Water/Aquifer Quality Issues that Need to be Considered in Enhanced Groundwater Recharge Projects[1]

Submitted by
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There is increasing interest by municipalities in enhanced groundwater recharge as a means of storing water during periods of surplus surface water for extraction and use during periods of drought. The authors strongly support conjunctive use of surface and groundwater, including aquifer storage and recovery projects. However, some of the proponents of aquifer recharge and recovery projects try to conduct the aquifer storage and recovery (ASR) projects at costs below the funding level that is needed to protect aquifer and water quality. This can lead to long-term project failure and polluted aquifers.

Background to These Comments

G. F. Lee has considerable expertise and experience pertinent to evaluating the potential public health, aquifer quality and groundwater quality impacts of groundwater recharge projects as part of developing/enhancing domestic water supplies. A summary of his experience and expertise is attached to these comments. Water quality issues associated with incidental and enhanced groundwater recharge is an area that has been of interest to G. F. Lee for over 40 years. Dr. Lee has been involved in various professional society committees concerned with groundwater quality protection, including an American Society of Civil Engineers (ASCE) Groundwater committee that was chaired by Dr. Karl Longley. About 10 years ago, G. F. Lee became involved in the American Society of Civil Engineers (ASCE) Artificial Recharge of Ground Water Committee. As one of the members of this committee knowledgeable in both surface water and groundwater quality issues, G. F. Lee was responsible for helping to develop several sections on water quality aspects of groundwater recharge in this committee's guidance manual on groundwater recharge. In 2001, this committee published "ASCE Standard Guidelines for Artificial Recharge of Groundwater," EWRI/ASCE 34-01 (ASCE 2001). The committee considered both surface infiltration and ASR well injection based recharge projects. This committee is currently updating this manual.

As part of G. F. Lee's activities on the ASCE groundwater recharge guidance manual committee, he became familiar with the technical literature on this topic and, with Dr. A. Jones-Lee, has developed several professional peer-reviewed papers on water quality aspects of groundwater recharge that have been presented at national conferences and published in conference proceedings. These include:

[1] Submitted to the Central Valley Regional Water Quality Control Board Basin Plan Triennial Review, Rancho Cordova, CA, May (2005)

"Water Quality Aspects of Incidental and Enhanced Groundwater Recharge of Domestic and Industrial Wastewaters," Proc. Symposium on Effluent Use Management, American Water Resources Association (1993).

"Water Quality Aspects of Groundwater Recharge: Chemical Characteristics of Recharge Waters and Long-Term Liabilities of Recharge Projects," In: Proc. Of the Second International Symposium on Artificial Recharge, American Society of Civil Engineers (1994).

"Total Dissolved Solids and Groundwater Quality Protection," In: Proc. of the Second International Symposium on Artificial Recharge, American Society of Civil Engineers (1994).

"Guidance on Pre-, Operational and Post-Operational Monitoring of Ground Water Recharge Projects," Report of G. Fred Lee and Associates, El Macero, CA (1994).

"Public Health and Environmental Safety of Reclaimed Wastewater Reuse," In: Proc. Seventh Symposium on Artificial Recharge of Groundwater, University of Arizona Water Resources Research Center (1995).

"Appropriate Degree of Domestic Wastewater Treatment Before Groundwater Recharge and for Shrubbery Irrigation," AWWA, WEF 1996 Water Reuse Conference Proceedings, American Water Works Association (1996).
http://www.members.aol.com/apple27298/awwawat2.pdf

"Issues in Recharge of Contaminated Surface Waters in Conjunctive Use Projects," presented at the National Groundwater Association Conference Session on Conjunctive Use (2000).

"Water Quality Issues in Conjunctive Use Projects," HydroVisions Groundwater Resources Association, Fall (2000).

Copies of these papers are available from Drs. G. F. Lee and A. Jones-Lee's website, www.gfredlee.com, or from gfredlee@aol.com by request. A summary of the topics covered in these papers/reports is presented below.

Lee and Jones-Lee (1993) provided overall guidance on several aspects of incidental and enhanced groundwater recharge. They provided an overview of water quality issues including,

- Potential of chemicals in the recharge water to pollute the aquifer and thereby impair and in some instances destroy the area of the aquifer that has been used for the recharge projects for use for continued groundwater recharge,
- Potential for the groundwater recharge to lead to pollution of the recovered waters that requires extensive treatment to produce a potable and palatable water,
- Potential for injected chemicals to interact with chemicals/conditions in the aquifer which can impair the hydraulic characteristics of the aquifer.

Lee and Jones-Lee (1993) provided a discussion of each of these issues.

Lee and Jones-Lee (1994a; 1995; 2000a,b) reviewed a number of the issues that should be considered in developing a groundwater recharge project, focusing on the characteristics of the recharge waters. Also discussed is the issue associated with recharging water that contains constituents that accumulate in the aquifer, which ultimately causes the recharge project to have to be terminated and a "Superfund"-like cleanup program to be initiated to remediate the polluted aquifer.

Lee and Jones-Lee (1994a) recommended that those responsible for developing a groundwater recharge project,

- Provide a high degree of treatment of the recharge waters to protect the aquifer quality and to prevent long-term liability for aquifer cleanup,
- Avoid reliance on the "Black Box" method of soil aquifer treatment where pollutants are added to the aquifer until aquifer problems are encountered,
- Treat the recharge waters to remove contaminants to the maximum extent readily possible,
- Take a proactive/protective approach to aquifer and water quality protection, where in those situations where there is a lack of information, those responsible for developing the groundwater recharge project should err on the side of public health and aquifer protection.

As Lee and Jones-Lee (1994a) discuss, while this approach makes recharge projects initially somewhat more expensive than those projects that recharge poor-quality water, in the long term, this approach could readily be less expensive.

Lee and Jones-Lee (1994b) provide guidance on pre-, operational and post-operational water quality and other monitoring that should be an integral part of a groundwater recharge project.

Lee and Jones-Lee (1995) have discussed the public health and environmental safety of reuse of reclaimed domestic wastewaters as a supplemental domestic water supply and for other purposes including groundwater recharge. Their paper discusses both chemical- and pathogen-related water quality issues.

Domestic Wastewater Derived Pollutants

An issue that is receiving increasing attention in groundwater recharge projects is the large number of unregulated chemicals that are present in domestic, industrial and agricultural wastewaters. Dr. C. Daughton, Chief, Environmental Chemistry Branch, US EPA National Exposure Research Laboratory, has developed a summary presentation entitled, "Ubiquitous Pollution from Health and Cosmetic Care: Significance, Concern, Solutions, Stewardship – Pollution from Personal Actions." This presentation covered information on pharmaceuticals and personal care products (PPCPs) that are present in wastewaters as environmental pollutants. (A copy of Daughton's PowerPoint presentation on this issue is available upon request from gfredlee@aol.com.)

Daughton (2004a) pointed out that there is a wide variety of chemicals that are introduced into domestic wastewaters and are being found in the environment. These include various chemicals (pharmaceuticals) that are derived from usage by individuals and in pets, disposal of outdated medications in sewerage systems, release of treated and untreated hospital wastes to domestic sewerage systems, transfer of sewage solids ("biosolids") to land, industrial waste streams, landfill leachate, agricultural runoff containing pesticides and fertilizers applied to cropland and hormones and antibiotics in livestock wastes, releases from aquaculture of medicated feeds, etc. Many of these chemicals are not new chemicals. They have been in wastewaters for some time, but are only now beginning to be recognized as potentially significant water pollutants. They are largely unregulated as water pollutants and even less regulated in drinking water.

According to Daughton (2004a),

> *"PPCPs are a diverse group of chemicals comprising all human and veterinary drugs (available by prescription or over-the-counter; including the new genre of "biologics"), diagnostic agents (e.g., X-ray contrast media), "nutraceuticals" (bioactive food supplements such as huperzine A), and other consumer chemicals, such as fragrances (e.g., musks) and sun-screen agents (e.g., methylbenzylidene camphor); also included are "excipients" (so-called "inert" ingredients used in PPCP manufacturing and formulation)."*
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> *"Since the 1970s, the impact of chemical pollution has focused almost exclusively on conventional "priority pollutants," especially on those collectively referred to as "persistent, bioaccumulative, toxic" (PBT) pollutants, "persistent organic pollutants" (POPs), or "bioaccumulative chemicals of concern (BCCs).*
>
> *The "dirty dozen" is a ubiquitous, notorious subset of these, comprising highly halogenated organics (e.g., DDT, PCBs).*
>
> *The conventional priority pollutants, however, are only one piece of the larger risk puzzle."*

Daughton has indicated that there are over 22 million organic and inorganic substances, with nearly six million commercially available. The current water quality regulatory approach addresses less than 200 of these chemicals, where in general PPCPs are not regulated as potential water pollutants. Drinking water regulatory programs generally address even fewer of these chemicals. According to Daughton, *"Regulated pollutants compose but a very small piece of the universe of chemical stressors to which organisms can be exposed on a continual basis."* More information on PPCPs is available at www.epa.gov/nerlesd1/chemistry/pharma/index.htm.

While the full range of impacts of PPCPs is just beginning to be investigated, PPCPs are being found to have adverse impacts on aquatic ecosystems. For example, they are believed to be responsible for causing sex changes in fish. Eggen et al. (2004), in a feature article ("Challenges in Ecotoxicology: Mechanistic understanding will help overcome the newest challenges") in *Environmental Science and Technology*, have reviewed a number of the issues that are pertinent to understanding the impacts of PPCPs and other chemicals that can cause endocrine disruption, DNA damage/mutagenesis, deficiencies in immune system and neurological effects in fish and other aquatic life. There is also concern about the effects of these chemicals on humans in domestic water supplies.

Daughton (2004b) has discussed a number of the issues that need to be considered in reuse of domestic wastewaters, including the use of wastewater-contaminated surface waters in groundwater recharge projects. As he has indicated, it is important to recognize that recharge waters that contain wastewater-derived constituents potentially contain a large number of unregulated potential pollutants that are a threat to the health of those who use these waters as a domestic water supply if it has only received conventional domestic water supply treatment.

With respect to agricultural use of pesticides in the Central Valley, Kuivila (2000) has reported that there are approximately 150 pesticides used in the Central Valley. Only about half a dozen of these pesticides are regulated as potential water pollutants in surface waters and in treated drinking water. In addition to concern about the pesticides/herbicides, there is also concern about the potential water quality impacts of the degradation products of these and other chemicals. Is some cases the degradation/transformation products of chemicals are more toxic/harmful than the parent chemical.

Dr. Susan Anderson of the University of California, Davis, Bodega Marine Laboratory, (Whitehead et al. 2003) made measurements of DNA strand breakage and Ames test mutations in fish caged in Orestimba Creek water. Orestimba Creek is located on the west side of the San Joaquin River. Its water is primarily composed of agricultural drainage and runoff. There was evidence for positive responses in both tests, indicating that there may have been chemicals in the water that have the potential to be adverse to aquatic life. There is also concern about the impact of these chemicals to humans in drinking water. Typical domestic water supply treatment consisting of coagulation, sedimentation, filtration and disinfection is not designed to remove the wide variety of potentially harmful unregulated chemicals that are present in water supplies that contain municipal, industrial and agricultural wastes.

Sedlak et al. (2005) conducted a study devoted to the "Occurrence Survey of Pharmaceutically Active Compounds (PhACs)." The American Water Works Association Research Foundation funded this study to assess the occurrence of PhACs in drinking water supplies in the United States. According to the AWWA Research Foundation, this report presents the results of the research.

"*Specific objectives of the research included*

- *Evaluation of available information on the use, occurrence, and analysis of PhACs that are potentially present in the US.*
- *Selection of PhACs that are likely to be present at detectable concentrations in municipal wastewater effluent and agricultural runoff in the US.*
- *Development of analytical methods for quantifying PhACs in the aquatic environment.*
- *Analysis of samples from sites that are likely to contain elevated concentrations of PhACs.*

- *Preliminary assessment of the ability of advanced wastewater treatment plants, engineered treatment wetlands, and soil aquifer treatment systems to remove PhACs."*

The Sedlak et al. study found PhACs in some drinking waters.

The USGS (2005) Toxic Substances Hydrology Program has recently reported developing analytical methods to measure trace levels of 22 human-health pharmaceuticals in surface water and groundwater. This same website contains several references to studies by the USGS on the occurrence of chemicals in the nation's waters.

Aquifer Quality Issues
Lee and Jones-Lee (1994a,b,c; 1995; 2000a,b) and ASCE (2001) "Standard Guidelines for Artificial Recharge of Ground Water" (Guidelines) point to the importance of protecting aquifer quality as part of groundwater recharge projects. As discussed, it is important that detailed evaluation be made as part of recharge project development to evaluate the potential for constituents in the recharge waters to accumulate in the saturated aquifer, thereby affecting the long-term ability of the aquifer to yield recovered water that is of high quality. The statement made by proponents supporting essentially unlimited groundwater recharge independent of the characteristics (quality) of recharge waters, that so long as more water is recovered from the aquifer than recharged, the recharge should not cause adverse impacts on the ability of the aquifer to yield water of the same quality as recharged, is in error. As discussed by Lee and Jones-Lee (see their publications on the attached list), such a statement reflects a lack of understanding of the aquatic chemistry of groundwater aquifer systems. **Some of the constituents in recharged water that are introduced into the saturated part of the aquifer through an ASR project will remain in the aquifer.**

Surface waters typically contain a wide spectrum of organic and inorganic chemicals that can interact with aquifer solids to change the characteristics of the recovered water compared to the recharged water. Of particular concern is the introduced total organic carbon (TOC) and dissolved organic carbon (DOC). Much of the TOC/DOC that is introduced into an aquifer is sorbed (attached) to aquifer solids. The buildup of TOC/DOC on the aquifer solids will change the characteristics (quality) of the aquifer, including impacts on the oxidation/reduction (redox) conditions of the aquifer as a result of introducing small amounts of biochemical oxygen demand (BOD) into the aquifer that remains in the saturated part of the aquifer. The organics in TOC/DOC introduced into the saturated aquifer in an ASR project can lead to mobilization of some naturally occurring constituents, such as arsenic, that will be present in the recovered water. These issues are discussed in the papers by Lee and Jones-Lee.

Water Quality Issues as Impacted by Type of Groundwater Recharge Project
One of the issues of primary concern in evaluating a proposed enhanced groundwater recharge project is the impact of the chemical/biological characteristics of the recharge waters on the successful long-term operation of the project. As discussed in ASCE (2001), there are various types of groundwater recharge projects. Several of these are based on surface infiltration, where the recharge occurs from shallow basins in which the recharge waters pass through the vadose zone before entering the saturated aquifer. This approach simulates the natural recharge that occurs. The other recharge approaches are through wells, such as in aquifer storage recovery

(ASR), where the recharge water is pumped into the saturated part of the aquifer in an injection well.

The infiltration basin approach for recharge is significantly different in its ability to use contaminated water as the recharge water without adverse impact on aquifer quality and the long-term operation of the recharge project. In a recharge basin based recharge project, the TOC/DOC is removed in the upper part of the vadose (unsaturated) zone and therefore does not enter the saturated part of the aquifer. This is why the natural recharge of an aquifer results in groundwater with low DOC. Basically, the infiltration basin recharge approach simulates the natural processes that normally occur in incidental groundwater recharge.

In ASR based recharge projects, the natural removal of constituents such as TOC/DOC, BOD, etc., does not occur in the vadose zone, but takes place in the saturated part of the aquifer near the point of discharge of the recharge well. This accumulation of organics on the aquifer solids can lead to problems with the long-term quality of the recovered water, which can cause the ASR project to have to be abandoned. Lee and Jones-Lee discuss that under extreme conditions, the introduction of inadequately treated recharge water can result in a "Superfund"-like situation where the ASR project sponsors would be named as responsible parties in having to fund the aquifer cleanup.

In order to protect aquifer quality, ASR based groundwater recharge projects should be conducted with high-quality recharge water. Even then, the project should be conducted with intensive monitoring of the recharge and recovered water to determine if potential aquifer quality problems are beginning to occur. Similar monitoring should occur with infiltration basin based recharge projects, where the focus of the monitoring includes buildup of chemical constituents in the near-surface vadose zone where the removal of potential pollutants should be occurring. Further information on the need for and the characteristics of the recharge project water and aquifer monitoring is provided by Lee and Jones-Lee (1994b).

Use of Drinking Water in Groundwater Recharge Projects

Some proponents of ASR based recharge projects assert that waters that are treated to meet US EPA and state drinking water maximum contaminant levels (MCLs) are suitable for use as a source water for an ASR recharge project. Basically their position is that a water that meets drinking water standards is suitable to inject into the groundwater aquifer and to be recovered for use as a domestic water supply. In an overly simplistic sense this position seems to make sense to someone who does not understand how US EPA and state MCLs are established and the potential for water that meets MCLs to contain constituents which can cause aquifer quality problems of the type discussed above.

The US EPA allows waters that have several mg/L of DOC to be present in a treated water supply. TOC/DOC is of concern in a raw water supply since, upon disinfection with chlorine, the chlorine interacts with the DOC to form disinfection byproducts such as trihalomethanes (THMs) and haloacetic acids (HAAs). The city of Tracy, California (Pinhey 2004) attempted to gain California Central Valley Regional Water Quality Control Board (CVRWQCB) support for ASR injection of a domestic water supply into the aquifer underlying the city. While the proposed recharge water met drinking water MCLs, it is derived from South Delta water. As discussed by Lee and Jones-Lee (2004) this water is at times primarily derived from agricultural irrigation tailwater and contains domestic waste waters from wastewater discharges in the South Delta watershed. This water is only of marginal quality as a suitable domestic water supply without extensive additional treatment.

One of the issues of concern is that trihalomethanes and haloacetic acids are present in the treated water as disinfection byproducts resulting from the reaction of the chlorine used for disinfection and TOC/DOC present in the raw water. The CVRWQCB (2004a,b,c) staff and Spano (2004) of the California Department of Health Services were concerned that the City of Tracy proposed to inject the treated domestic water into the aquifer without removal of the THMs and HAAs. The injection of water with these compounds would be a violation of the CVRWQCB Basin Plan water quality objectives which prohibit introducing toxic chemicals into the groundwater. While the focus of concern in using treated domestic water supply as recharge water is on the THMs and HAAs, Plewa et al. (2004) of the University of Illinois (Urbana-Champaign) and the US EPA have indicated that there are 600 identified disinfection byproducts. Plewa et al. (2004) stated that,

> "*This research says that when you go to alternatives, you may be opening a Pandora's box of new disinfection byproducts [which] may be much more toxic, by orders of magnitude, than the regulated ones we are trying to avoid.*"

In addition to concern about the unregulated chemicals, such as those derived from domestic, industrial and agricultural runoff/discharges, there is also justified concern about the adequacy of some of the MCLs established by the US EPA and states for the limited number of regulated chemicals that have received MCLs. As discussed by Lee and Jones-Lee (1994d), several of the MCLs that are supposed to protect human health are based on factors other than their impact on human health. The US EPA MCL for the THMs is not based on the potential for chloroform and related chemicals that make up the THMs to cause cancer at a low risk level. It includes consideration of the desire to achieve adequate water supply disinfection at a very low cost. The cancer risk associated with a domestic water supply that just meets the THM MCL represents a relatively high cancer risk compared to that commonly accepted as an acceptable cancer risk for carcinogens in domestic water supplies.

A similar situation exists for the MCL for arsenic of 10 µg/L. The cancer risk for people who consume water from a water supply that has arsenic at the MCL over their lifetime is about two to three additional cancer cases in 1,000 people. Ordinarily, an acceptable cancer risk for establishing an MCL is one additional cancer case in 100,000 to one million people. The US EPA in establishing the arsenic MCL chose to allow the much higher cancer risk in order to not cause small water utilities to have to significantly raise the cost of their treated water supply. The California EPA Office of Environmental Health Hazard Assessment (OEHHA 2004) has established a public health goal (PHG) for arsenic in domestic water supplies of 0.004 µg/L. This PHG is based on an acceptable cancer risk. This goal is about three orders of magnitude below the US EPA current MCL. The California Department of Health Services (DHS 2005) is in the process of establishing an MCL for arsenic in domestic water supplies.

In summary, contrary to the implication of statements made by some who advocate that it should be possible to recharge a domestic water supply that meets drinking water MCLs, drinking water MCLs are not necessarily protective of public health. Some MCLs are based on economic and other factors which allow MCLs to be developed that represent a significantly elevated human health risk. Domestic water supplies can contain a wide variety of unregulated potentially harmful hazardous chemicals and still be considered to be acceptable to be distributed to the public for consumption. This is especially true for water supplies that have domestic, industrial and agricultural wastewater discharges/ runoff in the water supply watershed. In addition, domestic water supplies are not treated to remove constituents such as DOC and other organics that, when injected into the aquifer in an ASR recharge project, will remain in the aquifer. Over time, the aquifer solids will become coated with an organic layer that will change the properties of the aquifer, which can result in polluted water being recovered from the aquifer. The pollutants may not be regulated constituents and therefore may not be recognized as a harmful condition. Under extreme conditions an ASR project that uses poor-quality water in the recharge water can accumulate sufficient oxygen demand to totally change the redox conditions of the aquifer which can mobilize natural and anthropogenically derived chemicals that can make the recovered waters unuseable for domestic purposes without extensive treatment.

In addition to the concern about constituents in the recharge water adversely affecting the reuse of recovered water for domestic water supplies, there is also concern about constituents in the recharge water being adverse to the use of the water for agricultural purposes. A comparison of MCLs and agricultural use-based water quality limits clearly shows that water that meets drinking water standards can do significant harm to sensitive crops. A comparison of these values is presented in Table 1. Agricultural supply is an important beneficial use of groundwater aquifers that should be protected.

Table 1
Comparison of Drinking Water and Agricultural Use Limits (µg/L or ppb)

	Drinking Water Limit		Agricultural Use Protective Limit
Boron	Notification Level	1000	700
Chloride	Secondary MCL - Upper	500	106
Copper	Primary MCL/Secondary MCL	1300 / 1000	200
Fluoride	Primary MCL	2000	1000
Selenium	Primary MCL	50	20
Dissolved Solids (salt)	Secondary MCL - Upper	1000	450
Zinc	Secondary MCL	5000	2000

MCL = Maximum Contaminant Level (California)
Agricultural limits from Ayers and Westcot (1985)

It is in the best interest of public health protection and preservation of aquifer quality to restrict ASR projects to the recharge of high-quality water. Surface infiltration recharge projects can recharge somewhat poorer quality water, provided that the DOC and other potential pollutants are removed in the vadose zone under the infiltration area. Vadose zones composed primarily of sand and gravel may require treatment of the recharge water if the DOC, etc., is not able to be removed in the vadose zone.

Demonstration Projects

The CVRWQCB has required that the city of Roseville, California, conduct a demonstration project of the proposed ASR groundwater recharge project. The demonstration projects that have been proposed by the city of Tracy, California, and conducted by the city of Roseville, California, do not adequately address the aquifer quality issues discussed in this review. Many of the problems that can occur will not be evident in short-term demonstration projects of a few months' duration.

Cost of Adequate Treatment of Recharge Waters

An issue that is often raised by those who want to inject poor-quality water into an aquifer as part of an ASR project is that treatment of the water to substantially reduce the concentrations of potential pollutants in the recharge water is "too expensive." However, Lee and Jones-Lee (2004), in their comments on the city of Tracy's proposed ASR recharge project, mentioned that the cost of treating the recharge waters with treatment through activated carbon beds would likely be on the order of a few tens of cents per person per day for the population served by the ASR project. Treatment by passing the domestic treated water through activated carbon beds would remove some of the TOC/DOC as well as many of the unregulated potentially hazardous chemicals that are present in the city of Tracy's treated domestic water supply. The city of Tracy staff attempted to discredit the Lee and Jones-Lee (2004) statements on the affordable nature of advanced treatment, by statements that presented the costs in terms of the total cost to the city of several million dollars. However, the proper way to judge affordability of the additional treatment is to determine what it would cost the public in terms of the amount that individuals would pay for their domestic water. As indicated by Lee and Jones-Lee (2004), the public who use the city of Tracy treated water would only be paying a few tens of cents per person per day for substantially improved quality of the recharged/ recovered water.

Legislative Approach to Gaining Reduced Regulation of ASR Projects

Proponents of less regulation of groundwater recharge projects have been able to convince Senator Cox of the California legislature to introduce SB 773 "Urban Water Suppliers: Groundwater Recharge" (recently amended to "Groundwater aquifers: injection wells"). This bill would provide that the CVRWQCB could not regulate groundwater recharge of treated domestic water supplies with waste discharge permits. Adoption of this bill would prevent the CVRWQCB from establishing groundwater recharge requirements to protect aquifer quality. It will be extremely important, should the legislature adopt the current SB 773, that the bill be amended to include a regulatory approach that would enable the Regional Boards to regulate the recharge of poor-quality domestic water supplies into an aquifer through an ASR project, which would be a threat to aquifer quality.

DHS Regulations Governing Groundwater Recharge Reuse

The California Department of Health Services (DHS 2004) has been developing regulations governing the recharge of domestic wastewaters to a groundwater aquifer system since the early 1990s. In December 2004 the Department issued its most updated draft regulations. These draft regulations represent the Department's current approach on permitting the recharge of an aquifer with water that contains some highly treated domestic wastewaters. An important aspect of these regulations is the Department's approach toward regulating the total organic carbon (TOC) of the recharge waters. The Department uses TOC as a surrogate for the vast arena of unregulated potentially hazardous chemicals that are present in domestic wastewaters.

The Department's approach is to severely restrict the amount of TOC that can be present in a water that can be recharged to an aquifer if it contains any amount of a recycled water contribution. For those recharge systems that involve injection of the recharge waters through a recharge well, the Department requires that all recharge waters that contain any amount of a recycled water contribution be treated by reverse osmosis. The Department does not make this same requirement for the recharge of a surface water that contains a recycled water contribution if it is to be recharged through groundwater basin based recharge systems (i.e., spreading). However, the Department does restrict the amount of TOC that can be present in the surface infiltration based recharge system, as part of the Department's efforts to address the public health concerns associated with the recharge of waters that can contain unknown, unregulated potentially hazardous chemicals. Such concerns are further mitigated by restricting the recycled water contribution (RWC) by requiring diluent water of non-municipal-waste origin.

The Department of Health Services has limited regulatory authority over the recharge of surface waters that do not directly contain some recycled water contribution. This means that the Department does not regulate situations where a municipality discharges domestic wastewaters to a waterbody that, at some location downstream, is recharged to an aquifer. Also, the Department has limited authority to regulate the recharge of surface waters that are primarily composed of agricultural tailwater. The Department can require that the recharge waters comply with the Surface Water Treatment Rule (US EPA 2001, 2002), which limits regulated contaminants (cryptosporidium) and turbidity in waters used for domestic water supply.

While the Department has authority to limit the TOC in the recharge waters, based on the presence of unrecognized, unregulated hazardous chemicals derived from domestic wastewaters being a component of the TOC, it does not have the authority to limit the TOC injected into an aquifer because of the accumulation of the TOC in the aquifer which would affect aquifer quality and therefore the long-term sustainability of a recharge project.

CVRWQCB Triennial Basin Plan Review

At the March 18, 2005, CVRWQCB meeting devoted to receiving input on the Triennial Basin Plan Review, R. S. Roscoe, General Manager, Sacramento Suburban Water District (SSWD), stated that the CVRWQCB should address what he termed to be the inappropriate regulation of enhanced groundwater recharge by the Board staff. Subsequently, on March 23, 2005, Roscoe (2005) submitted written comments as backup to his March 18, 2005, statements on this issue.

Roscoe, in his March 23, 2005, statement on the need for a different regulatory approach toward enhanced groundwater recharge, provided a discussion of the importance of enhanced groundwater recharge to water utilities in the Sacramento area, the Central Valley, and the state of California. His position is that groundwater aquifers in many parts of the state are being overdrafted, and that surplus surface waters should be recharged into groundwater basins as a means of storing water that can be recovered during periods of limited surface water availability (groundwater banking). The authors find that his assessment of this issue is appropriate, and that enhanced groundwater recharge should be strongly supported and implemented wherever possible. However, as discussed herein, the authors find that Roscoe's (2005) discussion of the need to change the regulatory approach governing enhanced recharge of treated domestic drinking water does not properly consider the potential problems that can occur with essentially unrestricted recharge of treated domestic water supplies. A discussion of the issues raised by Roscoe (2005) is presented below.

Roscoe (2005) stated with respect to regulation of ASR,

> ***"Regulation of ASR***
> *Where the source of water is a state permitted public water supply, groundwater banking through artificial recharge methods should not be regulated as a waste discharge. The water is not being "discharged" or "disposed," it is being stored for subsequent reuse. The quality of water injected in an ASR system from a public water system is permitted by the state and meets state requirements for public health. Additional state regulation is imposed on the extraction side of an ASR system through the Drinking Water Source Assessment Program where water quality threats to wells providing drinking water are assessed and reported as part of the State Department of Health Services Water Supply Permit."*

The authors agree that it is inappropriate to classify a permitted public water supply as a "waste" when injected into an aquifer through an ASR system. However, as discussed above, under current regulatory requirements, DHS cannot regulate the enhanced recharge of surface waters, including treated domestic water supplies, with respect to protection of aquifer quality. The responsibility for this regulation belongs to the Regional Boards. Under the Porter-Cologne Water Quality Control Act, the Regional Boards are charged with protecting the quality of surface and groundwaters, which includes aquifer quality. As discussed herein, current domestic water supply treatment requirements are not based on the removal of constituents which, while not a threat to health or drinking water quality when consumed in a domestic water supply, are a threat to aquifer quality and the long-term sustainability of an enhanced groundwater recharge project, especially when recharge takes place through an ASR project.

Roscoe (2005) further stated,

> ***"Lack of Statewide Uniformity***
> *SSWD also has concerns for the uniformity of regulations application statewide. In at least 7 of the 9 regional boards, aquifer storage of public drinking water is either not regulated (purveyors receive written confirmation that the Regional Board is not involved in such activities) or waivers of discharge requirements are routinely issued.*

SSWD anticipates competing with other purveyors for state grant monies for conjunctive use and ASR projects. It presently appears that we would not be eligible for funding as we could not show such a project would receive all necessary regulatory approvals. Indications from CVRWQCB staff imply that to meet the antidegradation policy and a narrative toxicity standard would require a water purveyor to provide treatment such that the stored water precisely matched native groundwater quality. This would render ASR economically infeasible in the entire central valley."

It is inappropriate for the CVRWQCB to lower its level of protection of groundwater and aquifer quality to that of other Regional Boards. The CVRWQCB is responsible for protecting the largest contiguous groundwater basin in the State, the second largest groundwater basin in the continental United States. The CVRWQCB should be highly proactive in protecting aquifer quality within the Central Valley so that enhanced groundwater recharge can take place without a significant threat to the sustainability of ASR projects. The CVRWQCB has not proposed to require that injected water be of equal quality to native groundwater quality.

With respect to Roscoe's claims that, if an ASR project treated the domestic water supply so that it would not be a threat to aquifer quality, such as through passage of the water through an activated carbon bed, *"this would render ASR economically infeasible,"* as discussed above, the additional cost to the consumer of the recovered water from a properly treated ASR injected water would represent only a few tens of cents per person per day above what they would be paying for the domestic water supply if inadequately treated domestic waters were injected into the aquifer. As discussed above, it is important that the public be reliably informed about the true cost to them on an individual basis of a greatly enhanced recovered water quality and the protection of the long-term sustainability of the aquifer for enhanced groundwater recharge.

Another aspect of this situation is that, for many areas where enhanced groundwater recharge could occur in the Central Valley, high-quality Sierra water is available for recharge. The issue of primary concern is the enhanced recharge through ASR of waters from the valley floor that have received domestic wastewater discharges and/or contain agricultural tailwater discharges. These waters are a significant threat to the quality of domestic water supplies and the aquifer.

According to Roscoe (2005),

"Public Confidence in Water Supply
SSWD has additional significant concerns with the potential for additional treatment requirements suggested by CVRWQCB staff (such as activated carbon filtration or reverse osmosis treatment) prior to banking in an ASR well. The notion that water one state agency permits for human consumption is required by a different state agency to be further treated before storing in an aquifer for later withdrawal for human consumption is incongruous. If additional treatment prior to storage is required, the public would likely incorrectly perceive that the drinking water must not be safe. Public confidence in the safety of the state's regulation of drinking water supplies must not be eroded by the state."

Roscoe has not properly assessed the reasons for the additional treatment of a domestic water supply before ASR recharge. The issue is not one of a lack of "safety" of the domestic water supply with respect to human health, but of protection of aquifer quality, although, as discussed above, it is well recognized that the approach that the US EPA and the state are following with respect to establishing some of the MCLs for drinking waters is not based on protection of human health, but on social, economic, political or other factors. The key to this issue is for water purveyors and regulatory agencies to reliably inform the public about the justification for the additional treatment based on providing for aquifer quality, with additional public health protection arising from the additional treatment needed to prevent unregulated constituents from accumulating in the aquifer which can damage its ability to serve as a source of water supply.

Roscoe (2005) further states,

> ***"Regulatory Options Exist***
> *Perhaps a difference in discharging wastes to groundwater and groundwater banking for later recovery could be recognized in allowing the point of compliance for banking programs to be a monitoring well located at some distance from the point of injection. This would conform to the approach used in other states and would recognize the rapid attenuation of certain trace compounds of concern (notably disinfection by products such as the trihalomethanes and haloacetic acids) in the immediate vicinity of the injection well. This rapid attenuation has been analyzed and reported in numerous case studies including studies of other California ASR systems. The point of compliance for injecting water not regulated by the Department of Health Services and not intended for future recovery would remain at the point of injection. The regulatory approach must remain flexible for projects which provide overriding public benefits."*

Again, Roscoe has failed to address the issue of greatest concern with respect to injecting waters with an elevated TOC compared to the normal TOC that is present in groundwaters. As discussed above, groundwaters that are recharged naturally do not contain any significant amounts of TOC. This is because the TOC is removed in the vadose zone or the upper parts of the saturated aquifer. This, however, is not true for ASR projects that would inject treated domestic water supplies, where several mg/L of TOC (DOC) can be present in the injected water and still be acceptable for public consumption under current regulatory requirements. This TOC/DOC is not a "trace compound," but would accumulate in the aquifer, coating the aquifer solids, thereby changing the chemical and physical characteristics of the aquifer.

Roscoe (2005) also stated,

> ***"SSWD's Interest in the Roseville and Tracy Projects***
> *SSWD's interest in the CVRWQCB's regulation of ASR projects presently pursed by the Cities of Roseville and Tracy originates for two principal reasons. First, the District has invested heavily in conjunctive use water supplies including construction of five wells designed for ASR use. Additional wells are planned. To date we have been banking in-lieu by purchasing more expensive surface water when it is available and resting wells for the past several years. Groundwater replenishment is occurring and the 60 year decline in groundwater levels is beginning to be arrested. Secondly, SSWD has*

essentially reached the maximum in-lieu potential as system demands are low when surface water and contracted treatment plant capacity is available in the winter. SSWD will only be able to fully exercise banking potential through ASR. If SSWD is not able to fully execute conjunctive use plans due to an inability to permit ASR operations, the Water Forum Agreement is at jeopardy. If the District is unable to bank sufficient water during wet years, we risk the ability to forgo surface diversions in critically dry years with concomitant downstream impacts on the lower American River and the delta."

Roscoe has failed to properly discuss the situation with respect to the quality of the waters that are proposed by the communities of Roseville and Tracy for injection into the aquifers underlying the respective communities. Both Roseville and SSWD have the potential to inject through an ASR project waters of high quality derived from the American River system. This is not the case for Tracy. While Tracy has an option to inject high-quality waters, the managers of the Tracy water utility propose to inject Delta-Mendota Canal water derived from the South Delta that, while treated to meet minimal domestic water supply water quality requirements, contains potentially significant amounts of agricultural and some domestic-wastewater-derived components. It is the Tracy situation which mandates that higher degrees of treatment be practiced on the recharge waters because of the poor water quality with respect to protection of aquifer quality.

Overall

Enhanced groundwater recharge with surplus surface waters should be strongly supported as a supplemental source of water supplies that can be used during periods of drought and limited surface water availability. Since some of the constituents that are present in surface waters, including those that have been treated to just meet current US EPA and state drinking water MCLs, contain DOC and other chemicals that will remain in the aquifer upon recovery of the injected water, recharge of waters of poorer quality should be done through surface infiltration basins where the pollutants can be removed in the near-surface area (vadose zone) of the aquifer. ASR based recharge projects should inject only high-quality water into the aquifer. This will require treatment of the recharge waters by activated carbon beds to remove chemicals that can pollute the aquifer. All groundwater recharge projects should include intensive pre-, operational and post-operational monitoring of the aquifer characteristics and injected and recovered waters. The additional cost to the consumer of adequate treatment of the recharged/recovered water to protect public health and the environment is small and readily affordable.

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Dr. G. Fred Lee's Background to these Comments

Dr. G. F. Lee has over 50 years of experience in domestic water supply water quality and groundwater quality issues. In 1955, while a graduate student at the University of North Carolina, School of Public Health, his master's degree work focused on studying reactions associated with the use of chlorine dioxide for disinfecting and controlling tastes and odors in domestic water supplies. In 1960, he earned a PhD degree from Harvard University in environmental engineering, focusing on aquatic chemistry. His PhD dissertation was concerned with the kinetics of chlorination of phenol as it relates to the development of taste and odor
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problems in domestic water supplies. He found some of the first indications reported on the reactions between chlorine used for disinfection of water supplies and various types of organics present in surface water based water supplies. Through these studies it became evident that chlorine interacted with aromatic compounds such as phenols to produce a variety of chemicals, only some of which at that time were identified; the majority of the reaction products were not identified. Subsequently, studies conducted by others demonstrated that those reactions led to what has become known as "trihalomethanes," which are chloroform and chloroform-like compounds. These chemicals are regulated as carcinogens in domestic water supplies. The trihalomethanes are of concern in enhanced groundwater recharge projects as potential pollutants.

Throughout G. F. Lee's more than 45-year professional career, 30 of which were spent as a professor at several major US universities, he has been involved in issues of domestic water supply water quality. He has served as a consultant to a number of water utilities on disinfection byproduct formation and control. He has published hundreds of professional papers on aquatic chemistry issues in peer-reviewed journals and conference proceedings. In the 1960s, while a professor at the University of Wisconsin, Madison, G. F. Lee became involved in evaluating groundwater quality as it affects the use of groundwaters for domestic water supply purposes. In the early 1960s he became interested in groundwater quality protection issues. This interest led to becoming involved in various professional society committees, including an American Society of Civil Engineers (ASCE) Groundwater committee that was chaired by Dr. Karl Longley. As discussed herein, G. F. Lee has been involved in several ASCE committees concerned with groundwater quality and groundwater recharge, including the Artificial Recharge of Ground Water Committee.

G. F. Lee has been active in domestic water supply surface water quality issues, with particular emphasis on how land use in the water supply watershed impacts raw water quality, throughout his professional career. These activities included being a member of the national American Water Works Association (AWWA) Quality Control in Reservoirs committee. He served as chair of this committee for several years during the late 1970s and early 1980s. During this period he introduced the concept of source water quality protection to the AWWA.

Dr. Lee has been involved in TOC in surface water source investigations and impact issues for over 40 years. In the 1960s, while a Professor of Water Chemistry at the University of Wisconsin, Madison, Dr. Lee helped the state of Wisconsin organize the first statewide groundwater quality monitoring program. He has also developed national groundwater quality monitoring programs for several other countries.

In 1989, when G. F. Lee retired after 30 years of university teaching and research and expanded his part-time consulting into a full-time activity, he and Dr. A. Jones-Lee moved to California (near Sacramento). One of the areas of their initial efforts was groundwater quality protection. It was found in the early 1990s that the regulatory agencies in California had not been and, for that matter, are still not protecting the state's groundwaters from pollution (impairment) from agricultural activities, and domestic, industrial and commercial wastewater management on land and by landfills. Following on to Dr. Lee's experience in developing groundwater quality monitoring programs for Wisconsin and other areas, G. F. Lee made an effort to develop a

California statewide groundwater quality monitoring program. In support of this effort he became active in the Association of California Water Agencies (ACWA) Groundwater Committee. He was instrumental in having this committee develop a Groundwater Quality subcommittee, which he chaired.

When G. F. Lee suggested that there was need to develop a statewide groundwater quality monitoring program for California that included a proactive approach to detection of the potential for land surface activities, such as irrigated agriculture, to lead to groundwater pollution, members of the Groundwater Quality subcommittee from irrigation/agricultural interests were opposed to any groundwater quality monitoring that would show that irrigated agriculture was polluting groundwaters. Following suggesting this approach to the members of the ACWA Groundwater Committee, G. F. Lee found that the management of ACWA imposed an over $800 ACWA membership fee on G. F. Lee's participation in ACWA. Prior to this time he was able to participate in ACWA as an advisor at a small membership fee. The increased fee led G. F. Lee to terminate his membership in ACWA. The ACWA Groundwater Quality subcommittee was disbanded by ACWA. It is clear that there is strong opposition by many of those potentially responsible for groundwater pollution to developing any area/statewide groundwater quality monitoring program.

Throughout G. F. Lee's university teaching and research career he was involved in research devoted to groundwater transport of pollutants in the saturated and unsaturated (vadose) part of an aquifer. The pollutants investigated included pesticides and nutrients. This research included participation in an $11-million, multi-year, US EPA-sponsored project on the transport of land-applied domestic-wastewater-derived potential pollutants in the over one-hundred-foot-thick vadose zone of the Ogalalla aquifer in west Texas.

More recent groundwater quality studies in which G. F. Lee has been involved include serving as the US EPA Superfund Technical Assistance Grant advisor to the public on two national Superfund sites that include groundwater pollution by hazardous organics, arsenic and radioactive wastes. G. F. Lee's work on drinking water quality includes considerable experience working on water quality criteria, including drinking water MCLs. He was asked by the US Public Health Service to chair a committee concerned with the need for a drinking water MCL for PCBs. He is familiar with the level of adequacy of US EPA drinking water MCLs to protect public health.

For a several-year period, G. F. Lee was a member of the editorial board for the journal *Groundwater* and is currently a member of the editorial board for the journal *Remediation* (the Journal of Environmental Cleanup Costs, Technologies, & Techniques). Additional information on Dr. G. F. Lee's recent activities and professional experience is available on his and Dr. Jones-Lee's website, www.gfredlee.com.