# ESTIMATING RESIDENTIAL INDOOR AIR IMPACTS DUE TO GROUNDWATER CONTAMINATION

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## ABSTRACT

The reliability of making risk-based corrective action (RBCA) decisions using ASTM methods was evaluated. Indoor air quality (IAQ) testing results for 153 residential homes in 1998 at a site in Denver, Colo., were evaluated in this study. Decisions regarding groundwater remediation and indoor air mitigation in residences located over a shallow groundwater plume contaminated with chlorinated compounds were made based on actual test results. These decisions could have been based on the predicted concentrations of the compounds in indoor air using the Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM E1739-95). Risk-based screening levels may be useful to guide general project decisions. However, variance of results from house to house is significant due to site-specific geological, building, and ventilation factors. Based on the results of this evaluation, indoor air quality testing should be used, rather than RBCA predictive modeling, to establish the extent of impacts and determine the need for mitigation.

***Key words:*** *chlorinated, decisions, groundwater, residential, risk*

## INTRODUCTION

At a number of industrial sites, volatile organic compounds (VOCs) have seeped into groundwater beneath the site and then migrated off site. These plumes often flow below other commercial or residential buildings. VOCs in the groundwater can volatilize and migrate into the overlying structures. Depending on site conditions, building purpose, and the constituents present and their toxicity, individual VOCs may be present in the structures at concentrations above action levels for indoor air.

Although the groundwater-to-indoor air pathway for migration of and exposure to VOCs has been recognized for some time (e.g., Johnson and Ettinger, 1991; ASTM, 1995), there is little information in the literature concerning the potential for chlorinated compounds in groundwater to impact indoor air (Richardson, 1997). One reason for this may be the limited number of regulations requiring testing of indoor air in buildings over contaminated groundwater.

A few states have recently developed indoor air pathway criteria for groundwater; however, these may underestimate the occurrence of indoor air impacts (Fitzpatrick and Fitzgerald, 1996) and are based on models that have not been validated (Altshuler and Burmaster, 1997). For example, Massachusetts groundwater-to-indoor air criteria (310CMR40.0932) are not applied to groundwater more than 4.6 m (15 ft) below ground surface. Experience at the site in this study indicates groundwater at depths greater than 6 m can significantly impact indoor air quality based on current toxicity criteria for 1,1 dichloroethene (1,1 DCE).

Although benzene has generally received more attention than other VOCs in groundwater (e.g., Fischer et al., 1996), 1,1 DCE is more likely to cause indoor air impacts. The relative

risk to indoor air posed by volatile compounds in groundwater is a function of the product of the Henry's Law Constant and the cancer slope factor for each compound (ASTM, 1995). On this basis, risks posed by 1,1 DCE are approximately 28 times greater than benzene.

This paper evaluates the reliability of making corrective-action decisions using ASTM methods to determine the need for groundwater remediation and indoor air mitigation in residences located over a shallow groundwater plume contaminated with chlorinated compounds based on the predicted concentrations of 1,1 DCE in indoor air. If the ASTM method is reasonably accurate, it would provide a straightforward, cost-effective method for making mitigation decisions without the need for testing of individual homes. A reliable method would minimize the false prediction of indoor air concentrations above the action level where the actual result would be below the action level. This would minimize installation of mitigation systems in homes where a system is not needed.

**THEORY**

The ASTM Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM E1739-95) provides a method for evaluating the site-specific conditions and risks. While the guide focuses on examples of petroleum product releases, the RBCA process is not limited to a particular class of compounds. The purpose of the RBCA process is to evaluate appropriate action levels based on the potential risk to human health. Limited resources can then be used to remediate sites associated with greater risks. The RBCA process provides a means for quantifying risk that site conditions pose to human health at sites that vary greatly in complexity, and physical and chemical characteristics.

In practice, a site-specific risk-based screening level (RBSL) or target level concentration would be developed for a chemical of concern in groundwater based on a particular health-based action level for the compound in indoor air. These site-specific RBSLs in groundwater could be used to determine what homes receive indoor air mitigation systems to alleviate potential health concerns due to indoor air quality. The RBSLs have the following relationship:

$$\text{RBSL(water)} = \frac{\text{RBSL(air)}}{\text{VF}}$$

The "volatilization factor" (VF) considers depth to groundwater and effective diffusion coefficients for the progressive movement of a VOC from the groundwater surface to the capillary fringe, to the vadose zone, through foundation/slab cracks, and into the residential structure. This factor can be calculated for each location using the peer-reviewed equations in the ASTM standard. The same equations can be used to predict an expected concentration in indoor air for a given concentration in groundwater:

$$\text{C(water)} = \frac{\text{C(air)}}{\text{VF}}$$

or, rearranging:

$$\text{C(air)} = \text{C(water)} \times \text{VF}$$

In evaluating indoor air risks, an advantage of the RBCA process is a method for making

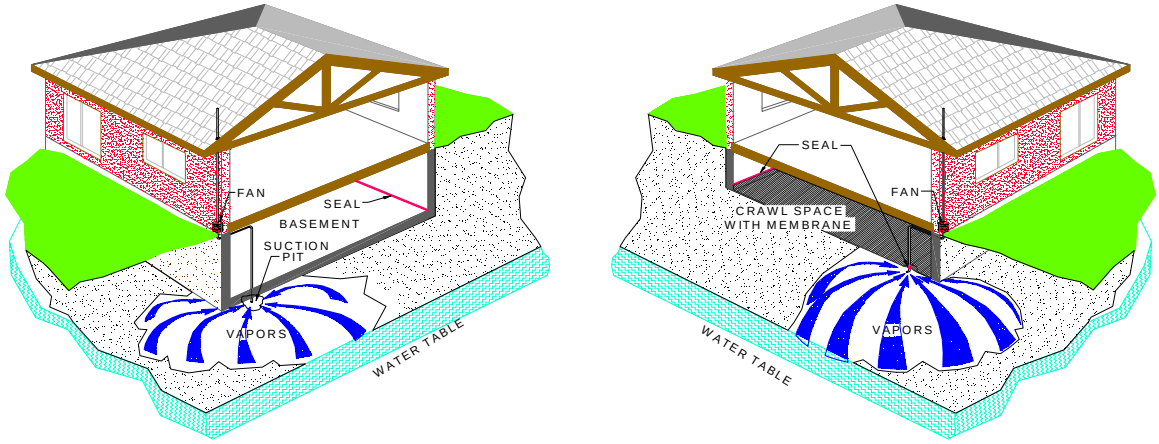

**Figure 1.** 1,1 DCE plume in groundwater.

risk-based corrective action decisions using VOC data from groundwater plumes without testing individual buildings over a plume. In this study, indoor air concentrations were calculated considering the 1,1 DCE concentration in groundwater and the associated volatilization factors for the progressive movement of 1,1 DCE from the groundwater surface into the residential structure at each location of 153 homes in the study. The 1,1 DCE concentration in groundwater beneath each home was estimated using concentration contours that were developed based on 1,1 DCE concentrations in a series of groundwater monitoring wells (Figure 1). Depth to groundwater was adjusted based on the depth of the basement or crawl space of the associated structure. The series of calculations associated with the volatilization factor and the default soil, building, surface, and subsurface parameters presented in the ASTM guidelines (ASTM E1739-95) were used to relate the VOC concentration in groundwater to the predicted concentration in indoor air.

## PROCEDURES

Indoor air quality testing results in 1998 for 153 residential homes at a site in Denver, Colo., were evaluated in this study. The homes overlie groundwater with 1,1 DCE concentrations ranging up to approximately 1,000 ug/l, resulting from the degradation of both 1,1,1 trichloroethane (TCA) and trichloroethene (TCE). Groundwater is at a depth of approximately 20 to 30 feet below the ground surface, flowing primarily in weathered sandstone and siltstone. Measured concentrations of 1,1 DCE in indoor air ranged up to 91 ug/m3 in residences located over the plume and were generally below detection in homes beyond the detectable groundwater plume. Variance of results from house to house is significant (plus or minus an order of magnitude in some cases), due to site-specific geological, building, and ventilation factors.

Indoor air samples were collected over a 24-hour period using an inert stainless steel container (SUMMA canister). Each canister




SUB-SLAB DEPRESSURIZATION

SUB-MEMBRANE DEPRESSURIZATION

**Figure 2**. Mitigation systems.

was laboratory cleaned, evacuated to a nominal vacuum of 0.01 torr, sealed, and shipped to the site under chain-of-custody documentation. The canister pressure was noted and recorded in the field at the beginning and end of the sampling event. Sample collection commenced with opening of the canister valve, which resulted in flow of air into the canister at a steady rate controlled by a regulator attached to the canister. Sample collection ceased approximately 24 hours afterwards by closing the valve. In some cases, the canisters had equilibrated with ambient atmospheric pressures when the canisters were retrieved, indicating that the sample collection period was less than 24 hours. The SUMMA canisters were shipped to the laboratory in batches under chain-of-custody protocols. Duplicate samples were collected at a rate of approximately 1 in 20.

SUMMA canister samples were analyzed at the laboratory in accordance with EPA Test Method TO-15, using a mass spectrometer operated in the selective ion monitoring (SIM) mode. For tests conducted after October 1998, equipment tuning procedures met the requirements of CDPHE (1999) guidelines. The SIM mode monitors a few compounds instead of the entire mass spectra, allowing a 1,1 DCE reporting limit of 0.04 ug/m3.

In this study, homes with 1,1 DCE concentrations in indoor air above the health-based action level were mitigated with sub-slab depressurization (SSD) or sub-membrane depressurization (SMD) systems in homes with basements or crawl spaces, respectively (Figure 2). Mitigated homes have been tested quarterly to monitor the effectiveness of these systems (Folkes and Kurz, 2000).

## RESULTS

The predicted 1,1 DCE concentrations in indoor air were compared to the actual indoor air results from the homes in the study. In approximately three out of five cases, the actual 1,1 DCE concentrations were within an order of magnitude of the predicted value. However, the RBCA calculations under-predicted 1,1 DCE concentrations in indoor air in four out of five

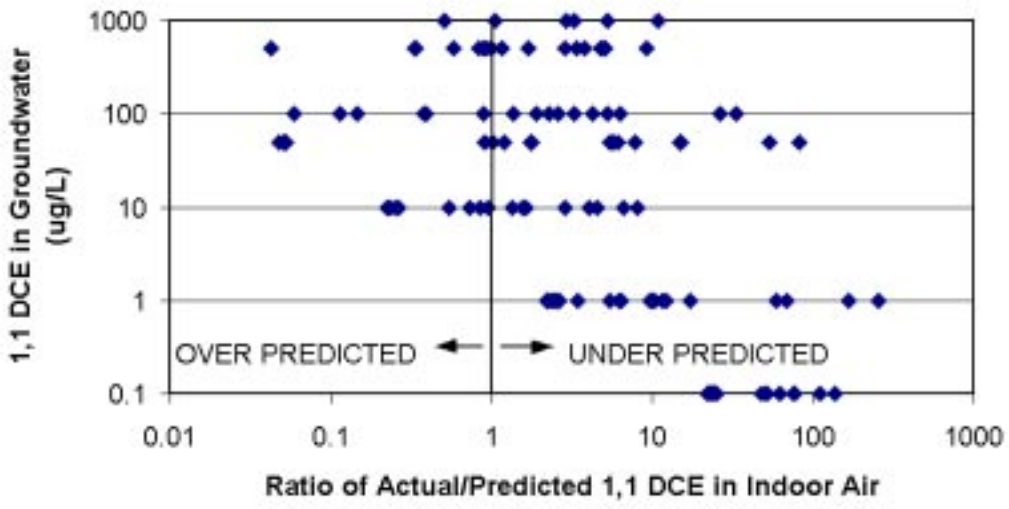



**Figure 3.** 1,1, DCE prediction ratio and groundwater concentration.

homes (Figure 3). Although a large number of results were under-predicted, the predicted and actual concentrations may both be below or both be above the action level. The primary concern in evaluating the reliability of a predictive method that has a tendency to under predict results is the probability of false negatives (i.e., homes predicted to be below the action level testing above the action level).

The overall false negative rate was approximately 10%. However, this rate was not consistent across the range of 1,1 DCE concentrations in the groundwater plume (Figure 4). The rate of the false-negative decisions appeared to be correlated to the concentrations of 1,1 DCE in the groundwater. Testing demonstrated that the estimates yielded false-negative rates varying from 5%, in homes above groundwater with 1,1 DCE concentrations below 10 ug/L, to over 50%, in homes above groundwater with 1,1 DCE concentrations of 50 ug/L. At 1,1 DCE concentrations greater than 100 ug/L in groundwater, there would have been no false-negative decisions; but the false positive rate (i.e., homes below the action level being predicted to be above the action level) was approximately 15%.

Although the results at the extremes of the range may be acceptable, it is in the middle of the range where a reliable predictive method for decision making would be most useful. In the range of 1,1 DCE concentrations in groundwater between 1 to 100 ug/L, there is a significant potential for predicting indoor air results below the action level in individual homes with actual results above the action level. Several mechanisms may be responsible for actual test results exceeding predicted results. Site-specific characteristics in individual houses are the most likely cause of this variance between predicted and actual results (e.g., underlying soil conditions, presence or absence of open joints or cracks in foundations, and heating and ventilating system conditions). In addition, the proximity of homes to nearby groundwater with higher concentrations may cause higher actual results than predicted.

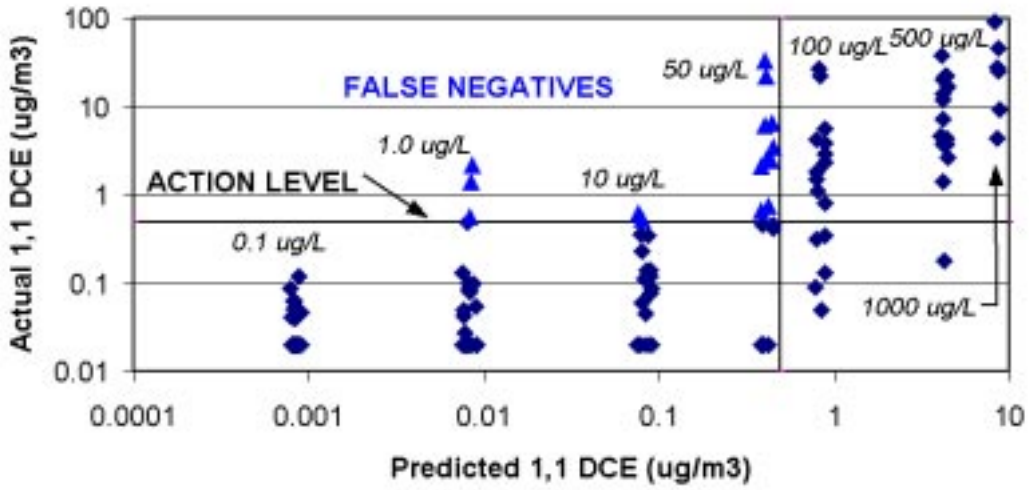



**Figure 4.** Actual and predicted concentrations of 1,1 DCE in indoor air (*1,1, DCE concentration in groundwater*).

Inherent in any predictive model is the attempt to include factors with a significant effect on results. One, seemingly significant, factor in the ASTM equations is the depth to groundwater at the location. Logically, the closer the groundwater to the basement or crawl space of the home, the higher the expected concentrations in indoor air. In this study, the depth to groundwater did not have a significant effect on the ability to predict the actual 1,1 DCE concentration in indoor air. At groundwater depths below the structure ranging from 3 m (10 ft) to 9 m (30 ft), the predictions were as likely to under-predict or over-predict at one depth as another (Figure 5).

A factor that has proven to be significant in actual results but is not included in the predictive methods is the seasonality effect. In several homes that did not initially exceed the action level (i.e., were not mitigated), indoor air test results were higher in the winter than in the summer months. Some homes that had test results below the action level during summer months had test results exceeding the action level during winter months. Cold weather, high winds, and furnace operation all tend to reduce the air pressure in houses compared to ambient pressures, creating additional forces for migration of vapors from the subsurface into a home. The test results for this study were collected during the summer months of 1998. Therefore, the tendency of the predictive methods to under-predict actual results would be expected to be more significant during winter months.

## CONCLUSIONS

Based on the results of this evaluation, indoor air quality (IAQ) testing should be used, rather than RBCA predictive modeling, to establish the extent of impacts and determine the need for mitigation.

At very low and high contaminant concentrations in groundwater, use of the RBCA equations may be an economical method for making mitigation decisions. The high false-negative rate at moderate concentrations in

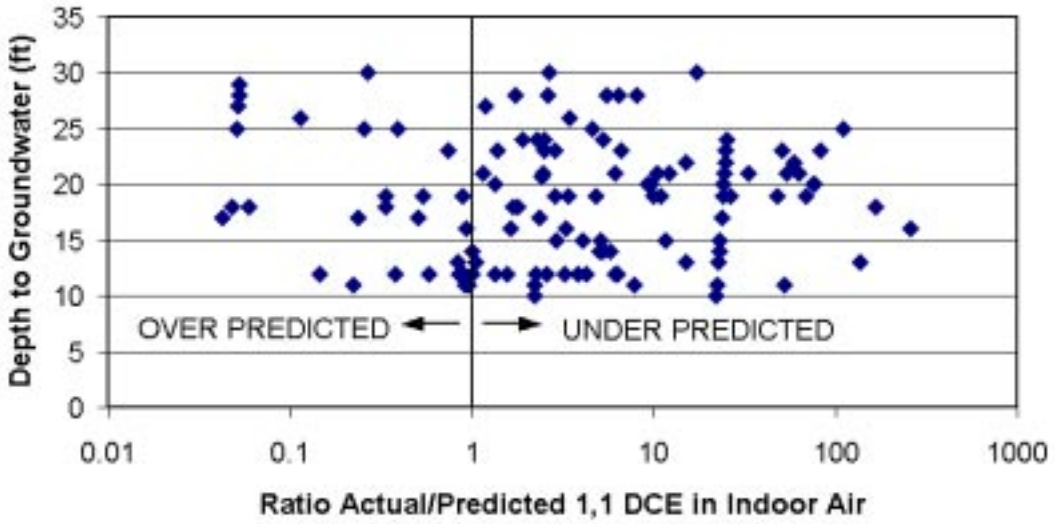



**Figure 5.** 1,1 DCE prediction ratio and depth to groundwater.

groundwater indicates testing is needed in homes that are predicted to be below the action level, to minimize the false-negative rate. This need for testing individual homes is further supported to avoid the seasonal influence on results.

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