Focus on Irrigated Agriculture Pollution of Groundwater
Excerpt from
"Groundwater Quality Protection Issues"

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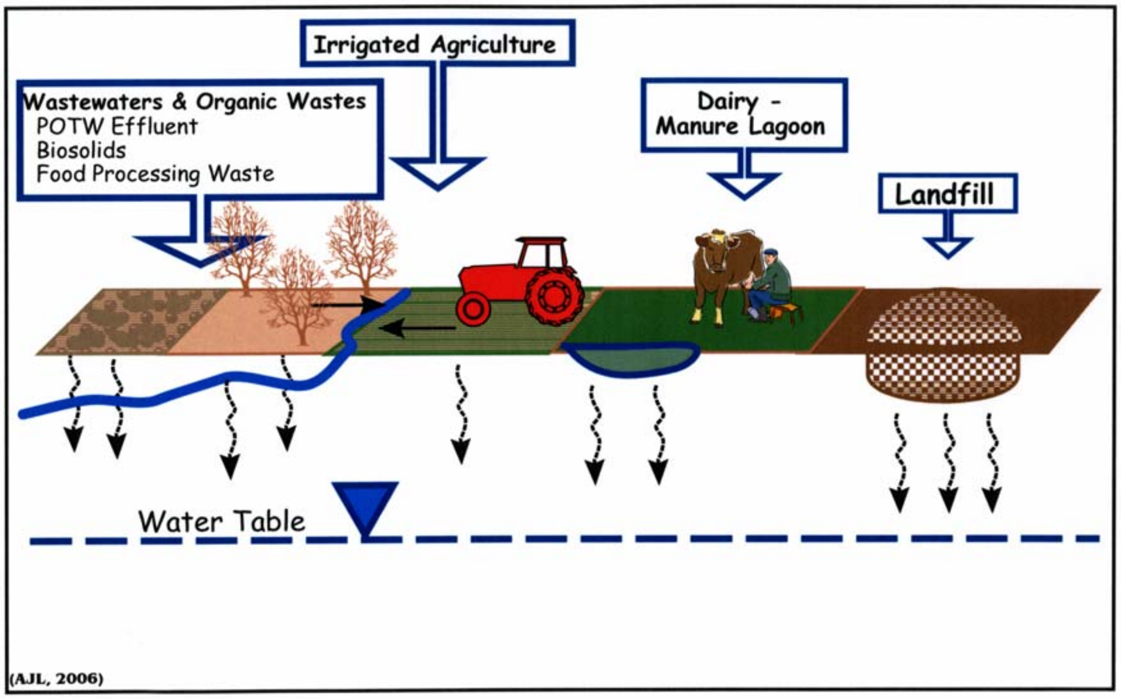

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Full report available at http://www.gfredlee.com/Groundwater/GWProtectionIssues.pdf

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 19 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 associated with irrigated agriculture in the Central Valley of California.

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.

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.

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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Appendix A

Appendix B

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

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.

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/water_issues/programs/gama/

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:

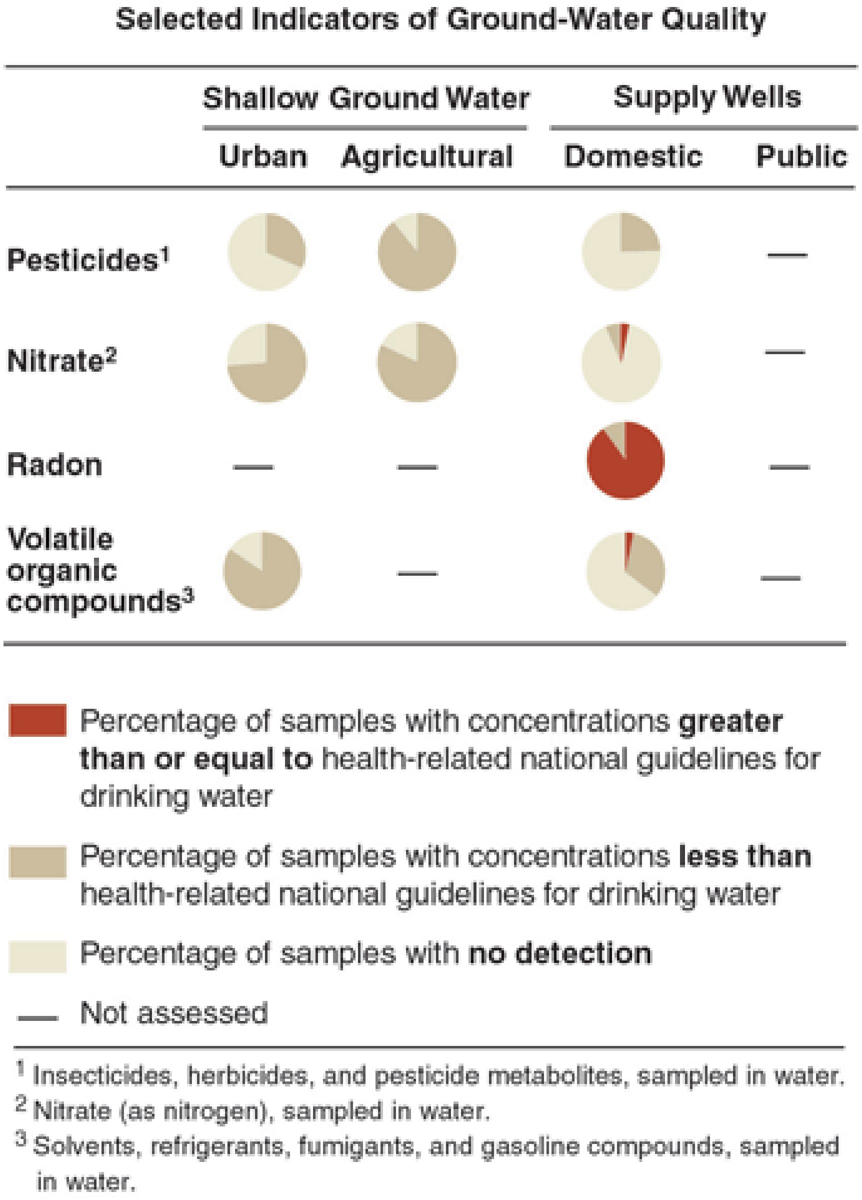
> *"The U.S. Geological Survey (USGS) maintains an active ground water monitoring and research program within the Central Valley as part of the National Water Quality Assessment (NAWQA) Program and associated studies and statewide through the Groundwater Ambient Monitoring and Assessment (GAMA) Program (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.

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.

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.

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 (θ) 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 θ 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 θ 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.

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

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.

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

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.

<u>Chemical Transformations</u>. 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^{TM}) 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.

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

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.

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

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.

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.

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.

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

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.

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.

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.

Precision farming is as modern approach to conserving resources.

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.

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

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.

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

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

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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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- 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

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ADDRESS:	27298 E. El Macero Dr. El Macero, CA 95618-1005	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)