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RISK IMPLICATIONS OF APPROACHES TO SETTING SOIL REMEDIATION GOALS

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Abstract

A framework has been developed to evaluate and compare the carcinogenic risk implications of two approaches to establishing soil remediation goals at hazardous waste contaminated sites. The approaches considered are (1) site-specific risk assessment to achieve a specified level of carcinogenic risk and (2) the use of uniform, concentration-based soil quality guidelines. Uncertainty in site-specific risk assessments and variability in site conditions when a uniform approach is used are taken into account. For each approach, cumulative distribution functions representing the regional variability in risk across sites are developed using a soil risk model. The two approaches are then compared based on these distributions. This paper describes the evaluation framework and presents some preliminary results of ongoing research to apply the framework to sites contaminated with trichloroethylene (TCE). Preliminary work in applying the framework to sites contaminated with polychlorinated biphenyls (PCBs) is also described.

1. Introduction

"How clean is clean enough?" How this question is addressed at individual sites has a major impact on the time and resources required to accomplish the cleanup effort and the consistency of the end result. Unlike other environmental media, few explicit concentration-based guidelines exist for judging soil contamination or establishing cleanup goals. Instead, cleanup goals are set site by site based on detailed risk assessments. For example, the National Contingency Plan for implementation of the Superfund[1] program, has specified an acceptable risk level rather than concentration levels to be achieved in remediation (U.S. EPA, 1990). Thus, measurable remediation goals must be determined at each site individually.

Although the site-specific approach is predominant in the U.S. currently, there is increasing interest in establishing uniform, concentration-based soil quality guidelines to promote consistency among remediation efforts. The uniform guidelines for polychlorinated biphenyls (PCBs) are among the few that exist at the national level (U.S. EPA, 1987). Several European countries and Canada have established soil quality criteria for a range of inorganic and organic contaminants. In some cases, the specified levels are applicable at all contaminated sites. In other cases, the levels differ according to site characteristics such as land use and soil organic content.

Some argue that a site-specific assessment is best because each contaminated site is unique (e.g,. Killian, 1989). However, this approach is resource and data intensive and

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[1] Comprehensive Environmental Responsibility, Compensation and Liability Act (CERCLA) as amended by the Superfund Amendment and Reauthorization Act of 1986 (SARA).

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often results in delayed cleanups. In addition, it can be applied inconsistently and result in an inconsistent level of protection of human health from site to site. For example, two neighboring Superfund sites in Texas, North Cavalcade and South Cavalcade, are contaminated primarily with polynuclear aromatic hydrocarbons (PAH) from creosote operations. Despite their nearly identical settings, the soil remediation goal for PAHs at the North Cavalcade site was set at 1 ppm, and at South Cavalcade site, 700 ppm. The difference is attributed primarily to disparity in the quality and extent of site data used for the assessments at the sites and widely varying exposure assumptions (Environmental Defense Fund et al., 1990).

Uniform soil quality criteria, on the other hand, can be applied consistently across sites without the need for costly site-specific risk assessments. However, differences in land use, soil types, and subsurface environments can influence exposure and health risk significantly at sites with similar contaminant levels in the soil. Hence, a wide range of risk levels can result from the application of the same soil quality criteria at different sites.

There has been a lot of debate about which of these two approaches is more appropriate, yet very little quantitative analysis has been performed to support the debate. An important question is, what are the risk implications of each approach? In principle a site-specific approach achieves a uniform level of risk at all sites. However, there is a great deal of uncertainty in risk assessment even if site-specific information is collected and taken into account. On the other hand, when a uniform soil concentration is achieved at all sites, the risk will vary because of differences in site characteristics.

The purpose of the work described herein was to develop a framework to quantify and compare the human health risk implications of the two approaches in terms of risk variability across sites in a region. The definition of risk used was excess lifetime cancer risk to the hypothetical maximally exposed individual. This paper also presents ongoing research to apply the evaluation framework to sites contaminated with TCE and preliminary work in applying it to sites contaminated with PCBs.

2. Development of a general framework for evaluating risk implications

2.1 Evaluating the site-specific approach

In a site-specific approach, an acceptable level of risk is established and a site-specific goal is back-calculated using a soil risk model (Figure 1). The input parameters are specified from measurements of or assumptions about contaminant and site-specific properties, and the exposure scenario. Currently, a deterministic approach is taken in which point estimates of the input parameters are specified.

The definition of risk used in this work is risk to a hypothetical individual faced with a reasonable maximum exposure (RME). This is the same approach adopted by the U.S. EPA to calculate carcinogenic risk (U.S. EPA, 1989) at Superfund sites. In general, the major exposure assumptions specified by the U.S. EPA are used here. From this point on, the word risk will be used to mean excess lifetime cancer risk to the RME.

In principle, the risk implications of the site-specific approach are obvious. It could be referred to as a 'uniform risk' approach since a level of risk is established as acceptable and site-specific assessments are intended to allow the determination of a soil concentration to be achieved in remediation which will result in the established risk level. However, the resulting risk is not without uncertainty. Incomplete knowledge of the physical/chemical

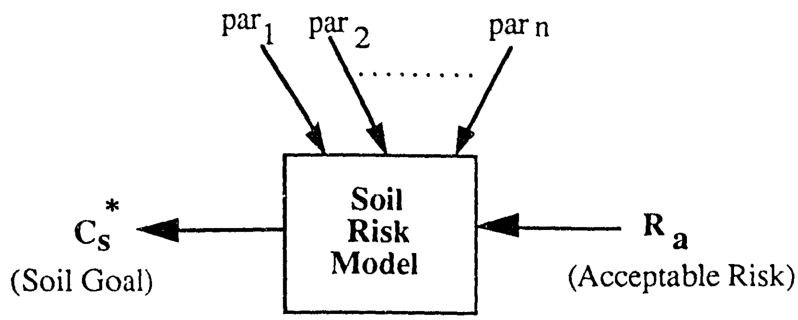

Figure 1. Schematic of the current site-specific approach. A soil goal is established using a soil risk model, point estimates of input parameters, and an acceptable level of risk.

processes governing contaminant fate and transport, incomplete characterization of site parameters, and unknown exposure conditions contribute to the uncertainty in the site-specific risk estimate.

To quantify the uncertainty in post-remediation risk estimates made using current risk assessment guidance for Superfund sites requires consideration of both model and parameter uncertainty. An evaluation of the sensitivity of the risk estimate to model uncertainty is performed by identifying alternative environmental fate and transport sub-models available for each of the major exposure routes and comparing the risk assessment at a single site using several model formulations. To examine the uncertainty in risk due to parameter uncertainty, a single version of a soil risk model is chosen. This is depicted in Figure 2. Parameter uncertainty is evaluated from information about current practices of site investigation and then cumulative probability distribution functions are assigned to the input parameters (par_1-par_n in Figure 2). *Uncertainty* in the post-remediation risk estimate, R, at a *single* site when the soil remediation goal, C_s^*, is used can be determined by evaluating a cumulative distribution function for R.

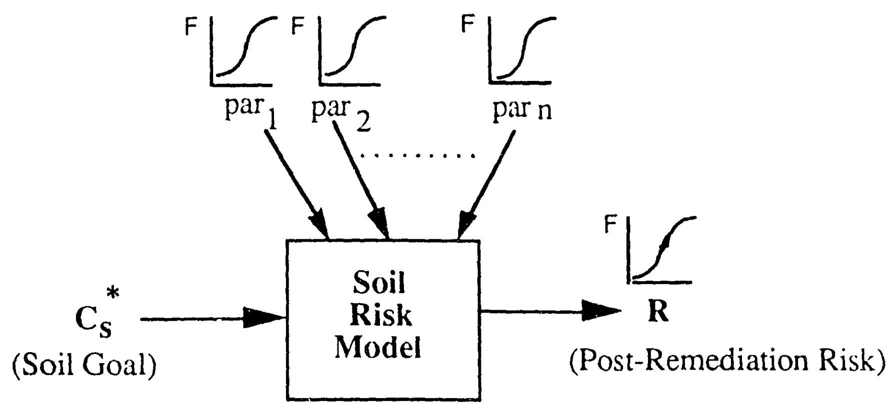

Figure 2. Uncertainty in the post-remediation risk estimate due to parameter uncertainty at a *single site* can be determined by characterizing the uncertainty in the input parameters. The deterministic soil goal is determined using the procedure illustrated in Figure 1.

In order to compare the uniform and the site-specific approaches, it is necessary to determine the *variability* in risk across a *number of sites* in a region that results from the use of each approach. An important question is: how generalizable to other contaminated sites is the cumulative distribution function of risk at the soil remediation goal for a case study site. One approach to this issue is to assume that the acceptable risk, the method used to establish the soil goal at each site, and the degree to which the site is characterized are the same at all sites in the region. Then the cumulative distribution function at the case study site can be shown to be representative, and it can be said to be equivalent to a regional distribution of risk variability.

2.2 Evaluating the uniform approach

When uniform soil concentration guidelines are used, risk can vary across sites because differences in land use and site characteristics can influence exposure and health risk significantly at sites with similar contaminant levels in the soil. A uniform level for a particular contaminant will result in some sites whose actual risk exceeds the desired risk goal and others whose actual risk is lower than the goal, suggesting a less or more stringent soil remediation goal would have been adequate at the respective sites. To evaluate the variability in risk across sites due to use of a uniform soil concentration, variability in site conditions across a region of sites must be quantified as cumulative distribution functions. As shown in Figure 3, these distributions, along with the uniform soil goal, are input to a soil risk model to determine a cumulative distribution function for the post-remediation risk at a random site.

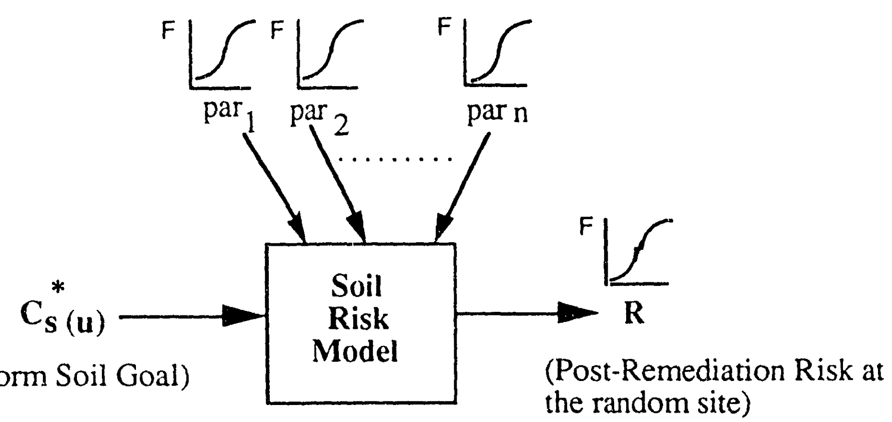

Figure 3. When a uniform soil goal for a particular contaminant is applied to all sites in a region, the post-remediation risk at the random site can be determined. The variability in the input parameters across the sites in the region must be specified.

2.3 Comparison of the two approaches

The general framework developed for creating cumulative distribution functions representing the regional variability in risk can be used to compare the site-specific and uniform approaches to setting remediation goals with respect to their relative risk implications. As discussed previously, use of the uniform approach will result in variation of risk across sites because of differences in site characteristics. However, the site-specific approach also results in variability of risk across sites due to the uncertainty and variability in the data and models used in risk assessment. A major question is how much more or less variability is associated with use of the uniform concentration approach. This question can be addressed with the framework described by comparing the cumulative distribution functions of risk developed for each approach.

3. Application of the framework

This section describes ongoing work to apply the framework developed to sites contaminated with TCE. TCE has been chosen because it is one of the most common contaminants found at Superfund sites (Grisham, 1986; Siegrist, 1992) as well as U.S. Department of Energy sites (Riley et al., 1992), it is classified as a probable human carcinogen by the U.S. EPA due to significant increases in the incidence of liver tumors in mice upon exposure to it (U.S. EPA, 1988; U.S. EPA, 1991), and it is representative of other chlorinated aliphatics and volatile organic compounds. Work on evaluating the risk implications of the uniform approach for PCB contaminated sites is also described. The work on PCBs was motivated by the fact that PCBs are the only contaminant for which uniform guidelines exist at the national level (U.S. EPA, 1987). PCBs are also classified as probable human carcinogens by the U.S. EPA (U.S. EPA, 1988; U.S. EPA, 1991).

Documentation on CERCLA sites with TCE contaminated soil is being reviewed to identify the soil-risk models being used, how they are applied, and the range of soil goals being established. Some results are summarized in Table I. Preliminary observations include that in all cases TCE levels in soil were set to achieve acceptable TCE concentrations in groundwater, several different modelling approaches are in use, and the soil goals established for TCE range over 3 orders of magnitude.

The different modelling approaches used at sites in the review will be evaluated to determine the sensitivity of the site-specific risk estimate to model uncertainty as described in Section 2.1. Then, a single TCE soil risk model will be developed for use in the development of a distribution function for risk. A case study site will be chosen based on those presented in Table I. Probability distribution functions will be assigned to site parameters after rigorous evaluation of the data collected at the case study site. A cumulative distribution function will be developed for the site-specific risk estimate (calculated at the soil remediation goal) at the site. Results of the single site analysis can be extended to estimate the variability in the risk across a region of sites when the site-specific approach is used as discussed in Section 2.2.

The risk implications of the uniform approach to establishing soil remediation goals at TCE contaminated sites will be evaluated as depicted in Figure 3. The variability of risk at the random site in the region can be determined by assigning probability distribution functions to the input parameters to a soil risk model. The variability in site conditions across the U.S. will be determined from a number of sources (e.g., Smith and Charbeneau, 1990). The soil risk model used will be the same as that used for the case study site above. As shown in Figure 3, a cumulative distribution function representing the variability in risk across the sites in the U.S can then be determined.

Table I: Site-Specific Soil Clean-up Goals for TCE (1)

Name	City	St	EPA Reg	Type (2)	ROD Date	Soil Remedy for TCE (3)	Soil Goal	Basis (4)	Model used (5)
Main Street Wellfield	Elkhart	IN	5	Wf	3/29/91	ISVE in one area; Exc/Incin in another.	100	Achieving 1.0 ppb in groundwater. (1.0 ppb is calculated to be the 10-5 risk level for ingestion of groundwater below site.)	Summer's model.
Zanesville Wellfield	Zanesville	OH	5	Wf	9/30/91	ISVE	6.3	Achieving MCL in groundwater below site.	Summer's model with assumption that background is MCL.
Verona Wellfield	Batllecreek	MI	5	Wf	6/28/91	ISVE	60	Michigan Act 307 Type B (risk based level).	NA
Enviro-Chem	Zionsville	IN	5	WRR	6/7/91	ISVE enhanced by RCRA cap.	240	Achieving MCL in groundwater below site. Note that ROD claims its at the boundary of the site, but the calculation does not show this.	Summer's model using assumed rather than measured area of contamination (1m*0.63m) and height of groundwater table (4m).
Acme Solvent Reclaiming	Winnebago	IL	5	Ind Disp	12/31/90	Exc/Treatment by LTTS and ISVE. RCRA cap (cap) or soil cover (sc).	16 sc 140 cap	For sc goal, achieving 2.45 ug/l in gw. This gives a 10-6 risk due ingestion of TCE alone in gw, and a 10-5 overall. For RCRA cap goal, achieving 0.245 ug/l in gw which gives 10-7 risk due to TCE alone, and 10-6 risk overall.	HELP model to determine infiltration rate with soil and RCRA caps. Summer's with modified MCL.
Springfield Twp Dump	Springfield Twp	MI	5	Ind Disp	9/29/91	Exc/Incin and ISVE of soils at depth.	60	Michigan Act 307 risk based level.	NA
Fisher-Calo Chem	Kingsbury	IN	5	Man/ WRR	8/7/90	Excavation and Soil flushing or ISVE.	TBD	Achieving MCL in groundwater.	TBD in design phase.
Wayne Waste Oil	Columbia City	IN	5	WRR /Lf	3/30/90	ISVE	TBD	Achieving MCL in groundwater.	Contaminant leaching model will be used.
Pristine, Inc	Reading	OH	5	Ind Disp	3/30/90	Exc/Incin of soils to 1'. ISVE of soils >1'.	175	Achieving MCL in groundwater.	Summer's Model.
Oconomowoc Electroplating, Inc	Ashippun	WI	5	Pl	9/20/90	Exc and offsite treatment and disposal.	TBD	Achieving Wisconsin standards in groundwater: if achieveable the PAL of 0.18 ppb or the ES of 1.8 ppb .	TBD
Wausau Groundwater Contamination	Wausau	WI	5	Wf	9/29/89	ISVE	TBD	Achieving Wisconsin standard in groundwater of 1.8 ppb at the source boundary.	A mass flux groundwater model will be used.

Table I: Site-Specifc Soil Clean-up Goals for TCE (1) (cont'd)

Name	City	St	EPA Reg	Type (2)	ROD Date	Soil Remedy for TCE (3)	Soil Goal	Basis (4)	Model used (5)
Metaltec-Aerosystem	Franklin Boro	NJ	3	Ind	6/30/86	Exc. Treatment via heat addition. Offsite disposal.	5	Achieving MCL in groundwater.	Equilibrium partititioning.
Greenwood Chemical Site	Newtown	VA	3	Ind	12/29/89	Exc of soil. Staging and screening. Incineration.	130	Achieving MCL in groundwater.	Two part soil leaching model: 1) dilution at bound between sat and unsat zones 2) back calc of soil concentration to achieve MCL in sat zone just below site.
Tyson's Dump	Upper Merion	PA	2	Lf	3/31/88	ISVE	50	Based on consent agreement. The level calculated to attain 10-6 risk due to gw ingestion, critical exposure route, is 25,000 ppb.	For 25 ppm level: 1) HELP to predict infiltration, 2) RITZ to predict mass transport in saturated zone, 3) GW dilution model to predict dilution due to well deeper than contaminant plume.
Byron Barrel and Drum	Byron	NY	2	LC	9/29/89	In situ flushing	47	Achieving MCL in groundwater.	Summer's Model with assumption that contaminated area is square w/ dimensions w x w.
Fulton Terminals	Fulton	NY	2	SI	9/29/89	Exc/treatment.	2000	Achieving MCL in groundwater.	Summer's Model
American Thermostat	Green County	NY	1	Ind	6/30/90	NA	400	Achieving MCL in groundwater.	Multi-Med
Groveland Wells 1&2	Groveland	MA	1	Wf	9/30/88	ISVE	6	ND	ND
Cannon Engineering	Bridgewater	MA	2	LC	3/31/88	Exc, onsite treatment, access	71	ND	ND
Waldick Aero. Devices	Wall Twp	NJ		Pl	9/29/87	Exc, air stripping.	1000	NJ level for total VOCs.	NA

Notes:
(1) Inormation obtained from Records of Decision and Remedial Investigation/ Feasibility Study Documents for each site.
(2) Man= manufacturing, Lf =landfill, Wf=wellfield, Pl=plating operation, SI=surface impoundment, CM=chemical manufacturing, WRR=waste recovery and reclamation, Ind Disp=industrial disposal, LC=leaking contaminer.
(3) ISVE=in-situ vapor extraction, Exc=excavation, Incin=Incineration
(4) NA= not applicable, TBD=to be determined, ND= not discussed in documents reviewed.

In preliminary work (Labieniec, 1992), an analysis similar to that described here was performed for PCB contaminated sites. A risk model developed by the U.S. EPA for soil contaminated with PCBs was reproduced and modified for the analysis. Continuous probability distributions representing the variability in site conditions across the U.S. (Smith and Charbeneau, 1990) were assigned to parameters in the fate and transport model to examine the effect that such variability has on individual risk when uniform cleanup levels for PCBs in soil are used. Two different definitions of the RME were used, one where the RME individual is present onsite, and one where the RME individual is present at least 0.1 km offsite and the contaminated site is inaccessible. It was found that consideration of variability in site conditions resulted in risk variability of only about a factor of two for onsite exposure, but roughly two orders of magnitude for the offsite exposure.

In the soil risk model for PCB contaminated soil, the exposure routes considered for the onsite exposure were soil ingestion, dermal absorption, vapor and dust inhalation. The groundwater ingestion exposure route was not considered mainly because PCBs are expected to partition strongly to the soil solid phase. PCBs have a relatively high octanol:water partition coefficient and thus adsorb readily to organic matter in soil.

For the other compound to be investigated, TCE, the groundwater exposure route is expected to be the major exposure route. TCE has a considerably lower octanol:water partition coefficient and is much more soluble in water than PCBs. It is expected that the inclusion of the groundwater exposure route and the different chemical properties of TCE will result in different conclusions than those drawn from the PCB analysis.

The two alternatives can be compared by comparing the cumulative distribution functions representing regional risk variability. The cumulative distribution functions will be displayed on the same scale. It is expected that the use of the uniform approach will result in an increase in risk variability relative to the site-specific approach. Of course, the increase will be affected by the method used to establish the uniform goals. This analysis will allow the amount of the increase to be quantified by examining the differences in the risk at various fractiles. The variances of the distributions will be compared also.

4. Summary

There has been a lot of debate about which approach is more appropriate for establishing soil remediation goals at hazardous waste remediation efforts, a site-specific approach or a uniform concentration approach, yet very little quantitative analysis has been performed to support the this debate. It is important to ask, what are the risk implications of each approach? In principle a site-specific approach achieves a uniform level of risk at all sites. However, there is a great deal of uncertainty in risk assessment even if site-specific information is collected and taken into account. On the other hand, when a uniform soil concentration is achieved at all sites, the risk will vary because of differences in site characteristics.

The purpose of this work is to evaluate and compare the risk implications of two general approaches to establishing soil remediation goals at hazardous waste contaminated sites. The definition of risk used is excess lifetime cancer risk to the hypothetical individual with a reasonable maximum exposure. A framework to quantify and compare the human health risk implications of the two approaches in terms of risk variability across sites in a region has been developed. This framework is being applied to sites contaminated with TCE. In preliminary work, the human health risk implications of uniform concentration guidelines at sites with PCB contamination have been examined. It was found that if the hypothetical maximally exposed individual is defined as residing onsite, risk varies by only about a factor of 2 from site to site. On the other hand, if the hypothetical maximally exposed individual is defined as residing offsite, risk varies a great deal, roughly two orders of magnitude, from site to site.

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