Guidance on Pre-, Operational and Post-Operational Monitoring of Ground Water Recharge Projects'

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Introduction

A key component of a ground water recharge project is the proper evaluation of potential water quality and aquifer quality problems associated with the introduction of contaminants in the recharge waters into the unsaturated and saturated zone of the part of the aquifer receiving the recharge waters. The development of reliable pre-, operational and post-operational monitoring programs is an integral part of the development of a successful ground water recharge project. Guidance is provided in this discussion on the approaches that should be followed in developing the pre-, operational and post-operational monitoring programs for ground water recharge projects. This discussion is designed to supplement the review that has been developed by Lee and Jones-Lee (1994) entitled "Water Quality Aspects of Ground Water Recharge: Chemical Characteristics of Recharge Waters."

Evaluation of Existing Water Quality Data

The first step that should be followed in evaluating the potential water quality problems associated with a proposed ground water recharge project is to obtain detailed information on the chemical characteristics of the proposed recharge waters. A critical examination of the existing data on the waters that would be recharged to the aquifer should be made to first determine their reliability and representativeness. Far too often those who examine previously collected data assume that this data is reliable. More times than not there are significant analytical problems with existing chemical data that are the result of inappropriate approaches having been used in sample collection, in the analytical methods used, and data manipulation and interpretation. The typical approach that has and continues to be used of collecting a water sample without adequate regard for contamination of the sample during the sampling process, loss of volatile constituents from the waters during sampling, and changes in the characteristics of the waters during sampling, sample transport and in pre-treatment of the sample during analysis has led to large amounts of highly unreliable data on the chemical characteristics of surface and ground waters. Those not knowledgeable in the proper conduct of water analyses often practice what Lee (1969) termed the Standard Method Syndrome where it is erroneously assumed that if the same procedures are consistently used in sample collection, preservation and analysis that comparable results will be obtained. This is only true if the water being sampled is identical to all other samples taken of that same water. However, in the real world, the chemical composition of waters changes significantly between each sampling period. The principal problem with the Standard Method Syndrome is that it fails to properly consider the role of interferences that can alter the analytical results. Varying the amount of interference in a sample, which almost certainly occurs between most samples, changes the reliability of the analytical procedure for accurately determining the concentration of the

' Reference as: Lee, G. F., and Jones-Lee, A., "Guidance on Pre-, Operational and Post-Operational Monitoring of Groundwater Recharge Projects," Report of G. Fred Lee & Associates, El Macero, CA (1994).

parameter of interest. It is erroneous to assume that analytical procedures in various standard methods publications such as APHA et al., US EPA, ASTM, etc. "Standard Methods" are accurate. All of these methods are subject to interferences which affect their accuracy and reliability.

The importance of properly evaluating the reliability of chemical data on aquatic systems has recently been brought home in a resounding way where it is now realized that essentially all of the heavy metal data collected in accord with US EPA, ASTM and USGS procedures on the surface waters of the US as part of water quality monitoring programs over the past 15 or so years that rigorous QA/QC programs have been in effect is unreliable. Much of it is in error by a factor of 10 to 100 due to the failure of those responsible for the analytical programs to use sample collection and analytical methods that practice "clean" techniques. While clean techniques have been known and practiced since the early 1960's by researchers in both marine and fresh water fields, they were not incorporated into the routine water analysis procedures that have been used for many years for monitoring the nation's surface waters with the result that all previously collected data on heavy metals now has to be judged unreliable and with few exceptions discarded.

It is important to distinguish between accuracy and precision for an analytical method. Reproducibility (precision) bears no relationship to the truth (accuracy) of the analytical procedure. Unfortunately, the QA/QC procedures that are used today in water and waste water analyses do not address the issue of interferences in the samples that cause the results to be inaccurate. The only proper way to evaluate the accuracy of a method is through the use of other potentially reliable methods on the same samples. If several different potentially reliable methods give the same answer, then it is reasonable to conclude that the analyses are accurate.

Development of Water Quality Data

Lee and Jones-Lee (1992a) have developed guidance for conducting water quality studies that has direct applicability to guiding the development of the water quality evaluation part of ground water recharge projects. Their guidance emphasizes the importance of developing a water quality characterization program that assesses the characteristics of a water over a period of time with a known degree of reliability. The typical approach of taking a sample of a potential recharge water on the first Monday of every month over a year is often not reliable in 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 (1992a) recommend that the water quality evaluation program be based on the characteristics of the system being studied and especially its variability.

The mechanical taking of one sample per week, month or some other arbitrary time period can readily miss important characteristics of the recharge waters that could influence the success of a recharge project. For example, short term events, such as high flow periods in rivers, could introduce into the aquifer concentrations of contaminants that would be of significance to the success of the ground water recharge project. It is rarely the "average" condition that exists in surface waters that will determine the important water quality characteristics of a ground water recharge project.

Pre- Operational Monitoring

While ground water recharge of untreated surface waters occurs naturally in many rivers, streams and lakes, and therefore the contaminants in such waters are of potential significance in influencing recovered water quality, the enhanced recharge of surface waters and their associated contaminants can greatly increase the potential for ground water quality problems due to the increased hydraulic and contaminant loading. The characterization of ground water quality is often not adequately done to properly evaluate potential ground water and aquifer quality problems associated with a ground water recharge project. It is well known that often the chemical characteristics of a ground water are dependent on a wide variety of factors associated with how the ground water is sampled. As discussed by Lee and Jones (1983a) it is important to properly assess how the variable parameters in sampling such as bore hole volume purged and rate of purging before sampling influences the composition of the samples. Chemical parameters of particular importance in reliably assessing ground water quality samples is the redox conditions within the aquifer and the presence of suspended solids in the samples. Because of the chemistry of ferrous and ferric iron small changes in the redox (oxidation reduction) characteristics of the sample as a result of the introduction of oxygen into the sample during sampling can drastically change the chemical characteristics of the samples. As they discuss, it is important to maintain the oxygen concentrations in a sample collected from an aquifer the same as that of the aquifer. Failure to do so could readily change the distribution between dissolved and particulate forms of many trace contaminants of water quality concern.

The presence of suspended solids in a water sample from an aquifer is a clear indication that the sampling well has been improperly constructed and developed and/or the sampling procedure used, especially the purging, has been improperly done. Aquifers typically do not contain large amounts of suspended material. Aquifer samples that contain suspended material are unreliable to properly characterize chemical characteristics of the ground waters within the aquifer and the point and time of sampling.

It is important to have a good understanding of the hydrogeology of the aquifer into which the waters are proposed to be recharged. The sampling program for these ground waters 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.

One of the frequently asked questions about establishing the background chemical characteristics of a surface or ground water is, what is the length of time needed in pre-operational monitoring? Similar questions are frequently asked about what is the appropriate frequency of sampling of a recharge source of water. Depending on the situation, at least one year and often several years of data may be needed to reliably characterize the aquatic system of interest. While most water quality monitoring programs are what Lee and Jones (1983b) term to be "passive," where the data is collected at an arbitrary frequency for an arbitrary period of time, then an attempt is made to analyze the data, a more appropriate approach is an "active" monitoring program where data analysis occurs throughout the monitoring period in order to evaluate the reliability of the data being collected and to provide guidance in modification of a sampling and analytical program to develop a more technically valid, cost-effective assessment of the characteristics of the system(s) being studied for the funds available.

As discussed by Lee and Jones-Lee (1992a), the best way to determine the length of time necessary in pre-operational monitoring as well as the frequency of monitoring a particular system is to examine the ability to predict the chemical characteristics of the system prior to collecting the next set of samples. Once it becomes clear that the characteristics of a particular recharge water source and aquifer are predictable with a high degree of certainty based on past monitoring results, it should then be possible to reduce the frequency and duration of pre-operational monitoring. If, however, it is not possible to make these predictions reliably because of the high variability in the systems, proceeding with the operation of the proposed recharge project could be met with significant problems in detecting incipient water quality problems before they adversely impact large parts of the aquifer.

Operational Monitoring

With the initiation of the recharge activities a significant increase in the frequency of sampling, especially near the point of recharge, should occur. Actually the operational sampling program should be initiated several months before actual recharge starts in order to evaluate the ability to conduct the monitoring program with the facilities and personnel available. If the pre-operational monitoring program has been **passive,** then it should at the time of initiation of recharge become an active program, where the data is examined in detail as soon as it is available for the purpose of determining its reliability and any potential problems that are developing with the recharge project. In addition to chemical and microbiological measurements in the recharge waters as well as within the aquifer, detailed monitoring of the hydraulic characteristics of the injection/infiltration system should be conducted to determine the changes in the hydraulic characteristics of the recharge system and the aquifer in the vicinity of the recharge. In addition to monitoring the chemical contaminants in the recharge waters as well as aquifer, consideration should be given to the contaminant transformation products that might be formed in the recharge water. Of particular concern are the contaminants that might be adverse to water quality in the recovered water, such as the conversion of TCE to vinyl chloride.

An area of particular concern in the recharge waters is whether there is sufficient BOD in these waters to exhaust the dissolved oxygen in the aquifer waters for those aquifer systems that are oxic prior to initiation of recharge. Bore hole dissolved oxygen measurements should be made at frequent intervals at various distances from the point of recharge in order to detect incipient dissolved oxygen depletion that could lead to its exhaustion from the recharge waters. Since in general, except for nitrate-related issues, anoxic conditions in aquifers tend to lead to poor water quality, care should be taken to prevent the recharge waters from becoming anoxic within the aquifer. Failure to do so could readily result in iron, manganese and hydrogen sulfide problems as well as the transformation of PCE and TCE to vinyl chloride. If problems of this type start to develop, it may be necessary to add dissolved oxygen either directly or through the introduction of hydrogen peroxide, in the recharge waters in order to prevent problems of this type from occurring.

Once the operational monitoring program data have become stabilized, i.e. are predictable based on past monitoring results, then the frequency of operational and post-operational monitoring can be decreased. This will likely take several years of operation, however, for fairly constant composition recharge waters and fairly homogeneous aquifer system with respect to its hydrogeologic and chemical characteristics.

Post Operation Monitoring

When a groundwater recharge is terminated it is important that the monitoring of the aquifer be continued until the waters in the aquifer stabilize in composition. This will normally take several years of monthly monitoring. This monitoring should continue for quarterly intervals for several years.

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