental Engineering & Environmental Science, Harvard University, Cambridge, Mass. 1960

M.S.P.H. Environmental Science-Environmental Chemistry, School of Public Health, University of North Carolina, Chapel Hill, NC 1957

B.A. Environmental Health Science, San Jose State College, San Jose, CA 1955

## ACADEMIC AND PROFESSIONAL EXPERIENCE

**Current Position:**
Consultant, President, G. Fred Lee and Associates

**Previous Positions:**

- Distinguished Professor, Civil and Environmental Engineering, New Jersey Institute of Technology, Newark, NJ, 1984-89
- Senior Consulting Engineer, EBASCO-Envirosphere, Lyndhurst, NJ (part-time), 1988-89
- Coordinator, Estuarine and Marine Water Quality Management Program, NJ Marine Sciences Consortium Sea Grant Program, 1986
- Director, Site Assessment and Remedial Action Division, Industry, Cooperative Center for Research in Hazardous and Toxic Substances, New Jersey Institute of Technology et al., Newark, NJ, 1984-1987
- Professor, Department of Civil and Environmental Engineering, Texas Tech University, 1982-1984
- Professor, Environmental Engineering, Colorado State University, 1978-1982
- Professor, Environmental Engineering & Sciences; Director, Center of Environmental Studies, University of Texas at Dallas, 1973-1978
- Professor of Water Chemistry, Department of Civil & Environmental Engineering, University of Wisconsin-Madison, 1961-1973

Registered Professional Engineer, State of Texas, Registration No. 39906

Diplomate, American Academy of Environmental Engineers, Certificate No. 0701

## PUBLICATIONS AND AREAS OF ACTIVITY

Published over 1,100 professional papers, chapters in books, professional reports, and similar materials. The topics covered include:

- Studies on sources, significance, fate and the development of control programs for chemicals in aquatic and terrestrial systems.
- Analytical methods for chemical contaminants in fresh and marine waters.
- Landfills and groundwater quality protection issues.
- Impact of landfills on public health and environment.
- Environmental impact and management of various types of wastewater discharges including municipal, mining, electric generating stations, domestic and industrial wastes, paper and steel mill, refinery wastewaters, etc.
  Stormwater runoff water quality evaluation and BMP development for urban areas and highways.
- Eutrophication causes and control, groundwater quality impact of land disposal of municipal and industrial wastes, environmental impact of dredging and dredged material disposal, water quality modeling, hazard assessment for new and existing chemicals, water quality and sediment criteria and standards, water supply water quality, assessment of actual environmental impact of chemical contaminants on water quality.

## LECTURES

Presented over 760 lectures at professional society meetings, universities, and to professional and public groups.

## GRANTS AND AWARDS

Principal investigator for over six million dollars of contract and grant research in the water quality and solid and hazardous waste management field.

## GRADUATE WORK CONDUCTED UNDER SUPERVISION OF G. FRED LEE

Over 90 M.S. theses and Ph.D. dissertations have been completed under the supervision of Dr. Lee.

## ADVISORY ACTIVITIES

Consultant to numerous international, national and regional governmental agencies, community and environmental groups and industries.

## SUMMARY BIOGRAPHICAL INFORMATION


NAME: Anne Jones-Lee

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PLACE OF BIRTH:
Menominee, Michigan, USA


## EDUCATION

Ph.D. Environmental Sciences, University of Texas at Dallas, Richardson, TX, 1978. Areas of Specialization: Aquatic Toxicology/Chemistry, Aquatic Biology, Water Quality Evaluation and Management

M.S. Environmental Sciences, University of Texas at Dallas, Richardson, TX, 1975

B.S. Biology, Southern Methodist University, Dallas, TX, 1973

## ACADEMIC AND PROFESSIONAL EXPERIENCE

CURRENT POSITION

Consultant, Vice President, G. Fred Lee & Associates

PREVIOUS POSITIONS

1984 - 1989 Associate Professor of Civil and Environmental Engineering (tenured), New Jersey Institute of Technology, Newark, NJ

1988 - 1989 Consulting Engineer, Ebasco-Envirosphere, Lyndhurst, NJ (part-time)

1984 - 1988 Director of Environmental Engineering Laboratories, Department of Civil and Environmental Engineering, NJIT, Newark, NJ

1982 - 1984 Research Associate and Lecturer, Department of Civil Engineering, Texas Tech University, Lubbock, TX

1982 Coordinator for Aquatic Biology, Fluor Engineers Advanced Technology Division, Irvine, CA

1978 - 1981 Research Assistant Professor, Department of Civil Engineering, Colorado State University, Fort Collins, CO

1973 - 1974 Research Technician, Frito-Lay Research & Development Laboratory, Irving, TX

## SUMMARY OF PROFESSIONAL REPORTS AND PUBLICATIONS

Published more than 263 professional papers, and co-authored over 335 reports and occasional papers. Topic areas addressed include:

- Sources, significance, fate, and control of chemical contaminants in fresh water, marine, and estuarine systems
- Environmental impact of various types of wastewater discharges including mining, electric generating station, domestic, and industrial
- Causes and control of eutrophication; groundwater quality; impact of land disposal of municipal and industrial wastes; environmental impact of dredging and dredged sediment disposal; water quality modeling; hazard assessment of new and existing chemicals; water quality criteria and standards; water supply water quality; assessment of actual environmental impact of chemical contaminants on water quality; toxicity of sediments; impact of landfills on environmental quality

## SUMMARY OF PROFESSIONAL PRESENTATIONS

Presented 55 lectures and professional papers at professional society meetings, short courses, universities, public service groups, and national and international conferences.

## AWARDS

Charles B. Dudley Award - American Society for Testing and Materials award for contribution to, Hazardous Solid Waste Testing, "Application of Site-Specific Hazard Assessment Testing to Solid Wastes," published (1984).

1986 Best Paper of the Year - American Water Works Association Resources Division award for paper published in the Journal, "Is Hazardous Waste Disposal in Clay Vaults Safe?" (1986).

## TEACHING EXPERTISE AND EXPERIENCE

Graduate-level Courses in:

- Microbiological Aspects of Environmental Engineering
- Introductory Chemical Aspects of Environmental Engineering
- Aquatic Toxicology
- Water and Wastewater Analysis
- Introduction to Water and Wastewater Treatment
- Introduction to Environmental Engineering
- Faculty Director of Women in Science and Engineering Program (1988)

# Landfills Evaluated by G. Fred Lee and Anne Jones-Lee

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|---|---|
| **Arizona**<br>*(State Landfilling Regulations)* | Verde Valley - Copper Tailings Pile Closure<br>Mobile – Southpoint Landfill |
| **California**<br>*(State Landfilling Regulations)* | Colusa County - CERRS Landfill<br>San Gabriel Valley - Azusa Landfill (Superfund Site)<br>City of Industry - Puente Hills Landfill<br>North San Diego County, 3 landfills<br>San Diego County - Gregory Canyon Landfill<br>El Dorado County Landfill<br>Yolo County Landfill<br>Half Moon Bay - Apanolio Landfill<br>Pittsburg - Keller Canyon Landfill<br>Chuckwalla Valley - Eagle Mountain Landfill<br>Mountain View – Mountain View Landfill<br>Barstow - Hidden Valley (Hazardous Waste)<br>Mohave Desert - Broadwell Landfill (Hazardous Waste)<br>Cadiz - Bolo Station-Rail Cycle Landfill<br>University of California-Davis Landfills (4) (3 Superfund Site)<br>San Marcos - San Marcos Landfill<br>Placer County - Western Regional Sanitary Landfill<br>Placer County – Turkey Carcass Disposal Pits<br>Imperial County - Mesquite Landfill<br>Los Angeles County - Calabasas Landfill and Palos Verdes Landfill<br>Contra Costa County – Concord Naval Weapons Station Tidal LF (Superfund)<br>Nevada County - Lava Cap Mine Area Landfill (Superfund Site)<br>Sylmar - Sunshine Canyon Landfill<br>Roseville - Roseville Landfill<br>San Diego County – Campo Landfill |
| **Colorado**<br>(*State Landfilling Regulations)* | Last Chance/Brush – (Hazardous Waste Landfill)<br>Denver - Lowry (Hazardous Waste Landfill)<br>Telluride/Idarado Mine Tailings |
| **Delaware** | Various MSW landfills – Evaluate past disposal of industrial wastes |
| **Florida** | Alachua County Landfill |
| **Georgia** | Meriwether County – Turkey Run Landfill<br>Hancock County – Culverton Plantation Landfill |
| **Illinois**<br>(*State Landfilling Regulations*) | Crystal Lake - McHenry County Landfill<br>Wayne County Landfill<br>Kankakee County – Kankakee Landfill<br>Peoria County – Peoria Waste Disposal (Hazardous Waste) |
| **Indiana**<br>(*State Landfilling Regulations*) | Posey County Landfill<br>New Haven-Adams Center Landfill (Hazardous Waste) |
| **Louisiana** | New Orleans vicinity - Gentilly Landfill |
| **Michigan**<br>(*State Landfilling Regulations*) | Menominee Township - Landfill<br>Ypsilanti- Waste Disposal Inc. (Hazardous Waste - PCB's) |

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| **Minnesota** | Reserve Mining Co., Silver Bay - taconite tailings<br>Wright County - Superior FCR Landfill |
| **Missouri** | Jefferson County - Bob's Home Service (Hazardous Waste) |
| **New Jersey** | Fort Dix Landfill (Superfund Site)<br>Cherry Hill – GEMS (Superfund Site)<br>Lyndhurst - Meadowlands Landfill<br>Scotch Plains Leaf Dump |
| **New York** | Staten Island - Fresh Kills Landfill,<br>Niagara Falls Landfill – (Hazardous Waste),<br>New York City – Ferry Point Landfill |
| **North Dakota** | Turtle River Township - Grand Forks Balefill Facility Landfill |
| **Ohio** | Clermont County - BFI/CECOS Landfill (Hazardous Waste)<br>Huber Heights - Taylorville Road Hardfill Landfill (C&DD)<br>Morrow County – Washington and Harmony Townships C&DD Landfills |
| **Pennsylvania** | Pottstown – Pottstown Landfill |
| **Rhode Island** | Richmond – Landfill (C&D) |
| **South Carolina** | Spartanburg - Palmetto Landfill |
| **Texas** | Dallas/Sachse – Landfill<br>Fort Worth - Acme Brick Landfill (Hazardous Waste)<br>City of Dallas - Jim Miller Road Landfill<br>Pasadena – Mobil Mining and Minerals industrial waste pile |
| **Vermont** | Coventry, Vermont - Coventry Landfill |
| **Washington** | Tacoma - 304th and Meridian Landfill |
| **Wisconsin** | Madison and Wausau Landfills |
| **INTERNATIONAL LANDFILLS** | |
| **Belize** | Mile 27 Landfill |
| **Ontario, Canada**<br>(*Prov. Landfilling Regulations*) | Greater Toronto Area - Landfill Siting Issues<br>Kirkland Lake - Adams Mine Site Landfill<br>Pembroke - Cott Solid Waste Disposal Areas |
| **Manitoba, Canada** | Winnipeg Area - Rosser Landfill |
| **New Brunswick, Canada** | St. John's - Crane Mountain Landfill |
| **Nova Scotia, Canada** | Sydney Tar Ponds and Coke Ovens Site |
| **England** | Mercyside Waste Disposal Bootle Landfill |
| **Hong Kong** | Three New MSW Landfills |

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| **Ireland** | County Cork - Bottlehill Landfill<br>County Clare - Central Waste Management Facility, Ballyduff |
| **Korea** | Yukong Gas Co. - Hazardous Waste Landfill |
| **Mexico**<br>(*Haz. Waste Landfilling Reg.*) | San Luis Pontosi Landfill- (Hazardous Waste) |
| **New Zealand** | North Waikato Regional Landfill |
| **Puerto Rico** | Salinas - Campo Sur Landfill |