CONCENTRATIONS OF TCE + PCE FROM MUNICIPAL WELLS G AND H DELIVERED TO RESIDENCES IN WOBURN, MASSACHUSETTS FROM 1964 TO 1979

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ABSTRACT

In the 1986 trial described in the book and movie *"A Civil Action,"* the plaintiffs' allege that groundwater contamination from two properties was captured by municipal wells G and H in Woburn, Massachusetts and ingestion of the toxic chemicals caused severe health effects including childhood leukemia. To provide insight into the possible amounts of trichloroethene (TCE) and perchlorothene (PCE) exposure at residences across the city and, more specifically, at each plaintiff's residence between 1964 and 1979, when wells G and H periodically operated, we linked the results of a contaminant transport model to an existing water distribution model of the city's pipeline network (Murphy, 1991). The water distribution model, which divided the city into water districts and accounted for mixing with uncontaminated water supplied by six wells in other parts of the city, calculated the monthly fraction of water from wells G and H that each water district received, which varied spatially and temporally across the city due to management of pumping rates and schedules in the eight municipal wells. To estimate TCE + PCE concentrations likely delivered to residences, simulated concentrations of TCE and PCE in wells G and H from the contaminant transport model were multiplied by the fraction of water contributed from wells G and H to each water district. TCE and PCE exposure histories for the 54 water districts indicate that more than 4000 residences likely received concentrations of TCE + PCE exceeding the U.S. EPA health-based standard of 5 parts per billion (ppb). Many residences likely received concentrations of TCE + PCE greater than 5 ppb for more than 100 months. The results indicate that the worst exposures likely were in the range of several hundred ppb TCE + PCE for nearly 24 months.

RÉSUMÉ

Au cours du procès tenu en 1986 décrit dans le livre et le film *"A Civil Action"*, la prétention des plaignants est que la contamination de l'eau souterraine en provenance de deux propriétés a été captée par les puits municipaux G et H à Woburn, Massachusetts, et que l'ingestion de produits chimiques toxiques a causé des problèmes de santé graves, incluant la leucémie infantile. Pour évaluer l'exposition au trichloroéthène (TCE) et au tétrachloroéthène (PCE) aux différentes résidences à travers la ville et, plus spécifiquement, à chacune des résidences des plaignants entre 1964 et 1979, alors que les puits G et H étaient périodiquement en opération, nous avons relié les résultats d'un modèle de transport de contaminants à un modèle existant de distribution en eau du système d'aqueduc de la ville (Murphy, 1991). Le modèle de distribution d'eau divise la ville en districts d'approvisionnement en eau et tient compte du mélange avec de l'eau non contaminée fournie par six puits localisés dans d'autres parties de la ville. Ce modèle a calculé la fraction mensuelle d'eau en provenance des puits G et H reçue par chaque district d'approvisionnement, fraction qui variait dans l'espace et le temps à travers la ville à cause de la gestion des taux de pompage et des périodes d'opération des huit puits municipaux. Pour estimer les concentrations de TCE + PCE qui on pu être fournies aux résidences, les concentrations simulées de TCE et de PCE aux puits G et H obtenues du modèle de transport ont été multipliées par la fraction d'eau provenant des puits G et H pour chaque district. L'historique de l'exposition au TCE et au PCE pour les 54 districts d'approvisionnement indique que plus de 4000 résidences sont susceptibles d'avoir reçu des concentrations en TCE + PCE excédant la concentration limite reliée à la santé de 5 parties par million (ppb) du U.S. EPA. Plusieurs résidences ont probablement reçu des concentrations en TCE + PCE excédant 5 ppb pour plus de 100 mois. Les résultats indiquent que les pires expositions étaient de l'ordre de plusieurs centaines de ppb en TCE + PCE pour plus de 24 mois.

1. INTRODUCTION

In the 1986 federal trial portrayed in *'A Civil Action'* (Harr, 1995) the plaintiffs' alleged that groundwater contamination emanating from two nearby properties was captured by municipal wells G and H in Woburn, Massachusetts, distributed in city water mains, and ingestion of the toxic chemicals caused severe health effects including childhood leukemia. After four months of testimony, the jury found W. R. Grace & Co. liable and Beatrice Foods, Inc. not liable of contaminating of the two municipal wells. Data obtained by U.S. EPA after the trial indicate that substantial concentrations of trichloroethylene (TCE) and perchloroethylene (PCE) occur in groundwater underlying five properties, including Beatrice and W.R. Grace, within the capture zones of the two municipal wells (Metheny, 1998; Bair and Metheny, 2002). The five contaminated properties, the Aberjona River, and the two municipal wells are all part of the 130-hectare Wells G & H Superfund Site (Figure 1).

Wells G and H operated periodically from October 1964 to mid-May 1979, when they were closed by state order because samples from wells G and H contained 267 ppb TCE and 21 ppb PCE, and 118 ppb TCE and 13 ppb PCE, respectively (Massachusetts Dept. Public Health, 1997). At that time, public health standards for TCE and PCE were 5 ppb. When the wells were in use, local residents complained about the foul taste and smell of their municipal water.

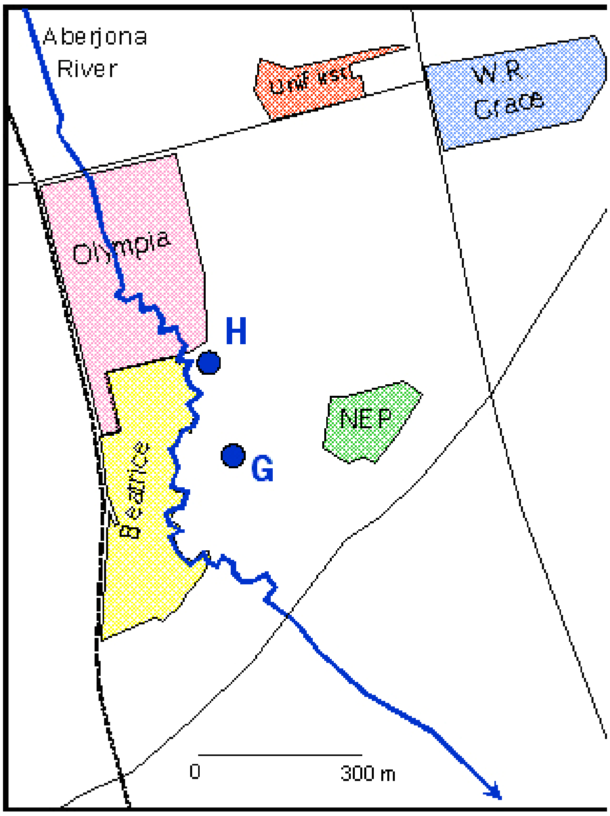

Figure 1. Map of the Wells G & H Superfund Site.

Over the years, many health studies have been performed in Woburn trying to determine relations between documented health problems (leukemia, perinatal deaths, eye/ear and oral cleft anomalies, kidney/urinary tract and lung/respiratory disorders) and environmental factors (Cutler and others, 1986; Lagakos and others, 1986). Costas and others (2002) state that the incidence of 24 cases of childhood leukemia in Woburn between 1969 and 1997 is twice what would be expected (11 cases, 0.4 cases per year) based on regional rates of incidence. A statistical analysis by Costas and others (2002) indicates a positive association between gestational exposure to wells G and H water and the occurrence of childhood leukemia in Woburn. Their work is founded on a model of Woburn's water distribution system (Murphy, 1991), which was used to compute month-by-month changes in the contribution of water from wells G and H delivered to residences throughout the city. This enabled characterization of temporal and spatial variations in the exposure of residents to wells G and H water. The positive statistical association did not differentiate among the various contaminants in the water from wells G and H, nor did it account for temporal variations in contaminant concentrations in wells G and H.

2. COMPUTER MODELING

Deterministic models commonly are used to simulate previous conditions when limited data are available to assess environmental exposures. We constructed a contaminant transport model of TCE and PCE movement from the five known contaminated properties within the Wells G & H Superfund Site to simulate the concentrations of TCE and PCE that likely were pumped by wells G and H from October 1964 through May 1979 (Metheny, 1998, 2004). We linked the simulated monthly concentrations of TCE and PCE produced by wells G and H with the results of the Woburn water distribution model (Murphy, 1991). The linked models enable us to estimate residential exposure histories in terms of concentrations of TCE and PCE delivered to residences in Woburn during the operational periods of wells G and H.

The contaminant transport model was constructed with MT3DMS (Zheng and Wang, 1999). A groundwater flow model constructed with MODFLOW (McDonald and Harbaugh, 1988) computed the transient, three-dimensional velocity fields required by MT3D. The flow model and the contaminant transport model use 55 stress periods to account for changes in pumping rates and schedules of wells G and H, and to account for temporal and spatial variations in recharge rates and land usage (Metheny and others, 2001) during the 26-year period of simulation from January 1960 through December 1985. The flow model and the contaminant transport model use a finite-difference formulation and a common grid design that contains 30,111 active cells in 6 layers, 93 rows, and 107 columns.

The groundwater flow model includes heterogeneous values of permeability, porosity, and storativity in the glacial outwash and ice-contact deposits filling the buried valley aquifer under the Aberjona River and overlying the adjacent bedrock uplands. Ten geologic cross sections, isopach maps, and structure contour maps were constructed using lithologic data from more than 300 soil borings and well logs drilled across the site (Metheny, 1998). Hydraulic conductivity ranges for specific sediment types were developed from numerous slug tests, pumping tests, and grain size analyses performed by the U.S. Geological Survey and U.S. EPA and its subcontractors working at the five contaminated properties within the Superfund Site (Metheny, 1998). The flow model also accounts for leakage into the buried valley aquifer from fractured crystalline bedrock, effects of the partially penetrating 10-foot long screens in wells G and H, which extend 90-feet below land surface, and effects of the wetland and Aberjona River.

The flow model was used to simulate groundwater levels and streamflow losses measured during a 30-day pumping test performed by the U.S. Geological Survey (USGS) in December 1985 to January 1986 (Myette and others, 1987). During the test, wells G and H were pumped at historic average rates of 700 gallons per minute (gpm) and 400 gpm. Values of hydraulic conductivity, bedrock leakage, recharge, and streambed hydraulic conductivity were adjusted within measured or accepted ranges to calibrate the flow model. The final agreement between simulated hydraulic heads and values measured in 93 observation wells produced a mean absolute error of 1.5 feet and a root mean squared error of 2.6 feet. The USGS also gaged the flow of the Aberjona River at stations upstream and downstream of wells G and H. At the end of the 30-day pumping period, there was 565 gpm less streamflow at the downstream station than at the upstream station, indicating the Aberjona River was losing water to the pumping wells by induced infiltration (Myette and others, 1987). The calibrated flow model simulated a streamflow loss of 550 gpm at the end of the 30-day test.

A steady-state flow model was created to simulate measured groundwater flow velocities estimated from tritium/helium ages of water samples collected in monitoring wells (Metheny and others, 2001). Measured groundwater ages varied from less than one year to more than 5.8 years and ages systematically increased with depth and with distance along the direction of flow. The agreement between simulated travel times and groundwater ages was excellent at one well, good at four wells, and poor at two wells. Overall, the correspondence between measured ground-water ages and simulated travel times indicated that the calibrated flow model was based on reasonable estimates of bulk transmissivity and recharge.

A 26-year transient flow model then was created to simulate historic changes in the flow system occurring between January 1960 and January 1986. Historic recharge estimates were based on baseflow separations (Rutledge, 1998) of streamflow records collected by the USGS since 1940 at Winchester, Massachusetts, two miles downstream of wells G and H on the Aberjona River and based on historic aerial photographs of the area that documented changes in land use (Metheny and others, 2001). The highly variable, historic pumping rates and schedules at wells G and H also were incorporated in the model. Between 1964 and 1979, well G was used by itself 10 times, well H by itself 2 times, wells G and H together 6 times, and neither well was used during 10 separate time periods. Due to the dynamic pumping stresses applied to the flow system, drawdowns, flow directions, and rates of induced streambed infiltration varied considerably over time. Figure 2 shows the simulated potentiometric surface in model layer 1 in May 1979, the month wells G and were closed.

The simulated period was extended past May 1979, when wells G and H were closed, to January 1986 in order to use the water-level and streamflow measurements made in December 1985 and January 1986 for history matching. At the end of the 26-year simulation, in January 1986, the mean absolute difference between measured and simulated water levels was 1.7 feet and the root mean squared error was 2.6 feet, while the difference between measured and simulated streamflow loss between the upstream and downstream gaging stations after the simulated 30-day pumping test was 107 gpm. Satisfied with the reasonable degree of history matching following 26 years of simulation, the transient contaminant transport model was created using the velocity fields produced by the transient flow model.

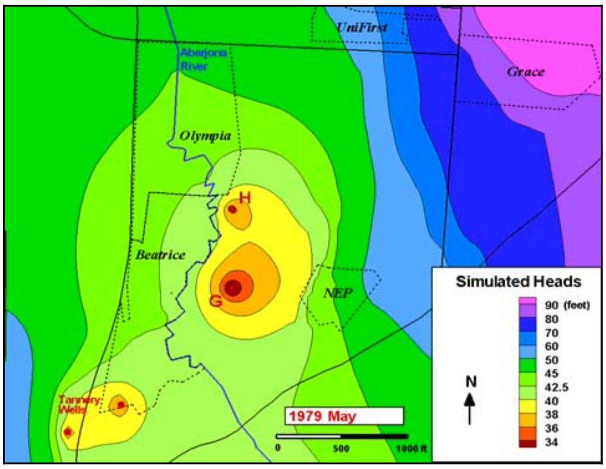

Figure 2. Simulated potentiometric surface in May 1979.

The contaminant transport model accounts for dispersion and chemical retardation of dissolved TCE and PCE. Because the exact nature of the five contaminant sources was not known, the contaminant transport model was used to identify a group of plausible TCE and PCE transport scenarios from hundreds of simulations run using different values of contaminant source locations, source concentrations, release times, dispersivity, and chemical retardation. The ranges of these values were constrained by measured TCE and PCE concentrations at each of the five source properties (Bair and Metheny, 2002), interpretation of 16 sets of historic aerial photographs that indicate approximate dates when drum piles containing the source chemicals at two properties were dumped, testimony presented during the federal trial, and measured values of the fraction of organic carbon in the aquifer sediments (Metheny, 2004). Plausible transport scenarios were selected based on comparison of simulated concentrations of TCE and PCE with measured concentrations in wells G and H in May 1979, July 1979, December 1985, and January 1986, and to TCE and PCE concentrations measured in 1985 in monitoring wells across the site.

Figure 3 shows simulated TCE concentrations in the aquifer in May 1979 based on Plausible Scenario #1B. In this scenario, the simulated concentrations of TCE in wells G and H (257 and 133 ppb) in May 1979 correspond well with measured concentrations (267 and 118 ppb). Similar plots and analyses exist for the PCE simulations, however, measured and simulated PCE concentrations are substantially lower than TCE concentrations. It cannot be determined which, if any, of the six plausible TCE and PCE scenarios actually represents what occurred even though each of the plausible scenarios closely reproduces measured values of TCE and PCE.

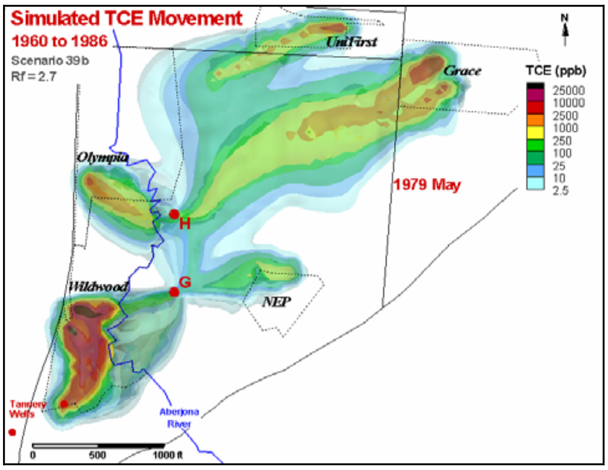

Figure 3. Simulated distribution of TCE in May 1979.

3. WOBURN WATER DISTRIBUTION MODEL

Between 1964 and 1979 when wells G and H were in use, the Woburn water distribution system took water pumped from eight municipal wells and delivered it through a continuous pipeline network to residential and commercial customers. Because of citizen complaints about the taste and odor of water from wells G and H, these two wells were used during periods of increased water demand.

The water distribution model (Murphy, 1991) divided the city into 54 user demand areas (water districts), accounted for water contributed from the six uncontaminated wells, calculated the monthly fraction of water from wells G and H that each water district received. Field validation of the water distribution model was accomplished by estimation fluoride tracer concentrations. These results indicated that the model could predict the boundaries of areas receiving wells G and H water to an accuracy of a several house area. The model was able to estimate mixture concentrations with the other six wells with an average error within 10 percent of the measured fluoride concentration (Costas and others, 2002).

The monthly fraction of wells G and H water delivered to residences varied spatially and temporally due to management of the overall water supply system. Figure 4 shows that the 219 residences in Water District #66 commonly received water containing more than 20 percent wells G and H water and occasionally received water containing more than 60 percent wells G and H water. Murphy (1991) compiled tables like the one used to construct figure 4 for each of the 54 water districts.

4. TCE + PCE CONCENTRATIONS DELIVERED TO RESIDENCES

Estimates of monthly TCE + PCE concentrations delivered to residences in each water district were obtained by combining the monthly values of the fraction of water from wells G and H (Murphy, 1991) with the simulated values of TCE and PCE concentration from the six plausible TCE and PCE scenarios (Metheny, 2004). Figure 5 shows the simulated ranges of TCE + PCE concentrations delivered to Water District #66 from the six plausible scenarios during the operational periods of wells G and H. Maps showing the spatial distribution of TCE + PCE in all the water districts for any month also can be plotted.

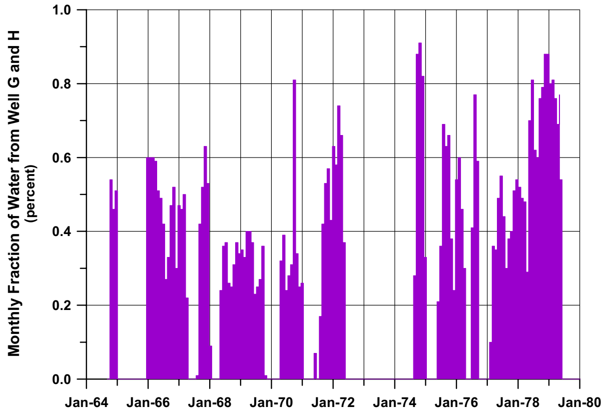

Figure 4. Monthly fraction (in percent) of water from wells G and H delivered to residences in Water District #66.

Under best-case conditions based on the six plausible scenarios, more than 5,400 residences in 35 water districts at some time received TCE + PCE concentrations greater than 5 ppb. The majority of these water districts received these concentrations for a total of 61 to 84 months. Under worst-case conditions, more than 6,760 residences in 39 water districts at some time received TCE + PCE concentrations greater than 5 ppb and the majority of these water districts received these concentrations for a total of 85 to 100 months.

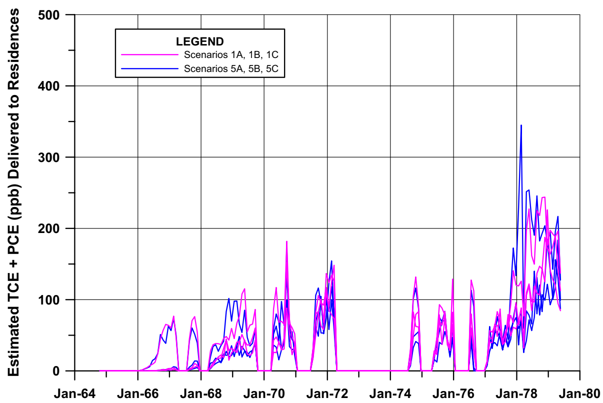

Figure 5. Temporal ranges of TCE + PCE concentrations delivered to residences in Water District #66 from the six plausible scenarios.

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