Case Study: Case Study for the Use of a Decision Support Tool: Using the Johnson and Ettinger Model to Calculate Indoor Air Concentrations for Human Health Risk Assessment at a Confidential Site, California

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FOREWORD

This case study is one in a series designed to provide information on use of decision support tools that support the use of data, models, and structured decision processes in decision-making. These case studies include reports on selected tools that have been used to support activities such as site assessment and remediation, data management and visualization, and optimization. They are prepared to offer operational experience and to further disseminate information to project managers, site owners, environmental consultants, and others who wish to screen decision support tools and benefit from their previous use at sites.

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TABLE OF CONTENTS

Section **Page**

1.0 SITE BACKGROUND

The data and information presented in this case study is based upon an evaluation conducted at an actual site in California. However, the data and information are presented as a confidential site (CS) to protect the confidentiality of the client. The CS occupies about 62 acres along the eastern side of an island. The CS is bordered to the north, south, and west by industrial land and to the east by a water body.

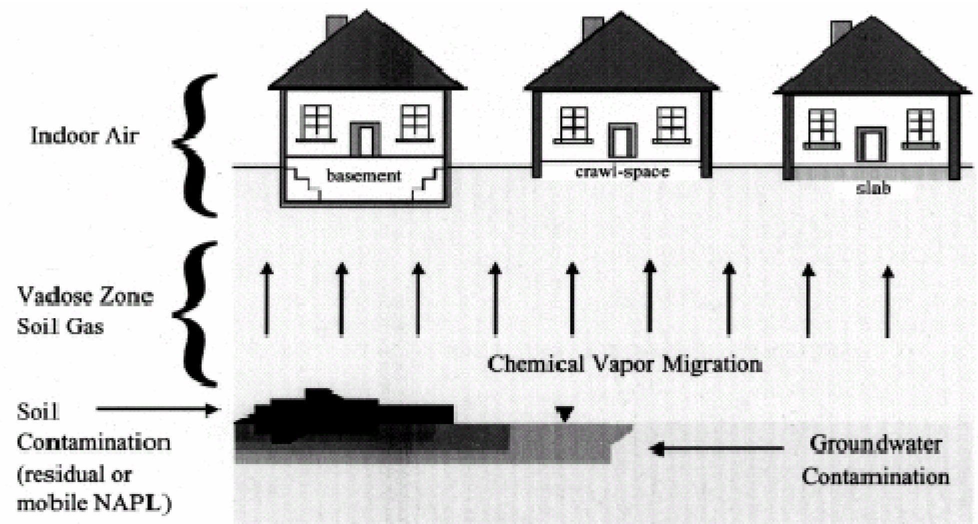
The CS is partially paved with asphalt, much of which is severely cracked and rutted. The CS is mostly underlain by artificial fill soils or partially underlain by spent sandblast material (SBM) overlying artificial fill. The ground surface generally slopes west to east, with surface elevations ranging from sea level on the east side to about 15 feet above mean sea level (msl) on the west side. Utility lines in and around the area include storm sewers, sanitary sewers, industrial wastewater pipelines, freshwater lines, and steam lines. The CS was used for historical painting operations; the manufacture and storage of machinery; and other maintenance activities from the early 1950s until the late 1990s, when these operations ceased. Chemicals of potential concern in the soil and ground water included volatile organic chemicals (VOCs). VOC contamination (primarily tetrachloroethene and trichloroethene) likely resulted from historical painting operations.

According to the site reuse plan, the CS was originally proposed for reuse as a marina with a residential housing area; however, this reuse plan has since been amended. The proposed amended reuse for all of CS is mixed-use industrial for heavy and light industrial redevelopment. Potential reuse of the property for industrial use necessitates the evaluation of vapor intrusion to indoor air from ground water via subsurface soil gas sampling.

Vapor intrusion is the migration of volatile chemicals from the subsurface into overlying buildings. VOCs in buried wastes or contaminated ground water can emit vapors that may migrate through subsurface soils and into indoor air spaces of overlying buildings in ways similar to that of radon gas seeping into homes, as shown in Figure 1 (EPA 2002). Risk estimates for vapor intrusion to indoor air were calculated using the EPA's 2004 vapor intrusion model, commonly referred to as the Johnson and Ettinger (J&E) model (http://www.epa.gov/oswer/riskassessment/airmodel/johnson_ettinger.htm), which is based on the work of Johnson and Ettinger (1991). These risk estimates generally are reported in terms of the likelihood that exposure to a chemical agent can cause an increase in the incidence of a particular adverse health effect (e.g., cancer, birth defects) in a given size population.

FIGURE 1

GENERALIZED SCHEMATIC OF THE PATHWAY FOR SUBSURFACE VAPOR INTRUSION INTO INDOOR AIR (from EPA 2002)



To estimate potential risks from vapor intrusion, soil gas samples were collected in the vicinity of the two buildings with potential future industrial reuse. Four soil gas samples were collected in vadose zone soil in the vicinity of two areas with impacted ground water. Summa canisters connected to soil probes were used to collect the samples. Following collection, soil gas samples were analyzed via EPA Method TO-15. Soil gas samples were collected at approximately 3 feet below ground surface (bgs). Soil overlying ground water at the site mainly consists of silty sand with lesser amounts of clay. A soil classification of silty loam (SIL) was used in the vapor intrusion model because silty sand is not recognized as a classification by the model.

2.0 USE OF DECISION SUPPORT TOOL

VOCs in ground water can migrate to other environmental media by volatilization, diffusion, or advection. For example, VOCs in ground water can vaporize and, in turn, migrate into indoor air (via cracks in a building's foundation) through migration of soil vapor. The J&E model was used to estimate risk for vapor intrusion to indoor air. The J&E model is a screening-level model that incorporates both convective and diffusive mechanisms for estimating the transport of contaminant vapors emanating from soil gas into indoor spaces located directly above or in close proximity to the source of contamination. Johnson and Ettinger (1991) reported that the results of the model agreed qualitatively with published, experimental case histories and also agreed qualitatively and quantitatively with detailed threedimensional numerical modeling of radon transport into houses (Loureiro and others 1990). The one-dimensional vapor intrusion model estimates convective and diffusive transport of chemical vapors emanating from soil gas into indoor spaces located directly above or near the source of contamination. A detailed description of the vapor intrusion model is provided in EPA's Draft *Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Ground Water and Soils* (Subsurface Vapor Intrusion Guidance) (EPA 2002) and EPA's Draft *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (EPA 2003).

Detected soil gas concentrations of trichloroethene, cis-1,2-dichloroethene, trans-1,2-dicloroethene, and vinyl chloride from the four soil gas samplers were evaluated. Inputs to the model include chemical properties of the contaminant, properties of soil in the saturated and unsaturated zones, structural properties of the building, and appropriate exposure assumptions for the receptors that are being evaluated. Input parameters are discussed in the following paragraphs.

Site-specific data for soil and hydrogeology were used for the evaluation of vapor intrusion. Soil overlying ground water consists primarily of silty sand with lesser amounts of clay. A soil classification of silty loam (SIL) was used in the vapor intrusion model because silty sand is not recognized by the model, and silty loam is considered the best fit based on the silty sand sediment typical of the CS. This evaluation assumed that the soil stratigraphy was homogeneous from surface to soil gas sample location (3 feet bgs), which is reasonable given the shallow depth of the soil gas samples.

Migration of constituents through soil depends on their ability to diffuse from the source, in this case ground water, into the vapor space and then through the soil. Vapor space is a function of the total porosity of the soil and the volume of water displacing the air within the pore volume. Research has shown that the vapor space immediately above free product and dissolved-phase hydrocarbons is typically low because of the capillary fringe effect; the capillary fringe is the zone above the water table and below the boundary of saturation where the soil is saturated but at pressures less than atmospheric. The total soil porosity (P_T), water-filled soil porosity (P_w), and air-filled soil porosity (P_a) used for this analysis were based on default parameters for silty sand obtained from a local guidance document, because silty sand is typical of the lithology beneath the site. The average soil temperature used for the analysis was based on the site location and information provided in Figure 8 of EPA (2003).

Building parameters for the industrial buildings in this analysis were based upon site specific building dimensions. Because of the shallow depth to the soil gas samples, this evaluation was based on buildings with slab-on-grade construction. The thickness of the foundation was assumed to be 15 centimeters (6 inches), which is typical for commercial/industrial structures.

The J & E vapor intrusion model conservatively assumes that the contaminant source is infinite (with respect to the duration of exposure) and that all vapor infiltration occurs through cracks in the foundation and below-grade walls (EPA 1997, 2000, 2002, and 2003). The area of cracks that would allow vapors to pass (A_{crack}) was calculated assuming that all cracks were 0.1-centimeter-wide (see equation 13 of EPA 2002, 2003).

The building ventilation rate ($Q_{building}$) is another parameter used as input to the vapor intrusion model. The building ventilation rate for the all commercial/industrial buildings (1.5 hr^{-1}) was based on the upper end of the range for residential structures because no default commercial/industrial values are provided in EPA references (EPA 2002, 2003).

Buildings can develop negative pressures when compared with ambient pressure as a result of temperature gradients and wind effects. These pressure differences (dP) affect contaminant flux into buildings and are taken into account in the vapor intrusion model. Typical dP values over time are 10 to 100 grams per centimeter per square second ($g/cm/sec^2$). Since flux is directly proportional to pressure difference, the recommended value from the subsurface vapor intrusion guidance (EPA 2002 and 2003) of 40 $g/cm/sec^2$ was used for dP over time.

Conclusions. Potential noncarcinogenic adverse health effects for the three compounds detected in the soil gas samples (cis-1,2-dichloroethene, trans-1,2-dicloroethene, and vinyl chloride) were estimated for commercial/industrial receptors that may occupy the two buildings at the CS; all hazard quotients were less than 1. Potential cancer risks from these compounds were also estimated for commercial/industrial receptors that may occupy the two buildings at the CS; all carcinogenic risks were less than 1E-06. Because all hazard quotients were less than 1 and carcinogenic risks were less than 1E-06, the J& E model output indicated no potential for unacceptable risks for commercial/industrial workers at the CS. Because other temporary workers (e.g., construction workers) would spend less time in the two buildings, the model also indicated no potential unacceptable risks to these workers. The benefit of using the J & E model was that potential future human receptors working in the two buildings evaluated could be assured that there was no unacceptable risk from vapor intrusion related to nearby ground water contamination.

3.0 LESSONS LEARNED

Practitioners with experience in using the J&E model at more than 100 sites have noted the following types of observations and lessons learned for use of this model.

- There are four computer-based versions of the J & E model for evaluating VOCs in the following media: soil, soil gas, ground water, and Non-Aqueous-Phase-Liquids (NAPL) (EPA 2004). Vapor intrusion modeling from soil gas is considered more accurate than for the other media because of the absence of phase transformation (e.g., ground water to soil gas), which must occur before vapors can seep into indoor air. However, soil gas concentrations collected from shallow depths (i.e., less than five feet below ground surface) tend to fluctuate due to changes in atmospheric conditions, so multiple samples may be required to account for temporal variations. Soil, ground water, and NAPL concentrations tend to be more stable over time. The partitioning of VOCs from soil and NAPL to soil gas is less exact due to the uncertainty associated with partitioning coefficients, so ground water modeling is the best alternative to soil gas modeling. If VOC concentrations from more than one media are available, it is customary to model both media and give preference to the media which provides the greatest cancer risk and noncancer hazard estimates to ensure a conservative risk evaluation. Modeling equations and further details pertaining to the vapor intrusion model can be found in EPA (1997, 2000, 2002, 2003). Web sites are provided in the reference section as appropriate (see Section 5.0).

- The J & E model may be used to estimate cancer risks or noncancer hazards using receptor-specific exposure parameters. If multiple receptors reside in the same indoor space, the J & E model can also be used to calculate an indoor air concentration, which is used to estimate cancer risks or noncarcinogenic hazards for all receptors using standard human health risk assessment equations (EPA 1989).

- The J & E model has proved to be a valuable tool in estimating indoor air concentrations. Correlations between estimated indoor air concentrations and indoor air sample concentrations collected using Summa canisters has been conducted at various sites. The results of these evaluations proved that estimated indoor air concentrations can be an order of magnitude higher or lower than actual indoor air sample concentrations collected using Summa canisters. This may lead to an order of magnitude under- or over-estimation of cancer risks (e.g., 1E-05 to 1E-06) or noncancer hazards (e.g., 10 to 1).

- The J & E model assumes that concentrations are steady-state over the duration of exposure (e.g., 25 years for commercial/industrial workers) and does not account for transformation or degradation processes, such as hydrolysis, photolysis, and biodegradation, which reduce chemical concentrations over time. Evans and others (1995) determined that the use of steady-state methods may over-predict risk by as much as two orders of magnitude. Also, the J & E model assumes that buildings are continuously under-pressurized, which neglects significant periods where neutral or positive pressurized conditions exist, thereby overestimating advective transport of contaminated vapors to indoor air, yielding higher indoor air concentrations.

- Important site-specific input parameters used in the J & E model include the following: fraction organic carbon in soil, water-filled porosity, soil bulk density, soil porosity, depth below grade to ground water, vadose zone soil type, enclosed space floor thickness, enclosed space floor length, enclosed space floor width, and enclosed space height. If site-specific parameters are not available, default parameters and other information can be found in Appendix G of EPA 2002.

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