# GROUNDWATER POLLUTION MONITORING CASE STUDIES

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## Summary

Investigators who were closely associated with five groundwater monitoring programs were asked to critically examine their studies as a guide to others involved in similar projects. The particular question to be answered was, "What monitoring techniques should have or could have been implemented?" given that time and money were not constraints.

The case studies involved contamination of aquifers from oil field brine disposal, plating waste disposal, landfill leachate, nitrate from multiple sources, and recharge from an oxidation pond.

Among the general recommendations of the investigators, resulting from the process of critical evaluation of their associated projects, were the following: establish interdisciplinary committees to set up the monitoring program; maximize the density of well network; use alternative methods to wells; completely analyze the samples, including heavy metals; thoroughly examine the hydrogeology of the problem site; use tracers; develop predictive computer models of the flow system; monitor in the zone of aeration, where applicable; develop innovative methodologies; and continue monitoring until the problem is thoroughly quantified.

## Introduction

Section 106 of the Federal Water Pollution Control Act stipulates that grants to State and interstate agencies for pollution control programs require the establishment of procedures to monitor the quality of groundwater. Methodology for monitoring in both the saturated zone (phreatic zone) and zone of aeration (unsaturated zone, vadose zone) are presented by Schmidt[1] and by Meyer[2]. However, as pointed out by Le Grand[3], "Seldom will sufficient money and time be available to completely delineate and monitor a contaminated area." Each monitoring program should therefore be carefully planned at the outset to minimize the effects of these two constraints (and others) on the yield of data. Often the experience of investigators who have been associated with similar programs will help in such planning, particulary if these individuals are willing to discuss frankly not only the merits, but also the limitations of their programs.

As an example of this approach, individuals closely associated with the monitoring programs of five representative case studies were asked to critically examine their projects. They were requested not only to summarize the objectives, methodology and results, but also to indicate alternative monitoring techniques or approaches which could have, or should have, been used if time, funds, or other factors, had not been limiting. This paper is based on the critiques of these individuals.

The case studies and related investigators were; (1) Arkansas Brine Disposal, J. S. Fryberger[4], Engineering Enterprises, Inc., Norman, Oklahoma; (2) Plating Waste Pollution in Long Island, New York, by James J. Geraghty and N. M. Perlmutter[5], Geraghty and Miller, Inc., Tampa, Florida; (3) Landfill Leachate Pollution at an East Coast Location, by James J. Geraghty and N. M. Perlmutter[6]; (4) Monitoring Nitrate Pollution of Groundwater from Multiple Sources in the Fresno-Clovis Metropolitan Area, by K. D. Schmidt[7], Fresno, and (5) Arizona Oxidation Pond, by L. G. Wilson[8], University of Arizona, Tucson, Arizona.

## Case Studies

### Arkansas Brine Disposal

Details of this study were presented by Fryberger[9]. The pollution problem involved the contamination of a shallow, alluvial aquifer during disposal of oil-field brine in southwest Arkansas, first, by recharge from an "evaporation" pond, and later by leakage from a faulty disposal well. Vertical distribution of alluvium consists of alluvial clays and sand, overlying alluvial sand. The latter unit is underlaid by sedimentary formations of Eocene and Cretaceous ages. Static water table levels average about eight ft below land surface. The monitoring program related entirely to the saturated zone. Monitoring facilities to supplement existing pumping wells comprised 36 observation wells at 28 locations near the pollution source. At some locations several wells were installed at different depths to obtain vertical salinity profiles. Observation wells consisted of plastic well-screens attached to 2-1/2 inch pipe. Several wells were sampled at successive depth increments during installation. The following techniques were considered and rejected as alternatives to permanent cased wells: surface resistivity surveys, to estimate the lateral spread of the pollution plume; and uncased rotary holes, coupled with electric logs, to estimate the vertical distribution of salinity. Several construction alternatives were considered: drive points; continuous flight auger; mud/water rotary drilling; cable tool drilling; and air-rotary drilling. The method which was eventually selected entailed: drilling with a continuous flight auger through the overburden, then driving well points to the desired depth in the sand aquifer. Brine and well water were analyzed chemically to estimate mixing of brine and groundwater. Analysis included evaluation of both major and minor constituents.

### Plating Waste Contamination, Long Island, N. Y.

Background information together with monitoring procedures and results of this problem were reviewed in detail by Perlmutter, et. al.[10]. Briefly, a pollution plume, mainly comprising chromium, was monitored in the vicinity of a former aircraft plant at South Farmingdale. The source of the plume was a basin used to dispose of plating wastes. A principal concern to health officials was that an auxiliary groundwater supply at Massapequa would be contaminated by the plume. The problem was first detected in samples from a water supply well near the plant. Later a network of sampling wells was installed.

The groundwater reservoir in the problem area comprises 1300 ft of saturated consolidated deposits on crystalline bedrock. The distribution of the three principal aquifers is: upper glacial aquifer, Magothy aquifer, and Lloyd sand. Water table averages about 15 ft.

The upper glacial aquifer formation has been primarily affected by contamination. In 1962, the dimensions of the plume, detected by sampling were 4300 ft long, 1000 ft wide, and from land surface to 50-270 ft below land surface.

The monitoring program involved sampling entirely within the saturated zone. Test wells, installed in 1949, consisted of 1-1/4 inch driven well points. Water samples were obtained in five ft increments during installation of the points. Drilling was continued to about 60 ft, i.e., until field sampling produced an absence of chromium contamination. In 1962, 100 additional wells were constructed together with several test holes for defining lithology and hydraulic characteristics of the geologic formations. Massapequa Creek and underlying formations were sampled to evaluate heavy metal concentrations. A water budget was conducted for the region. Patterns of flow of groundwater into the stream were characterized.

## Landfill Leachate Contamination, Milford, Connecticut

The third representative case study of groundwater quality monitoring related to contamination by landfill leachates. Specifically, the landfill site investigated was in Milford, Connecticut. The purpose of the study was to determine whether contamination of groundwater and surface water by leachate would preclude the development of a park on the site. A monitoring program was established to evaluate chemical water quality and gas production and the patterns of surface water and groundwater movement.

The landfill was constructed on a tidal marsh bordering on Long Island Sound. Underlying the surface landfill and marsh deposits are unconsolidated deposits, 40 to 60 ft thick, consisting of glacial till and outwash sediments. Glacial deposits are underlain by consolidated bedrock of schist and gneiss. The water table varies from an elevation at sea level to about eight ft above sea level. Again, monitoring was restricted entirely to the saturated zone.

Based on a water-budget evaluation, it was estimated that the daily flow of precipitation into the fill averages 80,000 gallons and that an equivalent volume of leachate moves out of the fill. Several hundred million gallons of groundwater have evidenced contamination by leachate, which apparently is gradually displacing underlying good quality water.

The monitoring program for the site involved an initial review of background information, eg., topography, vegetation, well data, rainfall, tides, etc. Subsequently, seismic and electrical resistivity techniques were employed, followed by installation of 36 test wells. Well depths ranged from 12 ft to 96 ft, and at several locations paired wells were used to determine vertical head gradients.

Water levels and temperature profiles were measured in wells. Well water samples were collected for chemical analysis, including a few determinations in the field. Surface waters were also analyzed. Gas samples were collected from shallow gas sampling tubes. Studies were conducted by biologists to relate vegetative stress to the groundwater system.

## Nitrate Pollution, Fresno-Clovis Metropolitan Area

The fourth monitoring project entailed estimating the extent, sources and time trends in nitrate pollution of groundwater underlying a 145 square mile area of the San Joaquin Valley, California. The area is predominantly urban, although the surrounding area is agricultural. The principal sources of nitrate are leakage from septic tank fields, land disposal of sewage effluent, sewer line leakage; deep percolation of fertilizers during irrigation; and recharge of meat packing and winery wastes. Aquifers are located within unconsolidated alluvium, locally thousands of feet thick. Water levels average 70 ft.

The study was conducted to fulfill the requirements of a Ph.D. dissertation[11,12].

Initial steps in the program involved collecting background data on soils, groundwater, well construction and drillers logs, pollution sources, and chemical analysis of sources and groundwater, particularly relating to the areal distribution of nitrates.

Because of limited funding, monitoring was restricted to the sampling of available wells, coupled with the use of field kits for chemical analyses. To reflect regional conditions, only high capacity (500 to 2500 gpm) municipal and irrigation wells were sampled. Well construction was considered an important parameter because of the vertical distribution of nitrate with depth. To obtain the most representative quality of regional groundwater, principal sampling occurred during the warmest time of the year, the period of maximum pumping in the majority of the high capacity wells. According to Schmidt[7], a key factor in his study was to subdivide the area on the basis of predominant nitrogen sources together with the hydrogeology and nitrate areal distribution in groundwater. Sampling of wells occurred on a weekly or monthly basis near point source, compared to seasonal sampling near diffuse sources. In addition to nitrate, the following were determined: chloride, potassium, ammonium and calcium.

Schmidt[11] did not monitor in the zone of aeration, but speculated that movement of water in this zone is rapid because of well hydrograph response. He further assumed that there is no gross uptake of nitrate during flow in the zone of aeration.

## Arizona Oxidation Pond

The fifth case study was concerned with monitoring seepage during the filling of a new 10-acre oxidation pond near Tucson, Arizona. In contrast to the above case studies, an attempt was made in this study to monitor in the zone of aeration as well as in the saturated region. Particular emphasis was placed on monitoring the movement of nitrate because groundwater in the area has manifested an increase in this constituent. Details of the study were presented by Wilson, et. al.[13], and by Small[14].

The site abuts the Santa Cruz River, an ephemeral stream, and is immediately downstream of two principal tributaries of the Santa Cruz River. Unconsolidated alluvium underlies the area to great depth. Water levels average about 70 ft in the vicinity of the pond.

Monitoring facilities were installed at the site during a study on land disposal of oxidation pond effluent[15]. The new pond encompassed several of these facilities, which thereby functioned for two projects. The facilities consisted of two 100 ft deep access wells, two PVC wells, suction cups and an irrigation well. The access wells were used with a neutron moisture logger for monitoring water content changes in the zone of aeration. Each access well contained a screened well point for sampling in the vicinity of the water table. Depths of the PVC wells, 40 ft and 60 ft, were based on neutron probe data showing that perched water tables (mounds) develop in the zone of aeration at these depths during percolation of applied surface water. Two batteries of suction cup samplers (suction lysimeters) were installed to permit sampling within the soil zone down to five ft. A nearby 300 ft deep irrigation well was used to sample an extensive region of the saturated zone.

During filling of the pond, water was metered into the pond and the seepage rate was estimated. Analysis of pond water and groundwater samples included the entire nitrogen sequence, together with major constituents and coliform organisms. Project results illustrated that indigenous nitrogen, or soil nitrogen concentrated during past irrigation and land disposal operations, contributed a high initial peak of nitrate which exceeded the nitrate levels which could have been derived from pond effluent. Furthermore, denitrification and/or ammonium sorption effected a control on nitrate levels.

## Retrospective Alternatives and Recommendations for Similar Monitoring Studies

Each of the investigators of the above monitoring case studies were, to a large extent, successful in characterizing their groundwater contamination problem. Nevertheless, each individual believed that if money and time had not been constraints, additional or alternative procedures could have, or should have been implemented. Many of these procedures have relevance only to the specific case study. Others were of a general nature, being listed by several or all of the investigators.

The general procedures may be regarded as recommendations for other investigators to bear in mind during establishment of monitoring programs. The more noteworthy of these recommended procedures are summarized below:

1. If possible, establish at the outset an interdisciplinary committee to ensure collection of interrelated quality parameters. As an example, for the Arizona pond study, Wilson[8] indicated that such a committee could have included a soil chemist, soil physicist, sanitary engineer, aquatic biologist, and hydrogeologist.

2. Obtain a thorough understanding of the hydrogeology of the project area from examination of available reports, drillers logs, etc. Particular emphasis should be placed on defining groundwater flow direction and vertical and lateral gradients. The latter information is useful in determining whether the groundwater system in the vicinity of the pollution source is recharging or discharging. A hydro-chemical balance should be attempted. Along the same line, establish base-line water quality data and water levels in the region of the pollution source. Also obtain information on well construction.

3. Ensure that the network of sampling wells is as dense as possible in the vicinity of the pollution source. Where feasible, use wells for multiple purposes: eg., sampling and neutron logging. Be certain that each pollution source is defined.

4. In addition to wells, use alternative techniques for defining the confines of the pollution plume. For example, several of the individuals reporting on the above case studies, suggested using surface resistivity techniques. Stollar and Roux[16] outline methodology and limitations of earth resistivity techniques for defining groundwater contamination.

5. Establish a thorough regular sampling program in wells and surface water supplies. If available, use large capacity wells to obtain more representative samples.

6. Analysis of samples should be as complete as feasible, including not only determination of major constituents, but also heavy metals, and organic toxins. If germane to the project, microbial concentrations (eg. total coliform, fecal coliform) should also be evaluated. When possible, samples should be analyzed in the field (eg. for pH, $CO_2$, $HCO_3$, etc.). Check that cations and anions balance in complete analyses and prepare water analysis diagrams.

7. Trace the flow of the pollution plume using specific tracers (eg. nitrogen isotopes in nitrate problem areas) or indigenous tracers (eg. chloride).

8. Consider using available, or specially constructed, digital models of the flow system. Available models include the finite difference model of Prickett and Lonnquist[17]; or the finite element model of Pinder and Frind[18].

9. When possible, monitor in the zone of aeration as well as in the saturated (phreatic) zone, particularly when the former is of considerable thickness and perching layers may develop. Core or drill samples should be taken in this zone and characterized for particle size distribution, cation exchange capacity, etc. An example of an investigation which involved monitoring in the zone of aeration is that of Apgar and Langmuir[19], in which suction cups were extensively employed.

10. Develop, when necessary, innovative or specialized monitoring techniques or well construction methods (see for example, Yare[20]).

11. Monitoring should be continued until the problem is quantified. Several of the individuals reporting the above case studies regretted that their projects had to be shut down before long-term trends could be defined.

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Acknowledgments

The author gratefully acknowledges the assistance of Mrs. Sarah Schuster in typing the final manuscript, and Mr. Vincent Uhl for reviewing and contributing to the original manuscript.