

"GEOTECHNICAL METHODS COMBINED WITH CLUSTER WELLS TO INVESTIGATE AND MONITOR ORGANIC AND INORGANIC GROUND WATER CONTAMINATION"

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ABSTRACT

A hydrogeologic investigation of a fifteen year old manufacturing research facility located in the Northeastern United States was conducted to evaluate the significance of elevated organohalide contaminant concentration levels detected in ground water developed by two of the facility's seven process supply wells. These supply wells are drilled into a productive limestone aquifer overlain by a fairly heterogeneous sequence of unconsolidated glacial and glacio-fluvial derived deposits comprised chiefly of clays, silty clay, silts, silty sands and gravel, and till.

Aerial photography to trace observable bedrock fracture zones, structural geologic mapping of outcrop areas, electrical earth resistivity, downhole television surveys of supply wells, borehole data developed during various foundation investigations, correlation of well logs collected from test drilling, analyses of several hundred ground water samples pumped and/or bailed from over 70 multiple depth observation wells on a monthly basis, and water level measurements collected from test borings, observation wells, and deeper supply wells were all utilized to define the nature, extent, distribution, and movement of organic and inorganic ground water contamination. These data, in conjunction with a review of historical records and plant-wide engineering studies that were conducted to evaluate the structural integrity of chemical storage tanks and pipelines, served to identify sources of contamination, prioritize selected source areas, and provide the framework to recommend and implement remedial measures.

A preliminary ground water protection plan is being formulated based on the results of pilot-scale in-situ field experiments. Basic data collected from an on-going long term ground water monitoring program installed to provide a site-wide and facility boundary warning system is reviewed.

INTRODUCTION

The following discussion provides an overview of the various work stages used in a hydrogeologic investigation at a relatively large manufacturing-research facility, the methods utilized and why, procedures, alternative technologies, and results. Early chemical analyses of ground water withdrawn from select bedrock production wells and subsequent

monthly ground water monitoring from numerous cluster wells indicated the presence of the organic compounds 1,1,2,2 Tetrachloroethylene, Trichloroethylene, 1,1,1 Trichloroethane, 1,1 Dichloroethylene, Methylene Chloride, Freon 11, Toluene, and Xylene, in addition to inorganic chemicals such as heavy metals, pH, and chloride.

The purpose and objectives of the initial investigation was to determine, if possible, the probable source and cause of the detected contaminants dissolved in ground water from two closely spaced production wells. This primary objective targeted the central portion of plant property and would normally lead to unbalanced investigative emphasis relative to the remainder of plant property. However, review of production well construction details, television surveys, pumping test data, and plant files revealed similar construction history in all wells and that the potential for any existing shallow ground water in the upper unconsolidated glacial deposits to migrate downward into the underlying bedrock aquifer and eventually into production wells was possible.

The proper management of this investigation necessitated a systematic approach and included a series of sequential phases, the designed scope of each successive phase contingent upon the findings and conclusions developed from the preceding one. In this fashion, several geophysical, geotechnical, and hydrogeological exploratory methods were integrated, to facilitate identification of the problem, definition of its nature and extent, placement in perspective relative to background conditions such as water supply considerations, and cost-effective design and implementation of an in-situ protection plan. The sequentially phased approach to these types of investigations provides a cost-effective means to identify, define, and continuously monitor ground water conditions with sampling parameters and frequency specified in accordance with ground water quality and flow rate.

BACKGROUND

Site reconnaissance; on-site personnel interviews; review of available plant file data including previous engineering report foundation borehole data; available hydrogeologic and climatological literature from appropriate County, State, and Federal agencies; review of regulatory compliance requirements; local drinking water limitation standards; well inventories; historical records; and any ongoing or projected commercial development, all served to provide necessary and important information prior to the design and installation of an observation well network for logging, pump testing, measurement, and site-specific sampling considerations.

The importance of those types of surveys cannot be overemphasized since valuable information can often be gained by intelligent discussion with appropriate plant personnel particularly in regard to past plant practice thus allowing optimum observation well placement. Other practical applications that can be developed from the surveys are the preparation of surficial hydrogeologic maps of the site and the surrounding environs. Discussions may include past and present waste disposal practices, character and types of contaminants, potential contaminant sources, sketches and old plant drawings, updated blueprints, chemical storage facilities and locations, chemical transfer facilities, buried

pipeline locations, equipment specifications, spill frequency, handling and testing practices and transport schedules, etc. generally providing very useful data to enable refinement of proposed monitoring wells prior to their actual installation. Electrical resistivity surveys are also useful prior to, or in conjunction with, test drilling to confirm results. However, distortion arises from field interference such as pipelines or overhead electrical transmission lines. Frozen ground normally inhibits winter usage of such equipment, however, test holes hand dug (or post-hole digger) below the freeze line can circumvent this problem. High altitude satellite imagery can be scanned for regional geologic interpretation providing the background for structural geologic features often identified in more detail from low-altitude (1" = 200' scale) aerial photography obtained, enlarged, and studied to provide fracture trace analysis where applicable. Actual photo interpretation revealed structural lineaments and fracture systems throughout the region and included the projected delineation of a fault trace or series of fault traces transecting the middle of the site that was otherwise hidden from view without the use of wells. Confirmation of the photo interpretation was conducted in the field by structural mapping of rock outcrops.

In the first phase of this project, five test holes were hand-augered to provide soil samples for leachate testing, eleven 4-inch diameter observation wells were installed and screened in the unconsolidated glacial deposits, and three deeper 4-inch diameter observation wells were installed in the upper fifteen feet of the underlying bedrock. The observation wells were installed using auger and mud-rotary drilling techniques and served to evaluate subsurface ground water conditions including direction of ground water flow, flow rate, the general configuration of the water table, and selected aquifer characteristics at specific locations and depths. Continuous bedrock cores (NX-size core) were analyzed for rock quality designation, and soil penetration coefficients were developed from sample corer blow counts while coring through the unconsolidated glacial materials. Several replacement boreholes were necessary when drilling encountered large boulders or unanticipated refusal. Abandoned holes were sealed completely with grout. A bedrock contour map and generalized hydrogeologic cross-sections were constructed from field data and individual well logs.

Following installation of the observation wells, a surface water and ground water sampling program was planned and implemented. Sampling site, equipment, procedures, and frequency were designed to be compatible with site-specific conditions and the objectives of the monitoring program. A parameter-specific target approach was eventually developed to identify and quantify key chemical constituents dissolved in the ground water following initial fairly broad sampling analyses using generalized scanning techniques. The monitoring program was controlled so that the numerous sources where error could be introduced, were minimized to the extent possible to insure consistency, reliability, and analytical reproducibility. Laboratory detection limits were at approximately 8-10 ug/l. Replicate samples and laboratories were utilized as a basis for quality assurance comparisons. Soil samples were analyzed using soxhlet (infra-red) extraction and water samples were analyzed using gas chromatography/mass spectrometry. The depth to water was measured before and after

sample collection in each observation well, to 0.01 foot accuracy using an electric sounder and chalked steel engraved tape calculated relative to mean sea level. A Stevens Type F Automatic water level recorder was installed on one of the observation wells.

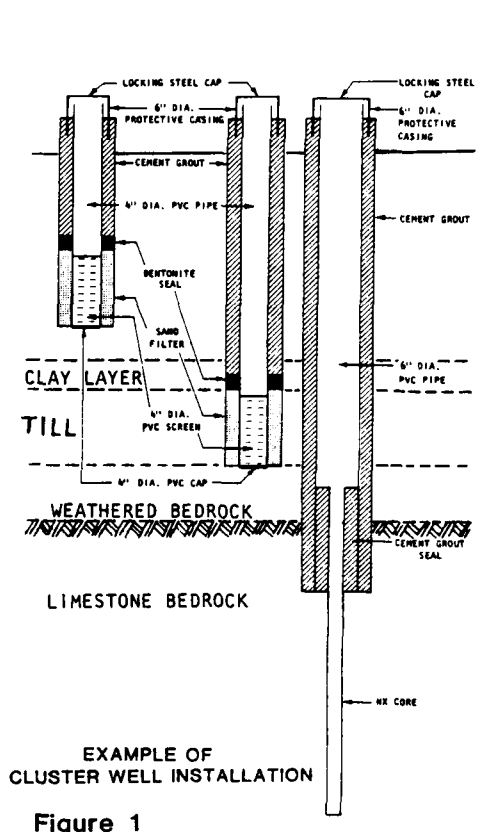
RESULTS

Site-specific hydrogeologic conditions are extremely complex due to the presence of a highly fractured and faulted steeply-dipping limestone dolomite bedrock aquifer. This aquifer is in turn, overlain by a highly variable heterogeneous sequence of glacially-derived lacustrine and fluvial deposits of variable thickness.

The bedrock aquifer has been developed by five closely-spaced production wells drilled to intermediate depths, 400-500 feet below land surface. The aquifer is partially dewatered due to excessive production well pumpage and water levels have dropped at least 50 foot and as much as 100 foot in places. Recharge to the aquifer is controlled by downward percolation of rainfall through the unconsolidated deposits and dependent upon overburden thickness and sediment type. Recharge is limited by several factors, for example; areas underlain by relatively impermeable glacial till, below average annual rainfall, surface drainage diversion, physical plant structures, and area-wide parking lots. Those areas where glacial fluvial/outwash deposits occur or where the steeply-dipping bedrock aquifer is exposed as outcrops in and around facility property are areas for direct recharge. Bedrock is susceptible to ground water contamination where it is exposed at land surface, at relatively shallow depths below land surface, and in those areas that show good hydraulic connection between the rock and overlying permeable overburden where a vertically downward component of ground water flow is measured repeatedly. Some of the weathered fractured zones in the upper bedrock appear to serve as conduits for rapid flow of ground water, particularly under areas of thicker glacial deposits with greater storage capacity and recharge potential.

The unconsolidated deposits consist of a thin layer of fill overlying glacial till, glacio-fluvial deposits, lacustrine deposits, and grey stiff relatively impermeable clay. These deposits can range up to 80-foot thick. Discontinuous clay lenses ranging up to 25-foot thick prevent or retard the flow of ground water in the upper portions of the saturated zone. Horizontal permeability is many times greater than vertical permeability which is complicated by discontinuous clay lenses of variable thickness. Fairly good hydraulic connection exists where the poorly-sorted till-like material is mixed with glacio-fluvial deposits.

Elevated concentrations of dissolved inorganic and organic compounds in ground water from multiple depth observation wells screened in shallow and intermediate depth glacial deposits together with deeper observation wells drilled to the subsurface sediment/rock interface or deeper within the underlying bedrock aquifer indicate degradation distributed throughout much of the saturated zone in the upper and lower glacial deposits and downward into at least the upper portions of the bedrock aquifer in one particular area. A schematic diagram and photograph of a typical cluster well as can be commonly used in these types of studies is shown in Figure 1. Prior to this point, faulty production well casing construction,



contaminant leakage down the annular space, or surface pollutants were suspected as potential sources of degradation in ground water pumped from the deep wells. The plant maintains above and below ground storage facilities for several hazardous chemicals some of which were either identical to, or parent derivatives of, compounds detected in ground water. The structural integrity of storage tanks and pressure tested pipelines were inventoried and those tanks having greatest leakage potential identified. Other potential sources for ground water degradation were also suspected including abandoned disposal areas and accidental or incidental spills and discharges. High Total Organic Carbon (TOC) levels and high Tetrahydrofuran (THF) levels were detected and identified during initial stages of the investigation and subsequently subsided with time. TOC at spurious concentration levels was due to bacterial growth around well screens not properly developed following use of an organic polymer drilling fluid during well construction, and THF levels were ascribed to dissolution of partially soluble compounds inherent to a particular brand of polyvinyl chloride glue used to connect plastic well casing.

The preliminary surveys identified the problem, however, further definition, was necessary in order to provide the necessary framework to properly assess alternative technologies and design an optimum preliminary ground water pollution abatement plan. As

a result, a second phase of work was initiated. Each work stage involved an expansion of the ground water monitoring system through selective placement of additional test/monitoring wells. Sixty multi-depth cluster wells were installed during the second phase of the program and used to obtain water quality data to determine severity of degradation; define flow paths of particular chemical constituents relative to fluid density, determine whether or not degradation has come from upgradient and/or offsite sources; projected pollutant migration patterns; and to determine the vertical and lateral extent of a heavy insoluble organic phase that had apparently accumulated at the bottom of the saturated glacial deposits between the unconsolidated silty clay materials and the underlying weathered bedrock interface. The highest concentration levels of dissolved organics detected thus far is 150 mg/l. A general overview of abridged results from the water quality analytical program is presented in Table 1.

AVERAGE CONCENTRATIONS OF SELECTED ORGANIC COMPOUNDS
AND INORGANIC CHEMICAL CONSTITUENTS IN
GROUND WATER IN RELATION TO DEPTH OF CLUSTER WELLS

	Glacial Shallow Wells		Glacial Deep Wells		Bedrock Wells	
	Mean	Median	Mean	Median	Mean	Median
1,1,1 Trichloroethane (μ g/l)	40	ND	7	1	50	ND
Trichloroethylene (μ g/l)	742	83	485	220	17,300	150
1,1,1,2,2 Tetrachloroethylene (μ g/l)	22,770	690	32,600	315	22,000	600
Freon 11 (μ g/l)	80	ND	5	4	850	23
Toluene (μ g/l)	10	ND	10	ND	90	3
Xylene (μ g/l)	65	ND	7	ND	14	ND
pH	7.5	7.6	7.6	7.5	8.7	8.0
Total Hardness as CaCO ₃ (mg/l)	193	191	240	187	284	281
Specific Conductance (μ mhos/cm)	1062	1100	1594	1050	2016	1150
Chloride (mg/l)	115	87	235	112	307	149

ND - Not Detectable

SUMMARY

In summary traditional cluster wells, continue to be a useful tool for defining hydrogeologic conditions, and further, a reliable source of ground water quality data for long-term monitoring purposes. Small-diameter, separately cased, observation wells drilled plumb to variable depths in close proximity to each other, although seemingly more costly to install than the multiple sampling tubes and transducer arrangements installed in single bore holes, provides meaningful, reliable, and reproducible results with minimal maintenance and error when used in a conscientiously and consistently applied long-term ground water monitoring program. In this manner, each well effectively screens a different zone of the saturated unconsolidated deposits above bedrock, providing a layered stratigraphic view into the subsurface. For investigations dealing with heterogeneous fluid densities and complex geology, the cluster concept minimizes some of the difficulties that can arise in the interpretation of contaminated flow systems in glacial terrain.