# Water Quality Aspects of Groundwater Recharge: Chemical Characteristics of Recharge Waters and Long-Term Liabilities of Recharge Projects

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Abstract

The development of a groundwater recharge project should require in-depth assessment of the characteristics of the recharge waters and their impact on the quality of the waters recovered from the aquifer and on the longevity of the recharge project. The residual contaminants in domestic and industrial wastewaters and surface water runoff from urban and rural areas that are recharged to groundwaters through incidental or enhanced recharge projects can be adverse to groundwater quality and aquifer quality. Attention should also be given to the chemical and other characteristics of the recharge waters and the aquifer to ensure compatibility so as to protect the quality of the aquifer and the recovered water from contaminants in the aquifer that are not associated with the recharge waters. Guidance is provided in this paper on the overall approach that should be followed in evaluating water quality issues in groundwater recharge projects. Particular attention is given to potential water quality and aquifer quality issues associated with the recharge of surface waters and wastewaters that have received limited treatment prior to recharge, where the unsaturated zone of the aquifer is used as an extension of the wastewater treatment system to remove contaminants that could be adverse to recovered water quality, aquifer quality, and the long-term longevity of the recharge recovery project. Owing to the accumulated (stored) contaminants, that aquifer waste treatment zone could become a source of contaminants for the aquifer that would require remediation to prevent groundwater pollution from current or previous recharge of surface waters that have not been adequately treated prior to recharge.

## Introduction

With groundwaters' providing about 50% of the US water supply and with groundwater basins' being overdrafted (mined) in many areas of the country, increasing attention is being given to supplementing groundwater supplies by enhanced recharge of surface waters to aquifers. One of the principal areas of concern in the development of a groundwater recharge project is the presence of chemical and microbial contaminants in the recharge water that could impair the use of the recovered waters for domestic or other purposes at the time of operation of the project or in the future after the project has ceased operation. Further, depending on the nature of the wastewaters used either directly or indirectly for recharge, there may be a myriad non-conventional contaminants introduced to groundwater that are not identified in conventional monitoring programs or for which drinking water standards have not been developed. Since recharge waters are often of poorer quality than those considered acceptable for domestic water supply, and since there are not water quality standards for all potentially hazardous or otherwise deleterious chemicals and agents that could be present in a recharge water, it is possible that passage through the aquifer would not adequately "treat" the recharge waters to render an acceptable quality in the recovered water.

Often overlooked in groundwater recharge projects is the fact that contaminants already in the recharge area of the aquifer from natural or anthropogenic sources, such as radon, arsenic, TCE and other organics, iron, manganese, etc., could be mobilized by the recharge water. Independent of the chemical contaminants in the recharge water itself, this mobilization could necessitate the treatment of the recovered water before they could be used for domestic or other water supply purposes. In addition to affecting the quality of the recovered water, chemical contaminants added to an aquifer in the recharge waters and reactions that take place in an aquifer can adversely impact the longevity of a recharge project. Hydrogeological properties of the aquifer can be affected by precipitation reactions (such as $CaCO_3$ formation) that cause mechanical blockage of the aquifer pores, and by ion exchange reactions that adversely affect the shrink/swell properties of some clays present in an aquifer.

Chemical contaminants introduced into an aquifer by recharging groundwaters with surface waters or treated wastewaters can build up in the aquifer. Eventually the contaminated part of the aquifer that was used for contaminant removal as part of the recharge project may need to be remediated. The introduction of inadequately treated recharge waters could readily lead to substantial, long-term, "Superfund"-like financial liabilities for the recharge project owner/operator, as well as loss of groundwater resources in the region for use by future generations. It is therefore imperative in the development and operation of a groundwater recharge project that a critical evaluation be made of potential water quality problems that could occur in the recovered waters, in the aquifer waste treatment zone, as well as in the aquifer itself.

Lee and Jones-Lee (1993) provided overall guidance on water quality aspects of incidental and enhanced groundwater recharge of domestic and industrial wastewaters. That review covers a number of the water quality issues that should be addressed in the development and management of a successful groundwater recharge project. This paper focuses on specific chemical water quality aspects of recharge waters used in groundwater recharge projects. In this discussion, the term, "aquifer quality," refers to the hydraulic properties of the aquifer that enable the transmission of water from the point of recharge to other areas within the aquifer as it may be affected by contaminants in or characteristics of the recharge waters. "Aquifer quality" also has reference to the potential for contaminants in the recharge waters to cause transformation or desorption of organics from the aquifer solids such that the water quality characteristics of the recovered waters are adversely affected during the active life of the recharge project or after the project has been terminated. "Water quality" has reference to the suitability of a water for its intended use, e.g., for groundwater recharge or drinking water.

Character of Recharge Waters

Groundwater recharge projects with domestic wastewater often enjoy favorable permitting status owing to their characterization as a water recycling effort. This can result in minimization of the scrutiny that the project receives for its potential long-term impacts, minimization that may not be realized if it were not a "recycling" project. In many groundwater recharge projects surface waters and wastewaters are recharged to the groundwater system without adequate pre-operational evaluation of potential problems associated with the contaminants in the recharge waters. Recharge projects are often initiated without proper evaluation of the potential longer-term problems, and are run until a significant problem develops with either aquifer quality or the quality of the recovered water.

One of the issues in need of particular concern in enhanced groundwater recharge projects is the degree of treatment needed for recharge water prior to recharge, to protect the quality of the recovered water and to enable the area of the aquifer receiving the recharge water to function reliably for an extended period of time as a successful recharge/recovery project. As discussed by Lee and Jones-Lee (1993), poor-quality surface waters are being recharged incidentally and through enhanced groundwater recharge projects to groundwaters that will at sometime in the future, adversely impact groundwater quality for use for domestic or other purposes. Secondarily treated domestic wastewaters and many industrial wastewaters, urban stormwater drainage, and agricultural and rural stormwater runoff and irrigation return waters contain high concentrations of a wide variety of inorganic and organic, dissolved, particulate, and colloidal contaminants that can adversely impact groundwater and aquifer quality. Without appropriate pretreatment of those wastewaters prior to recharge, those contaminants would have to be removed in the aquifer in order to produce recovered waters of sufficient quality to enable them to be used for domestic purposes.

Significant deficiencies exist in regulatory approaches for the permitting of wastewater discharges and surface water runoff from urban and rural sources, with the result that groundwater quality is not being protected from adverse impacts of contaminants in surface waters. In many areas, essentially no regulatory attention is being given to the prevention of the pollution of an aquifer from incidental groundwater recharge that normally takes place in streambeds. Some regulatory agencies such as the CA Department of Health Services (DHS), are proposing to require extensive domestic wastewater treatment, including the use of reverse osmosis and activated carbon, to improve the quality of wastewaters that are injected into aquifers through wells for the purpose of trying to protect aquifer and groundwater quality. However, DHS is also allowing enhanced groundwater recharge in streambeds of what are essentially 100% wastewaters and agricultural runoff, with no regulation of the composition of those waters. Similarly, DHS is allowing wastewater and water supply authorities to recharge in infiltration ponds domestic wastewaters that have received essentially only secondary treatment and contain large amounts of chemical and microbial contaminants that could be adverse to the quality of the recovered water and the aquifer. Regulatory agencies and recharge project owner/operators today are also, in general, not giving adequate attention to the build-up of contaminants within the upper parts of the aquifer's unsaturated and saturated zones that could at some time in the future, become sufficiently great as to require "Superfund"-like remediation of those parts of the aquifer that were used to provide for removal of contaminants in the recharge waters that should have been removed prior to their recharge.

Use of the Aquifer for Wastewater Treatment

In this discussion the term "aquifer waste treatment zone" is used to describe the part of the aquifer in which enhanced recharge of surface waters occurs, which is relied upon to remove (treat) contaminants in the recharge waters in order to prevent them from adversely impacting the near-term water quality in the waters recovered from the recharge project. Typically, the aquifer waste treatment zone is primarily the pre-operational unsaturated area of the aquifer where abiotic and biotic (biochemically mediated) transformations of contaminants present in the recharge waters occur. Those transformations can result in the removal of contaminants stored in the aquifer waste treatment zone through precipitation and sorption reactions, as well as transformation to other chemicals.

While the aquifer waste treatment zone may have been unsaturated prior to the initiation of recharge, during times of active recharge it likely becomes saturated. Further, many recharge projects operate with a pulsing from recharge basins that are allowed to dry out in order to improve their hydraulic characteristics through natural processes and/or mechanical removal of "fines" that have accumulated near the surface of the bottom of the recharge basin. Thus, the aquifer waste treatment zone likely fluctuates between saturated and unsaturated conditions. Such fluctuations can have a significant impact on the chemical/biochemical processes that occur in that area. Contaminant removal (waste treatment) can also occur within the saturated zone of the aquifer, especially in those systems with limited travel distances and short travel times through the formerly unsaturated zone of the aquifer below the recharge areas.

One of the areas of particular concern in groundwater recharge projects which utilize secondarily treated domestic wastewaters and/or poor-quality river waters that are substantially composed of domestic, industrial, or agricultural wastewaters (including irrigation return flows) that have received limited treatment prior to recharge is the long-term transformations that will occur within the pre-operational unsaturated part of the aquifer above the water table that is in the flow path of the recharge waters. Groundwater recharge of untreated surface waters that occurs naturally in many rivers, streams and lakes, contributes contaminants that are of potential significance in influencing recovered water quality. However, the enhanced recharge of surface waters and their associated contaminants can greatly increase the potential for groundwater quality problems due to the increased hydraulic and contaminant loading.

A number of recharge projects that use secondarily treated domestic wastewaters for recharge are relying heavily on the pre-operational unsaturated zone of the aquifer to provide additional wastewater treatment. While this practice can occur for a considerable period of time, eventually the build-up of contaminants within the aquifer treatment zone can become sufficiently great to limit the aquifer's ability to continue to provide waste treatment (contaminant removal). This can result in that part of the aquifer's becoming a significant source of contaminants for the groundwater for very long periods of time, effectively in perpetuity, through normal groundwater infiltration through the region, even if no additional recharge waters were added. In addition, it is likely that a number of the recharge project areas where secondarily treated domestic wastewaters or poor-quality surface waters are being recharged to groundwater systems, where the former unsaturated zone of the aquifer is relied upon to provide for contaminant removal, will ultimately become significant liabilities to the owner/operators of the recharge project; the project owner/operators will ultimately be required by regulatory agencies to prevent the contamination of the groundwaters from the residual contaminants that have built up in the aquifer waste treatment zone during the time that groundwater recharge of inadequately treated wastewaters and surface waters occurred.

Many of the critical issues pertaining to the impacts on aquifer and groundwater quality of incidental and enhanced recharge with lesser quality waters have not been properly investigated to allow reliable assessment or regulation of those activities. There is a need to conduct a number of comprehensive studies of aquifer quality and water quality in the unsaturated zone and the saturated area of aquifers below the recharge areas to identify and evaluate potential problems that can and will likely occur as a result of build-up of contaminants in the aquifer waste treatment zone. Those studies should include a number of locations at which the aquifer solids in the aquifer waste treatment zone have become contaminated with chemicals and organisms derived from the recharge waters to determine the degree of exhaustion of waste treatment capacity that has occurred and also the potential long-term leaching/release of contaminants from the solids that have been contaminated by the introduction of inadequately treated wastewaters into the aquifer through an enhanced recharge project. Attention should be given in selection of sites for study to recharge projects that use river water downstream of municipal and industrial wastewater discharges, and river water containing large amounts of agricultural wastewaters, land runoff, and/or urban stormwater drainage, as well as those projects in which domestic and industrial wastewaters have been recharged with limited treatment beyond secondary treatment to remove contaminants that could be adverse to groundwater quality and aquifer quality.

Every groundwater recharge project that is relying to any extent on the aquifer to remove contaminants should include detailed mass balance studies to determine the fate of various types of contaminants in the recharge waters within the potentially impacted aquifer system. If contaminants are being removed in the unsaturated zone below the point of recharge, the mechanism of removal should be determined and quantified. If removal is by precipitation or sorption on the aquifer solids, leaching studies should be conducted with appropriate types of waters to properly simulate the infiltration that will occur through the ground surface if the recharge system is allowed to continue as well as if it were removed. If the mechanism of contaminant removal appears to be chemical or biochemical transformations, studies need to be done to determine whether the transformations are leading to the development of transformation products that could be adverse to either groundwater quality or aquifer quality. Any groundwater recharge project should be required to include a comprehensive study to determine the fate (transport and transformation) of contaminants in the recharge waters from the point at which recharge occurs to the point at which the waters are recovered.

Great care should be exercised in recharge projects to prevent the aquifer treatment zones from becoming future "Superfund" sites that will eventually have to be remediated to prevent aquifer contamination from residual accumulated contaminants. Those operating recharge projects could readily develop significant financial liabilities (i.e., become responsible parties) by failing to provide sufficient pre-operational evaluation of near-term and long-term water quality problems associated with residual contaminants in the recharge waters that accumulate within the aquifer. Because of the potential for groundwater recharge projects to contaminate the aquifer with a variety of pollutants that can threaten groundwater quality, it is important that in planning a groundwater recharge project adequate funding be set aside in a dedicated trust fund of sufficient magnitude to generate in perpetuity the funds needed for post-operational monitoring of the recharge project area.

## Evaluation of Potential Water Quality Problems

The evaluation of the potential water quality problems associated with a proposed groundwater recharge project centers on the understanding, description, and quantification of the aquatic chemistry of the recharge operation. Contributing to that evaluation are a compilation and evaluation of existing water quality data, development of a monitoring program to collect reliable data to describe the chemical characteristics of the recharge and aquifer waters over time, and the use of aquatic chemistry modeling for predicting potential water quality problems for a specific, proposed recharge project.

### *Evaluation of Aquatic Chemistry of the Recharge Operations*

In planning the development of a proposed recharge program, a detailed characterization should be made of the physical and chemical composition and variability in composition of the waters proposed for use in recharging, the aquifer waters, and the aquifer solids. The data collection and monitoring program discussed by Lee and Jones-Lee (1994) and summarized below should be conducted in such a way as to not only develop information on the chemical characteristics of the waters that will be recharged and those within the aquifer, but also provide information that can be used to predict contaminant transformations that can be adverse to aquifer water quality and/or aquifer quality. A water chemistry modeling effort should be undertaken with that information to predict the abiotic and biochemically mediated transformations that components of the proposed recharge water will undergo within the aquifer in the interactions of the recharge waters with the aquifer solids and waters. Information from the literature on the kinetics and thermodynamics of specific reactions should be used to the maximum extent possible in the pre-operational modeling effort. The US EPA's MINTEQ model (Allison *et al*., 1991) can be used as a framework to make initial predictions of the potential for a number of reactions to occur in the aquifer system based on the chemical characteristics of the waters, particularly the pH and redox (oxidation/reduction) conditions. The review by Lee and Jones-Lee (1993) provides an overview discussion of many of the types of transformation reactions that are likely to be important in groundwater recharge projects and that should be considered in the modeling effort. It also provides references to the literature that provides additional information on this topic.

### *Water Quality Monitoring*

Pre-operational monitoring program for a proposed groundwater recharge project should be of sufficient detail and duration to provide the information needed on the characteristics of the recharge waters and the aquifer system to make reliable aquatic chemistry predictions of expected chemical characteristics of and transformations that will occur in the recharge areas. The first step in developing the pre-operational monitoring is the critical evaluation of the nature and reliability of the existing data on the characteristics of the recharge waters and the aquifer system. As discussed by Lee and Jones-Lee (1983a; 1994) it is important to not make the common, but mistaken, presumption that because data have been collected and analyzed with a "standard methodology" the data are necessarily reliable. This so-called "standard method syndrome" (Lee, 1969) has resulted in the development and inappropriate use of large amounts of highly unreliable data being developed on the chemical characteristics of the nation's surface and groundwaters. Those responsible for developing water quality monitoring programs associated with groundwater recharge projects (including using information from the literature) have the responsibility to evaluate the reliability of the sampling and analytical procedures used to ensure that they are developing reliable information on the characteristics of the groundwater recharge project. It is important to develop a good understanding of the hydrogeology of the aquifer into which the waters are proposed to be recharged. The sampling program for the groundwaters must be properly developed to reflect the site-specific hydrogeology of the various principal components of the aquifer. Failure to do so could readily lead to erroneous conclusions concerning the chemical characteristics of the aquifer waters and the chemical reactions that can take place within the aquifer upon introduction of recharge waters to it.

During the operation of the groundwater recharge project, monitoring should be conducted to evaluate the reliability of the pre-operational modeling of the aquatic chemical transformations that would be expected in the aquifer system based on its physical, chemical, geological, and hydrogeological characteristics. With the start-up of the recharge operation, measurements of the concentrations of contaminants in the recharge water and aquifer as well as their transformation products should be made and compared with the expected or estimated concentrations. Notable differences between the characteristics and concentrations expected and measured should be investigated further. The evaluation of the aquatic chemistry modeling should include a recharge water contaminant mass balance evaluation to support the accounting for the potentially significant reactions (transformations). This approach can provide useful information on the transformations that are actually occurring within the aquifer that could lead to problems with aquifer quality and/or quality of recovered water.

Post-operation (after project cessation) monitoring should be conducted for some time after the conclusion of the recharge project, depending on the nature and rate of movement of water through the unsaturated zone and in the aquifer itself, the character of the recharge waters, and the nature of the aquifer solids. The focus of this monitoring should be the detection of leaching of contaminants removed in the aquifer waste treatment zone, into the groundwater.

The principal area of concern for those responsible for developing a groundwater monitoring program for a groundwater recharge project should be the establishment of a reliable analytical program for data collection. Far more money and effort must be devoted to the analytical chemistry part of recharge and existing groundwater characterization than is typically done today in recharge projects if the data collected are to be reliable and adequate to meet the water quality protection needs of the project. Lee and Jones-Lee (1994) provide guidance on the approaches that should be followed in developing pre-operation, operation, and post-operation water quality data for groundwater recharge projects. In addition, Lee and Jones-Lee (1992; 1983b) provided guidance for conducting water quality studies that has direct applicability to guiding the development of the water quality evaluation part of groundwater recharge projects. Their guidance emphasizes the importance of developing a water quality characterization (monitoring) program that assesses the characteristics of a water over a period of time with a known degree of reliability. The typical approach used of taking a sample of a potential recharge water in an arbitrarily established regimen (e.g., the first Monday of every month over a year) is often not reliable for properly characterizing the chemical characteristics of the water that could be important in influencing the success of the recharge project. Instead of the mechanical approach to developing water quality studies, Lee and Jones-Lee (1992, 1994) recommend that the water quality evaluation program be based on the characteristics of the system being studied, and especially its variability.

## Conclusions

The groundwater resources of a region where recharge takes place are of significant value to the region and therefore should be protected from inappropriately conducted recharge projects. To that end, a significant, pro-active groundwater quality protection dimension needs to be added to groundwater recharge projects. The meeting of the current regulatory requirements for groundwater recharge cannot be presumed to protect groundwater quality or the groundwater aquifer resource from significant and irreparable damage. The typical project management approach of running the project until some problem develops which either terminates or significantly curtails the operations is not in the best interest of an effective project and can be expected to result in aquifer and/or groundwater contamination problems that will eventually have to be addressed.

Through the appropriate use of aquatic chemistry information - chemical thermodynamics and kinetics, modeling, and appropriate monitoring, it is possible to gain considerable knowledge about the behavior of the aquifer as a chemical system as influenced by the characteristics of the recharge waters. Further, if properly conducted, these evaluations can be predictive of potential long-term problems associated with the build-up of contaminants in the unsaturated and saturated part of the aquifer that could lead to "Superfund" liabilities. This assessment can be used to identify inappropriate recharge projects. For those projects determined to be appropriate, these efforts enable the anticipation and management of potential problem areas before the project is unnecessarily curtailed or terminated or before problems arise with contaminant build-up in the aquifer to result in long-term liabilities for the project owner/operators or the public.

Some recharge project managers will likely object to spending the necessary funds to properly characterize the recharge waters prior to and during recharge to the degree necessary to evaluate potential near-term and long-term water quality problems that could be associated with the contaminants present in the recharge waters. However, such a short-sighted approach fails to recognize the very high costs associated with attempts to remediate contaminated groundwaters and to control sources of contaminants to prevent further contamination, and the significant loss of water resources that can readily occur because of a failure to give adequate consideration to the potential consequences of using an aquifer to try to "treat" contaminants in the recharge waters. It is in the best interest of groundwater recharge projects, those who depend on those enhanced resources, and groundwater and aquifer resources to incorporate reliable groundwater quality evaluations and precautions in the design and execution of recharge projects.

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Presentation Slides Follow:

## Water Quality Aspects of Groundwater Recharge: An Overview

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Inadequate Attention Given to the Quality Characteristics and Potential Impacts of Waters Used to Recharge Groundwaters

- Can Lead to Significant Problems in the Wake of Recharge Projects

Suggestions for Improving Groundwater Recharge Projects for Protection of Groundwater and Aquifer Quality and Use

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*Presented at ASCE Second International Symposium on Artificial Recharge, Orlando, FL, July (1994)*

Suggested Approach for More Reliable Incorporation of Water Quality/Water Chemistry into Groundwater Recharge Projects

Water Quality/Water Chemistry Is Not Simply the Analysis of a Single or a Few Samples for a Laundry List of Chemicals

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Water Chemistry Water Analysis
*(Transformations) (Inventory)*
**Conventional Recharge Project Evaluations**

**Pre-Operation Investigation:**

- A Few Samples of Recharge and Aquifer Waters Analyzed for Selected Conventional Contaminants and Priority Pollutants
- Little Use Made of Data

**Operation Phase Groundwater Monitoring:**

- Recharge Water and Recovered Water Periodically Analyzed for Conventional Contaminants and Priority Pollutants
- Inadequate to Properly Plan Project, Evaluate Potential Problems, Protect Groundwater & Aquifer Quality, Assess Long-Term Liabilities
- Need More Reliable Water Chemistry/Water Quality Evaluation & Monitoring Efforts before and during Operation of Recharge Projects
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## Recharge Projects Potential Future "Superfund" Sites

Current Approach Relies on "Black Box" Soil Aquifer Treatment

Precarious Approach

Can Lead to Very Expensive Consequences:

- Long-Term Loss of Groundwater & Aquifer Use
- Clean-Up - Future "Superfund" Site

Reliable, Long-Term Protection of Groundwater and Aquifer Should Be High Priority for All Recharge Projects

More Important Than Contributing to Satisfying Short-Term Needs for Additional Water Supply

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## Recommendations for Pre-Operation Investigation

Conduct Sufficient Pre-Operation Monitoring and Studies to:

- Reliably Characterize Recharge Waters, Aquifer, & Groundwater

Conventional Contaminants Priority Pollutants Non-Conventional Pollutants

Variability in Composition

Collect Sufficient Data to Enable Reliable Prediction of the Chemical Characteristics of Next Set of Samples

- Predict Chemical Transformation & Fate of Contaminants Added to Aquifer via Recharge Waters and Otherwise Present in Aquifer
- Carefully Evaluate Hydraulic Properties of Unsaturated and Saturated Parts of Aquifer

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## Recommended Operation Phase Monitoring Water Quality/Water Chemistry Studies

Pro-Active Rather Than Passive Monitoring

- Critically Examine Data as Collected
- Use Data in Decision-Making Process
- Flexible to Allow for Adjustment Based on Findings

Carefully Monitor Hydraulic Properties of Aquifer to Detect Problems at First Occurrence

Conduct Special-Purpose Studies to

- Evaluate Pre-Operation Predictions of Transformation
- Detect Unexpected Transportation Products
- Assess Build-Up of Contaminants on Aquifer Solids That Could Be Long-Term Products

Conduct Sufficient Studies to Define Chemical Transformations in Unsaturated and Saturated Part of Aquifer

- Give Special Concern to Non-Conventional Contaminants
- Use Mass Balance Approach

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**Recommended Post-Operation Monitoring**

Monitor Releases of Contaminants from Soil/Aquifer Treatment Area; Active Data Review

- Unsaturated and Saturated Zones

Monitoring Program Will Likely Be Needed Forever

Flexibility to Address Changes in

- Parameters of Concern
- Water Quality Standards
- Technical Information

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**Recommended Operation Phase Monitoring Pathogens**

Migration of Enteroviruses in Unsaturated and Saturated Areas

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**Recharge Project Personnel and Budget**

Must Include Individuals with High Degree of Theoretical and Practical Expertise and Experience in:

- Water Chemistry
- Public Health/Water Quality

Adequate Budget to Support Appropriate Studies

- Pre-Operation Operation Post-Operation
- Site-Specific Evaluations - Nature and Intensity Depends on Complexity of Site and Recharge Waters
- Pro-Active; Not Passive

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## Conclusions

- Groundwater Recharge Projects Have Significant Potential to Cause Adverse Impacts on Water Quality and Aquifer Quality
- Insufficient Attention Given in Development of Recharge Project Development to Potential Problems
- Pro-Active Monitoring and Studies Needed before Operation, during Operation, and after Operation to Define System Reactions, and Fate and Impacts of Contaminants Added to Aquifer
- Can Be Highly Cost-Effective in Achieving a Successful Recharge Project with Reduced Long-Term Liabilities

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## Overall Recommended Approach

- Provide Very High Degree of Appropriate Treatment for Recharge Water to Reliably Reduce Contaminants Including Non-Conventional Pollutants to Protect against Deterioration of Aquifer and Groundwater Quality and Reduce Long-Term Liabilities
- Avoid Reliance on "Black Box" Soil/Aquifer Treatment Approach of Putting Contaminants into Aquifer until Problems Are Recognized
- Treat Recharge Waters to Remove Contaminants to the Maximum Extent Readily Possible
- Take Pro-Active - Protective Approach; Err on Side of Public Health Protection
- Initially Somewhat More Expensive; Likely Much Less Costly in the Long Term

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## Overview of Water Quality Issues

For All Recharge Waters, Evaluate Whether Contaminants Could:

- Pollute Aquifer to Impair Use for Domestic Water Supply
- Result in Pollution of Recharge-Recovered Water by Contaminants in Aquifer That Prevent Its Use for Water Supply
- Radon, As, Fe, Mn, $H_2S$, VOC's, etc.
- Limit Ability to Recharge and Recover Water from Aquifer
- Impair Hydraulic Characteristics - Cause Plugging of Aquifer by Precipitates, Biological Growths, Ion Exchange Shrink-Swell Characteristics

- Lead to Long-Term Liabilities for Clean-Up (Future "Superfund" Sites) for Recharge Project Organizers

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## Importance of Groundwater Quality Protection

Groundwater Provides 50% of US Domestic Water Supply; ~50% of California Water Supply

Superfund Studies Show That Once Contaminated, Groundwater Difficult If Not Impossible to Clean Up

Cannot Develop Surface Water Supply Sources

Future Water Supply Development Must Be Directed toward Groundwater and Aquifer Use

Conjunctive Use of Surface and Groundwaters

Enhanced Recharge and Recovery

Aquifer Must Be "Clean"

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## Current Approaches for Groundwater Quality Protection

**Reactive - After Groundwater Water Well Polluted**

- Abandon Use of Well; Move to New Location
- Start Clean-up Activities

**Pro-Active - Before Problem Occurs**

- Evaluate Potential Contaminants in Recharge Waters to Determine If Water Is "Safe" to Use for Recharge
- **Inadequate Regulation of Groundwater Quality Protection**

**Surface Waters -** 1972 Water Quality Act

Goal: Zero Pollutant Discharge

**Groundwater - No National Legislative Protection of Groundwater Quality**

Groundwaters Need Greater Protection Than Surface Water

Cannot Be Cleaned Up

More Vulnerable to Pollution by Some Chemicals

Limited Dilution

Most States Cannot Protect Groundwater Quality - Politics Prevent Development of Effective Legislation

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**Categories of Contaminants/Pollutants**

Regulated Chemicals

**Conventional Pollutants**

Potentially Deleterious Chemicals - e.g., Fe, Mn, $H_2S$, TDS, $Cl^-$, $SO_4^{=}$, $NO_3^-$

**Priority Pollutants**

Potentially Hazardous Chemicals - e.g., DDT, TCE, Benzene, PCB's

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**Categories of Contaminants/Pollutants**

Unregulated Chemicals

**Non-Conventional Contaminants/Pollutants**

Organics of Undefined Composition and Characteristics Seen by Difference between TOC and Identified Organics

95% of Organics in Many Wastewaters, Municipal Landfill Leachates, Stormwater Runoff Waters, etc. Are of Unknown Characteristics and Hazard

Could Contain the Next "Dioxin"

65,000 Chemicals in Use; 1,000 New Chemicals Each Year

**Cannot Assume That Because There Is No Exceedance of an MCL, a Water That Has Received Non-Conventional Pollutants Is Safe to Drink**

**Prudent Public Health Policy to Assume That Any Water Contaminated by Non-Conventional Pollutants Is Unsafe to Drink**

**Unknown & Unregulated Risk**

## Areas of Concern

Municipal and Industrial Wastewater Discharges to Surface Waters That Recharge Groundwaters without Regard to Incidental Recharge That Could Impair Uses of Groundwater

No Regulation of Non-Point Source Runoff from Urban and Rural Areas

## Aquifer/Soil Treatment

Unsaturated Part (Vadose Zone) and Saturated Part of Aquifer Used to Remove Contaminants from Recharged Waters

Unsaturated and Saturated Zones of Aquifers Have Limited Capacity to Remove Many Types of Contaminants from Recharged Waters

When Capacity Exceeded, Excessive Concentrations of Contaminants Can Be Present in Water Recovered from the Aquifer

## Components of Aquifer "Quality"

Hydraulic - Hydrogeology

Water Quality

Chemical Contaminant-Related

- Toxics, Carcinogens, Other Measured Potentially Hazardous Chemicals
- Chemicals Otherwise Deleterious to Use of Aquifer for Domestic Water Supply (e.g., Problems of Aesthetics, Tastes and Odors, Increased Costs to Consumer)
- Non-Conventional Contaminants - Unknown, Unmeasured
- Uncharacterized, Unregulated Risks and Impairments

Organism-Related

Pathogens and Other Organisms That Are Adverse to Use of Water

## Philosophy of Approach for Protecting Aquifer and Groundwater Quality

### Current Approach

Introduce Contaminants into Aquifer until Problems Recognized; Abandon Problem Area and Move to Another Area

### Prudent Practice for Protection of Public Health & Aquifer Quality

Remove Contaminants to the Maximum Degree Possible until It Is Shown That Less Removal Will Be Protective of Public Health and Groundwater Quality

Provide Groundwater Recharge Now for Costs Cheaper Than Real at the Expense of Future Generations

- or -

Require This Generation to Provide Protection of Groundwater Resources from Impairment Now and in the Future

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***References as:"Lee, G. F. and Jones-Lee, A., 'Water Quality Aspects of Groundwater Recharge: Chemical Characteristics of Recharge Waters and Long-Term Liabilities of Recharge Projects,' IN: Artificial Recharge of Ground Water, II, Proc. Second International Symposium on Artificial Recharge of Ground Water, American Society of Civil Engineers, NY, pp. 502-511, (1995)."***
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