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The Development of Chemical-Specific, Risk-Based Soil Cleanup Guidelines Results in Timely and Cost-Effective Remediation

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ABSTRACT: Millions of dollars of limited state cleanup funds are spent each year in New Hampshire to identify, sample, excavate, and treat thousands of tons of contaminated soil. Cost analyses of numerous sites indicated that soil remediation costs alone reach upwards of $300,000.00 per site. The New Hampshire Department of Environmental Services "Interim Policy for Management of Soils Contaminated from Spills/Releases of Virgin Petroleum Products" (DES, 1989, 1991) set conservative remediation goals based on total petroleum hydrocarbons in 1989 using the Leaching Potential Analysis method (California Luft Manual, 1989). A current review of available literature and several case histories indicated that chemical-specific soil cleanup levels may be more appropriate for establishing remedial goals. *New* chemical-specific soil cleanup guidelines using a risk-based approach have been developed. These new guidelines are conservatively based using two principal considerations: (1) an assumed soil exposure scenario that estimated the human health risks associated with potential long-term exposure to site soils via ingestion, inhalation and dermal contact and (2) the estimated fate and transport of chemicals of concern in the soil unsaturated zone. The first consideration assumed a total cancer risk that did not exceed 1×10^{-6}. The second consideration employed the use of the SEasonal SOIL Compartment (SESOIL) model which simultaneously models water transport, sediment transport, and pollutant fate (US EPA, 1981). Several state soil standards from Oregon, Wisconsin, Massachusetts, and other states were extensively reviewed in order to develop a level of confidence that use of the SESOIL model was appropriate. A series of "sensitivity" analyses was also performed in order to evaluate the response of the model to changes in various input parameters unique to New Hampshire's hydrogeologic conditions. Generic soil cleanup guidelines were developed for 24 petroleum-based volatile and semivolatile chemicals of concern to be applied statewide. Site-specific soil cleanup guidelines will be allowed if it can be demonstrated that insertion of site-specific data into the model will not adversely affect groundwater quality. As a result of the above processes, timely and much more cost-effective remediation will be achieved while still maintaining a high degree of protection of the groundwater quality and human health.

KEY WORDS: risk-based soil cleanup guidelines, total petroleum hydrocarbons (TPH), SESOIL, sensitivity analyses, site-specific, cost effective remediation.

I. INTRODUCTION

The New Hampshire Department of Environmental Services (NHDES) developed chemical-specific, risk-based soil cleanup guidelines that became effective on January 1, 1995. This article describes the process of that development. The cost effectiveness and protectiveness of this type of approach toward answering the question “How clean is clean?,” is examined. A summary of data from several petroleum-contaminated sites that represents the potential cost savings realized if the chemical-specific, risk-based soil cleanup guidelines were utilized in favor of conservative, indirect measurements such as total benzene, toluene, ethlybenzene, and xylene (BTEX) and total petroleum hydrocarbons (TPH) is also discussed. A case study is presented to further illustrate the differences in costs for the management of petroleum-contaminated soils using the chemical-specific, risk-based soil cleanup guidelines vs. numerical cleanup guidelines for BTEX and TPH. The case study and the data summary are based on actual sites located in New Hampshire where corrective actions have been conducted under the New Hampshire Leaking Underground Storage Tanks (LUST) program.

Millions of dollars of limited state cleanup funds are spent each year in New Hampshire to identify, sample, excavate, and treat thousands of tons of petroleum-contaminated soil. Based on a review of information collected from several sites, a cost analysis indicated that soil remediation costs alone represented an average of $350,000.00 per site (Denison, 1994). The NHDES Interim Policy for the Management of Soils Contaminated from Spills/Releases of Virgin Petroleum Products (policy) set conservative remedial goals in 1989 using the leaching potential analysis method (NHDES, 1989, 1991; CWRCB, 1988). These remedial goals, specifically for BTEX constituents and TPH compounds, had become standard for many states during the development of state and federal underground storage tank (UST) programs as a method of gauging when soil remediation was complete at a given site (Bell *et al.*, 1990). The remedial goals for BTEX and TPH measured as gasoline were set at 1.0 and 10.0 ppm, respectively. For fuel oils, the goals were set at 1.0 ppm for BTEX and 100.0 ppm for TPH. Recently, there has been an increased movement toward a chemical-specific, risk-based approach to the cleanup of petroleum-contaminated soils. Since 1990, state UST programs have moved away from the typical “1 ppm BTEX or 100 ppm TPH” cleanup standards or guidelines to more chemical-specific, risk-based approaches. Thirty-two of 50 states have made this transition (Oliver *et al.*, 1993).

II. BTEX/TPH MEASUREMENTS VS. CHEMICAL-SPECIFIC MEASUREMENTS

Traditionally, BTEX constituents have been combined together to determine the level of petroleum-related volatile organic chemicals (VOC) at a given site. However, this comprehensive method obscures whatever the real risk would be to human health and the environment. Moreover, BTEX constituents, the main components of gasoline that are often analyzed because of their toxicity, are easily decomposed in the environment. BTEX is measured in the laboratory against a gasoline standard. Because of its aforementioned affinity toward rapid decomposition, analysis of the BTEX compounds in a soil sample that is composed of weathered gasoline would not be appropriately addressed by a single cleanup guideline for just BTEX compounds that is based on a pure gasoline standard (Nicholson and Boyce, 1993). Other volatile and semivolatile constituents of gasoline exist for which an associated chemical-specific, risk-based cleanup guideline has been developed by NHDES.

The TPH measurement has several limitations. Chemical mixtures present in a given soil sample can vary greatly from site to site. Therefore, the individual constituents of the hydrocarbon mixture would be difficult to assess because the TPH measurement gives only the "total" amount of hydrocarbons present in the soil. As a result, the magnitude of risk from a specific TPH concentration will vary from site to site and be difficult to determine. Moreover, the chemical compounds found in a complex petroleum mixture can degrade over time and alter the composition, mobility, and toxicity of the initial mixture. This factor can result in a wide range of TPH concentrations between soil samples, and the results may not be comparable.

III. CHEMICAL-SPECIFIC, RISK-BASED SOIL CLEANUP GUIDELINES: A SCIENTIFIC APPROACH TO THE COST-EFFECTIVE SITE CLEANUP OF CONTAMINATED SOILS

Thirty-two states have developed and implemented site-specific, risk-based soil cleanup levels or guidelines, indicating an increasing scientific approach toward risk-based methodology for the cleanup of contaminated sites (Bell *et al.,* 1990; Oliver et al., 1993). New risk-based guidance has been developed by the American Society for Testing and Materials (ASTM). The guidance standard, ASTM Guide for Risk-Based Corrective Action at Petroleum Release Sites, offers a three-tiered approach to incorporating risk assessment into the corrective action process. These methods and others to a chemical-specific, risk-based approach to corrective action help to support the direction NHDES took in the development of its soil cleanup guidelines. The formation of these guidelines and their effect on the cost effectiveness of site remediation are discussed below.

A. Generic Soil Cleanup Guidelines

A literature review and file review of NHDES petroleum-contaminated sites were performed in order to develop a list of chemicals associated with petroleum hydrocarbon mixtures in contaminated soil (Anderson, 1992; MDEP, 1993a,b; Magee *et al.*, 1992). Initially, 50 chemicals commonly found in various hydrocarbon mixtures indicative of petroleum-contaminated soil at LUST sites were proposed to be included in the establishment of the chemical-specific, risk-based soil cleanup guidelines. However, due to (1) lack of accurate risk-based exposure data, (2) no available drinking water standards for several chemicals, and (3) infrequently detected petroleum-based chemicals in contaminated soil samples, the initial list of regulated contaminants was reduced to 24 chemicals.

The concentration in soil that was protective of human health and the environment was derived for each compound for both direct exposure and leaching to groundwater exposure pathways. The direct exposure pathway reviewed three routes of exposure: ingestion, inhalation and dermal contact. The leachability exposure pathway examined the transport of contaminants through the subsurface to the groundwater that would be used as drinking water supplies. The concentrations for the two exposure pathways were compared, and the lowest of the two values was used as the generic soil cleanup levels listed in Table 1. The development of the soil cleanup guidelines based on direct exposure and leachability along with the formation of a TPH guideline are discussed below.

1. *Development of Direct Exposure-Based Soil Cleanup Guidelines*

Risk-based soil cleanup guidelines have been developed for both carcinogens and noncarcinogens and are based on a residential exposure scenario, assuming that residents are exposed to the soil by both dermal contact and incidental ingestion routes. They are intended to be protective for children and adults and represent the maximum acceptable health risk for an ambient residential exposure scenario. For those chemicals (i.e., benzene) that are anticipated to exert similar target effects of toxicity via all routes of exposure, the various pathways were combined to develop a risk-based soil concentration. For those chemicals that exhibit different critical target effects from different routes of exposure, risk-based levels were calculated separately for the dermal contact/ incidental ingestion route vs. the inhalation route, and the most restrictive of these two values was used for the direct exposure cleanup level (Perlman, 1994).

These risk-based concentrations were calculated to correspond to a target risk of 1 in 1 million (1×10^{-6}) excess cancer risk over a lifetime for individual chemicals as well as cumulative carcinogenic risk for a given site, given that the exposure to multiple carcinogens through multiple routes was reviewed. Guidelines for noncarcinogens were developed based on an estimated exposure incurred in a young child. All assumptions used in the development of the direct exposure-based soil cleanup guidelines are recorded in Table 2.

TABLE 1
Virgin Petroleum-Contaminated Soils Generic Cleanup Guidelines

Regulated contaminants	Soil cleanup Guidelines (ppm)	Exposure pathways
Acenaphthene	0.66	[a]
Benzene	0.2	[a]
Benzo(*a*)anthracene	0.66	[a]
Benzo(*a*)pyrene	0.66	[a]
Benzo(*b*)fluoranthene	0.66	[a]
Benzo(*k*)fluoranthene	0.66	[a]
Chrysene	0.66	[a]
Dibenzo(*a,h*)anthracene	0.66	[a]
1,2-Dichloroethane	0.04	[b]
Ethylbenzene	75	[b]
Fluoranthene	0.66	[a]
Indeno(1,2,3-cd)pyrene	0.66	[a]
Isopropylbenzene	23	[b]
MTBE	0.6	[b]
Naphthalene	3	[b]
2-Methylnaphthalene	0.66	[a]
Toluene	75	[b]
Xylenes (Total)	750	[b]
Total Petroleum Hydrocarbons	10,000	
Total Noncarcinogenic PAHs	7,800	[a]
Acenaphthylene		
Anthracene		
Benzo(*g,h,i*)perylene		
Fluorene		
Phenanthrene		
Pyrene		

[a] Concentration is based on the direct exposure pathway via inhalation, ingestion, and dermal contact.

[b] Concentration is based on the leachability to the groundwater exposure pathway.

2. *Development of Leachability-Based Soil Cleanup Guidelines*

The analysis of the leachate pathway involved the use of computer models to model transport of the contaminant and to estimate safe levels of soil concentration for each compound. Several state petroleum soil management programs (Oregon, Wisconsin, and Massachusetts) were reviewed extensively (Anderson, 1992; MDEP, 1993b; Scott and Hetrick, 1994). These state programs used two models to develop soil cleanup levels. The SEasonal Soil Compartment (SESOIL) model was used to

TABLE 2
Assumptions Used in Developing Risk-Based Soil Cleanup Guidelines

Parameter	Assumptions
Target risk range	1×10^{-6}
Exposure scenario	Residential

Age group (years)	Body weight (kg)	Surface area (cm^2)	Soil ingested (mg/d)	Days exposed (yearly)
2–6	17	2,632	200	160
7–16	40	3,432	100	160
17–31	70	5,044	100	160

[a] Concentration is based on the direct exposure pathway via inhalation, ingestion, and dermal contact.
[b] Concentration is based on the leachability to the groundwater exposure pathway.

model the fate and transport of contaminants through the unsaturated zone down to the water table. Analytical model of transient 1-, 2-, and 3-dimensional waste transport in aquifers (AT123D) was used to simulate the mixing of contaminants in groundwater and transport within the saturated zone.*

A review of the analyses of the models performed by other state programs and analysis of the models using conservative assumptions and input parameters specific to New Hampshire resulted in the discovery that the two most critical parameters controlling the fate and transport of chemicals in an aqueous system were Henry's constant (H) and the organic carbon partition coefficient (K_{oc}). Henry's constant measures the ability of a compound dissolved in water to escape into air. The organic carbon partition coefficient measures the tendency of a compound dissolved in water to sorb onto soil.

The chemicals H and K_{oc} were then used in an empirical equation to calculate the soil cleanup levels for the leachate pathway. This empirical equation, first developed by Anderson (1992), is as follows:

$$\text{Soil/Water} = 0.150 \times K_{oc} + 5690 \times H \quad (1)$$

The resultant soil/water ratio relates a chemical's K_{oc} and H values to the ratio between the initial soil concentration for a given chemical and the maximum concentration of that chemical predicted for the groundwater.

Because the maximum concentration predicted for a chemical in the groundwater can also be viewed as that chemical's health-based safe drinking water standard, Equation 1 can be used to calculate soil cleanup guidelines that would be protective of the groundwater. This was accomplished by assigning the maximum groundwater concentration in Equation 1 to a New Hampshire ambient groundwater quality

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* SESOIL was initially prepared for the USEPA office of Toxic Substance by Arthur D. Little, Inc., of Cambridge, MA, in 1984 (Bonazountas and Wagner, 1984). AT123D was developed by Oak Ridge National Laboratory in 1981 (Odencrantz *et al.,* 1990).

standard (AGQS) and the initial soil concentration in Equation 1 to the soil cleanup level parameter. This produced the following equation:

$$\begin{array}{l} \text{Soil Cleanup} \\ \text{Guidelines} \end{array} = (0.150 \times K_{oc} + 5690 \times H) \times \begin{array}{l} \text{Safe Drinking Water} \\ \text{Standard} \end{array} \tag{2}$$

As conducted by Anderson (1992), ten indicator compounds were simulated in the SESOIL model and then a multiple linear regression model was developed relating the soil cleanup guideline to K_{oc} and H to provide additional soil cleanup guidelines for other chemicals of concern. NHDES concurred with this technique and selected conservative input parameters representative of site conditions in New Hampshire, which are outlined in Table 3.

These input parameters and their associated values were selected because they represented conservative site conditions. For example, soil organic carbon was selected with a value of 0.1%. The soil organic carbon content of soil is the primary controlling factor for the adsorption/retardation of organic compounds in soils. Increased retardation of a contaminant in the soil results in increased contact time with biodegrading organisms and allows for volatilization, which results in less of the contaminant reaching groundwater. However, with a soil organic carbon content value set very low, it was determined that more of a chemical was estimated to reach groundwater. Therefore, along with the other conservative input parameter values and the use of the AT123D model, conservative concentrations for the leachate pathway were produced. The concentrations for the leachate pathway represent the maximum concentration in soil that would not cause a violation of New Hampshire's drinking water standards. Site conditions used in the modeling research are illustrated on Figure 1.

TABLE 3
Representative Input Parameters Used in the SESOIL Model

Parameter	Value
Permeability	1×10^{-7} cm^2
Bulk density	1.5 g/cm^3
Porosity	0.3
Soil organic carbon	0.1%
Hydraulic conductivity	0.5 m/h
Hydraulic gradient	0.005
Longitudinal dispersivity	20 m
Transverse dispersivity	2 m
Vertical dispersivity	2 m
Annual precipitation	Concord data
Initial soil concentration	10 ppm
Volatilization	Vol. fraction = 0.2

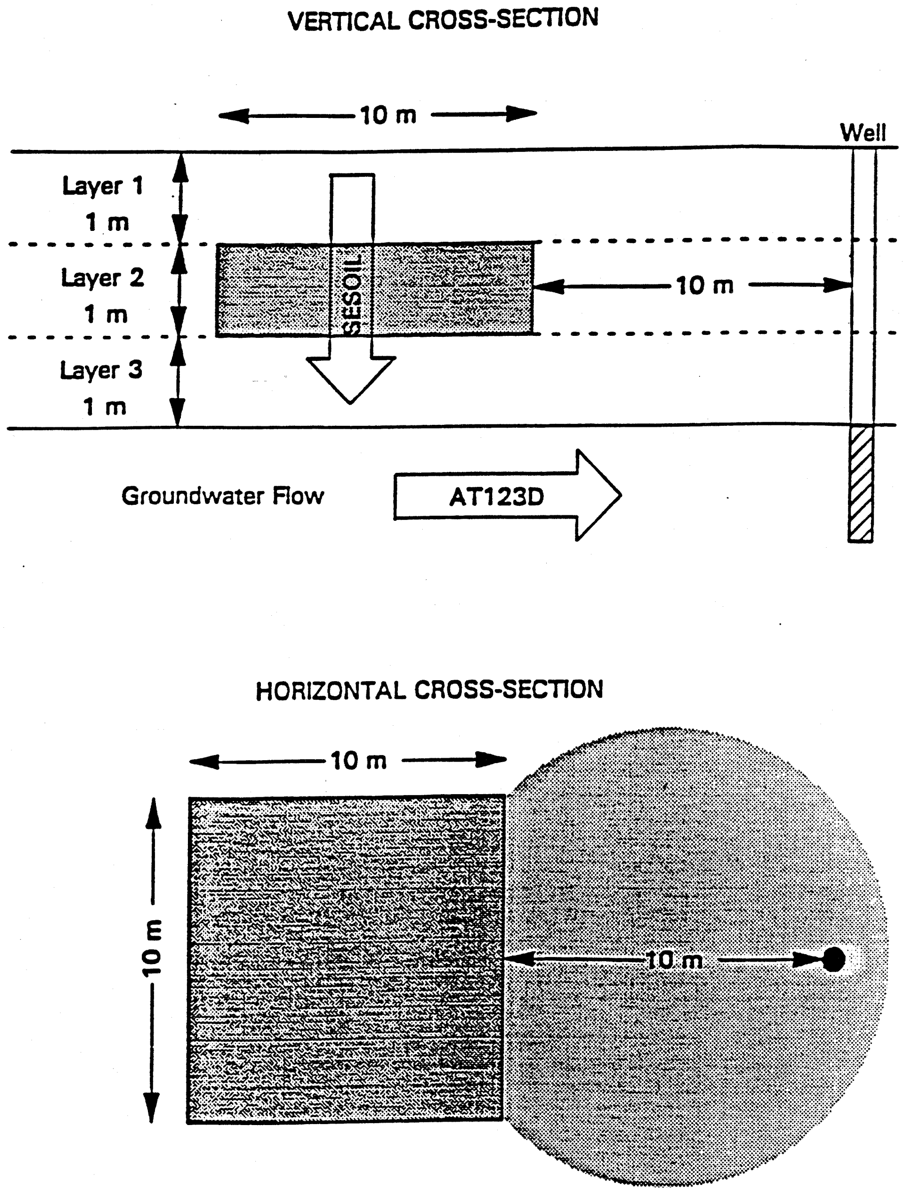

FIGURE 1. Site conditions used for the modeling studies.

3. *Development of a Total Petroleum Hydrocarbon Soil Cleanup Guideline*

As previously mentioned in this article, the use of a TPH measurement as a tool for assisting in a risk-based approach to site cleanup has limited value. Despite this information, use of the TPH measurement was incorporated into New Hampshire's generic soil cleanup guidelines for several reasons. Current available soil sample data were reviewed from numerous sites that indicated it is often the case that individual chemical-specific cleanup guidelines are often not exceeded with corresponding higher TPH values. However, with a greater concentration for the TPH measurement, objectional odors are sometimes present. A cleanup guideline of 10,000 ppm was established to deal with the possibility of any objectional odor from the contaminated soil. It should be noted that soils having TPH values in excess of 10,000 ppm can start to show free product droplets (Bickford, 1994).

Furthermore, the TPH measurement is a good indicator of general petroleum contamination. An initial TPH analysis indicating no contamination can eliminate the need for costly additional analysis. In addition, the option to remove any contaminated soil with a high TPH concentration that does not exceed the chemical-specific cleanup guidelines has been made available for aesthetic reasons.

IV. CASE STUDY

Potential cost savings were calculated as described below that illustrate how cost effective the use of chemical-specific, risk-based cleanup guidelines are. One selected case study, an airport, is explored in detail.

This site was initially operated as a municipal airport since the 1930s. In the 1950s, it was further developed into a military installation. Fifty 55,000-gal. UST that held aviation jet fuel (JP-4) exist at the site. In 1993–94, several UST and associated lines were removed.

VOC concentrations measured in 96 composite soil samples from the site did not exceed the new chemical-specific, risk-based guidelines. PAH concentrations measured in 23 out of 24 composite soil samples did not exceed the new chemical-specific, risk-based guidelines. The soil TPH concentrations measured ranged up to 1700 ppm at depths down to 16 ft. Polyaromatic hydrocarbons (PAH) and VOC concentrations measured in four groundwater samples did not exceed drinking water standards for New Hampshire. In addition, VOC and PAH analysis in groundwater from a municipal well located 2000 ft downgradient from the contaminated soil indicated no petroleum contamination. Because the cleanup was initiated when NHDES had in place the remedial goals developed in 1989, approximately 45,000 t of soil with TPH concentrations greater than 100 ppm was removed and disposed of at a local landfill.

V. DATA SUMMARY

Several typical gasoline service station sites consisting of UST with a capacity ranging from 3000 to 6000 gal and in operation since the 1950s had petroleum-contaminated soil removed due to corrective action. The soil removed ranged up to 8000 tons. Soil TPH concentrations measured at the sites ranged between 50 and 1000 ppm in soil. The soil at these sites was managed under the remedial goals established in 1989. All soil was thermally treated off-site at an average cost of up to $350,000.00 per site. The data summary for these sites is shown in Table 4.

VI. DISCUSSION OF RESULTS

For the case study reviewed in this article, the remedial goals developed in 1989 of 100 ppm for TPH were shown to be overprotective when compared with a chemical-specific, risk-based approach to corrective action. Groundwater was not adversely impacted at the site or at a municipal well located 2000 ft downgradient. On a chemical-specific basis, no VOC or PAH concentrations measured in the site soil exceeded the new chemical-specific, risk-based soil cleanup guidelines except for one sample.

As summarized in Table 4, data from several sites indicate the potential cost savings realized if a chemical-specific, risk-based approach had been implemented at these sites. Contaminated soil from these sites that was ultimately thermally treated at extremely high cost ranged upward to nearly 8000 t. If the soil from the military installation described in the case study had to be thermally treated, the costs for this one site alone would have exceeded $1 million. If the new chemical-specific, risk-based soil cleanup guidelines were in effect at the time of treatment of the soil from these seven sites, over $2 million could have been saved and

TABLE 4
Summary of Potential or Actual Cost Savings from Management of Petroleum-Contaminated Soils

Site name	Tons of soil removed	TPH range (ppm)	Potential cost savings (approx.)[a]
A	1,125	100–400	$73,000
B	2,200	100–1,000	$143,000
C	3,640	100–900	$237,000
D	2,300	100–1,000	$150,000
E	6,122	50–500	$398,000
F	7,932	50–500	$516,000

[a] Includes all average costs for excavation, stockpiling, transportation, treatment, and backfill. Sampling and analysis costs were not included because these costs are incurred during the site investigation phase.

remediation efforts could have been focused on more significant sources of human health or environmental risk.

VII. CONCLUSIONS

The following recommendations/observations are made:

1. At least 32 states have implemented a risk-based approach to the development of soil cleanup guidelines.
2. The use of the total BTEX measurement of the most volatile constituents of petroleum will obscure the real risk posed by these chemicals. Individual analysis of each selected volatile and semivolatile chemical is recommended.
3. The use of the TPH measurement in risk-based corrective action has a limited value. Use of the TPH standard alone at sites may be substantially under- or overprotective, but with a chemical-specific, risk-based approach a more efficient distribution of limited cleanup funds can be achieved.
4. Chemical-specific, risk-based soil cleanup guidelines derived from the use of fate and transport models and risk assessment methods based on conservative criteria can result in lower costs for petroleum-contaminated soil cleanups and at the same time be protective of human health and the environment. This methodology can also demonstrate the negligible risk posed to potential human or environmental exposure pathways when a risk-based site cleanup approach is implemented. Therefore, remediation efforts can focus on more significant sources of human health or environmental risk.
5. SESOIL and AT123D are appropriate models for use in developing generic soil cleanup guidelines that are protective of human health and the environment.

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