Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater

Volume 1: User's Guide

Tropical Pacific Edition

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DISCLAIMER

This report, *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater – Tropical Pacific Edition* (Fall 2016), is a technical guidance document prepared in cooperation with the US Environmental Protection Agency (USEPA), the Commonwealth of the Northern Mariana Islands Division of Environmental Quality (CNMI DEQ) and the Guam Environmental Protection Agency (Guam EPA). The guidance and associated models represent an update to a similar document prepared under the direction of the USEPA and CNMI DEQ in 2005, as well as subsequent updates prepared under the direction of Guam EPA. Similar guidance documents have been prepared for the State of California (CAEPA 2016) and State of Hawai‘i (HDOH 2017a) by the same author (Dr. Roger Brewer). This version of the guidance, referred to as the *Tropical Pacific Edition* (referred to as the “Pacific Basin Edition” in earlier versions), adheres most strictly to USEPA standards and publications and is considered to be the most widely applicable of the three to other areas of the tropical Pacific. Use outside of the tropical Pacific could require adjustment of some screening levels, particularly those associated with vapor intrusion (see Section 4.3.2)

The document provides guidance for identification and evaluation of potential environmental hazards associated with contaminated soil and groundwater. The Environmental Screening Levels (ESLs) presented in this document and the accompanying text are specifically *not* intended to serve as: 1) a stand-alone decision making tool, 2) guidance for the preparation of a baseline environmental risk assessment, 3) a rule to determine if a waste is hazardous under the state or federal regulations, or 4) a rule to determine when the release of hazardous substances must be reported to the overseeing regulatory agency.

The information presented in this document is not final action. The overseeing regulatory agency reserves the right to change this information at any time without public notice. This document will be periodically updated. Please send comments, edits, etc. in writing to the above contacts. The overseeing regulatory agency should be contacted prior to use of this document in order to ensure that the document is applicable to the site under investigation and that the user has the most up-to-date version available. This document is not copyrighted. Copies may be freely made and distributed. It is cautioned, however, that reference to the screening levels presented in this document without adequate review of the accompanying narrative could result in misinterpretation and misuse of the information.

Updates

Nov 6, 2017: Screening levels for BROMO,1,2- CHLOROPROPANE,3- and DIBROMOCHLOROMETHANE (error in soil vapor model) and TRICHLOROPROPANE, 1,2,3- (error in tapwater model) corrected.

ACKNOWLEDGEMENTS

This guidance represents the most recent, Tropical Pacific edition of the original *Risk-Based Corrective Action* document originally published by the Hawai’i Department of Health in 1995. Other editions of this document were prepared by the same author for use as a consultant with Dames and Moore in the mid-1990s and with the California Environmental Protection Agency from 1999 to 2005, followed by periodic updates to the HDOH guidance since returning to Hawai‘i in 2005. The author is deeply indebted to the countless consultants, regulators and private individuals who provided their expertise on thousands of individual projects during this time and continue to do so today. The guidance is an attempt to present their collective expertise in a manner that improves the efficiency and effectiveness of the work we undertake for the mutual benefit of all parties involved.

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Executive Summary

This document presents soil, groundwater and soil vapor screening levels for the rapid identification of potential environmental hazards associated with contaminated soil and groundwater. Guidance is also provided for the preparation of an *Environmental Hazard Evaluation* (EHE) report that summarizes the results of the initial screening and makes recommendations for completion of the site investigation as well as the need remedial actions. Note that the term "hazard" is used in a generic fashion to indicate any potential threat to human health or the environment and not in the strict sense of a noncancer "hazard" used in human health risk assessments.

The Fall 2016 and earlier editions of this guidance (2005, 2008, 2009, 2016) were prepared in cooperation with the US Environmental Protection Agency (USEPA), the Commonwealth of the Northern Mariana Islands Division of Environmental Quality (CNMI DEQ) and the Guam Environmental Protection Agency (Guam EPA). Updates to previous editions of the "EHE guidance" are summarized in Appendix 9. Similar guidance documents have been prepared for the State of California and State of Hawai‘i by the same author (Dr. Roger Brewer). Although prepared specifically for use in CNMI and Guam, the use of well-accepted, US Environmental Agency (USEPA) standards, models and protocols should permit flexible use of the Tropical Pacific edition of the EHE guidance throughout tropical areas of the Pacific region with little or no modification. These areas are characterized by a mean, daily temperature of ≥65ºF throughout the year. Natural ventilation is often preferred for ventilation of residences (ICC 2012).

Use of the EHE guidance outside of tropical region is primarily limited by the need for a more detailed evaluation of subsurface, vapor intrusion hazards in areas where buildings are heated during part of the year. This is due to poorer ventilation during colder periods of the as well as an increased threat of vapor intrusion from contaminated soil or groundwater due to reduced air pressures inside of buildings. More stringent groundwater and soil vapor screening levels for potential vapor intrusion concerns may be required in areas where buildings are heated for much of the year and/or otherwise poorly ventilated and susceptible to intruding vapors. This is discussed in more detail in Section 4.3.2.

Updates to the 2015 and 2009 edition of this guidance are summarized in Appendix 8. These included more stringent screening levels for leaching and groundwater protection concerns in areas of thin soils over bedrock and unconfined aquifers (2015 updates; i.e., less than one-meter or three-feet thick). This primarily affects soil screening levels for organochlorine pesticides, including termiticides like Technical Chlordane and aldrin or dieldrin that would normally be immobile in soil and pose little threat to groundwater. More stringent soil screening levels for Total Petroleum Hydrocarbon (TPH) are also included. Soil vapor screening levels that can be used to evaluate leachate conditions in the vadose zone have also been added. These screening levels should likewise be useful in areas of thin soil cover over bedrock that overlies unconfined aquifers. The screening levels reflect the concentration of a volatile chemical in soil vapor at equilibrium with the chemical in soil moisture at the target groundwater screening level, times a default dilution-attenuation factor of twenty. Updates to the 2015 edition of the ESLs included extensive but relatively minor changes to physiochemical constants used to calculate screening levels, based on updates to the USEPA Regional Screening Levels guidance (USEPA 2017). Changes to the actual screening levels were relatively minor.

Refer to the Hawaii department of Health (HDOH) *Technical Guidance Manual* (TGM) for guidance on the collection and analysis of samples for comparison to EALs (HDOH 2016 and updates). Regulators from CNMI and Guam participated in development of the HDOH guidance. The ESLs apply to the *mean* concentration of the contaminant for the targeted “Decision Unit (DU)” area and volume of media investigated, in the same manner as if the entire DU could be submitted to the laboratory and tested as a single sample. The ESLs are not intended for direct comparison to individual, “discrete” sample data collected within a subarea or volume of a targeted DU beyond simple screening purposes. This is a fundamental principal of sampling theory. This approach is well developed for soil, as discussed in Sections 3, 4 and 5 of the HDOH TGM, with final decisions to be based on Multi Increment sample rather than discrete sample data. Development of methods to better apply the concept of DUs to soil vapor are currently underway. The concept is already well developed for testing of indoor air (refer to Section 7 of the HDOH TGM).

An *Environmental Hazard Evaluation* should be carried out at all sites where contaminated soil or groundwater is identified. A brief but properly prepared EHE will in most cases replace what is traditionally referred to as an environmental “risk assessment.” An important part of the EHE is the use of pre-approved, *Environmental Screening Levels* (ESLs) summarized at the end of Volume 1 and discussed in detail in the appendices, as well as electronic lookup tables referred to as the *ESL Surfer* that accompanies this guidance. The ESLs are used to rapidly screen soil, soil vapor and groundwater data collected for a site and identify potential environmental hazards. Under most circumstances, and within the limitations described, the presence of a chemical in soil, soil vapor or groundwater at concentrations below the corresponding Tier 1 ESL can be assumed to not pose a significant threat to human health and the environment. This allows sites or portions of sites with minimal or no contamination to be quickly cleared of potential environmental hazards, a task which could easily take months or even years using a traditional, environmental risk assessment approach.

The ESLs incorporate an enormous amount of technical expertise across fields as diverse as toxicology, geology, chemistry, physics, ecology, engineering and even economics. Much like driving a car, however, it is not necessarily to understand the technical intricacies of the ESLs in order to use them. Exceeding the Tier 1 ESL for a specific chemical does not necessarily indicate that the contamination poses significant environmental concerns, only that additional evaluation is warranted. As potential problems are identified, internal or external expertise can be brought in to help evaluate and mitigate the problems as needed. A detailed review of specific hazards can be carried out if time- and cost-beneficial, or contamination that exceeds the ESLs can simply be remediated. This can even include the preparation of detailed, site-specific, human health or ecological risk assessments, if necessary.

An EHE serves as the link between site investigation activities and the selection of final response actions. As potential environmental hazards are identified, the site investigation can be modified to ensure that adequate types and amounts of data are collected to understand the extent and nature of potential hazards. For example, additional soil data may be needed to fully evaluate potential direct-exposure hazards soil vapor data may be needed if groundwater or soil data suggest a potential vapor intrusion hazard. Once the site investigation and EHE are completed, *Environmental Hazard Maps* can be prepared to summarize areas of a site where contamination poses specific environmental problems and serve as a tool to help guide and design subsequent remedial efforts. The type of remedial actions required at a site will vary, depending on the nature of the environmental hazards identified and the current and future use of the site.

The following information should be included in an EHE (or included in a report that contains the EHE):

1. **Site History:** Brief summary of the site history and operations that lead to the release of hazardous chemicals;
2. **Past Investigations and Remedial Actions:** Overview of past investigations and remedial actions;
3. **Extent and Magnitude of Contamination:** Summary of the extent and magnitude of contamination in soil, soil vapor and/or groundwater above Tier 1 ESLs, depicted on to-scale maps of the site;

4. **Identification of Potential Environmental Hazards:** Identification of potential environmental hazards by comparison of site soil, soil vapor and/or groundwater data to Tier 1 ESLs and screening levels for specific hazards;
5. **Detailed Evaluation of Specific Environmental Hazards (optional):** Detailed evaluation of specific environmental hazards using approaches described in this document or alternative approaches approved by the overseeing regulatory agency;
6. **Conclusions and Recommendations:** Provides a summary of EHE findings and recommendations for followup actions.

The level of detail needed in the EHE will vary depending on the nature of the contamination and anticipated cleanup actions. A basic EHE should be used to screen for potential environmental hazards, identify data gaps and complete the site investigation. The completed EHE should conclude with recommendations for followup actions, such as no further action, collection of additional data to better evaluate a specific environmental hazard or evaluation of remedial alternatives. At sites where full cleanup is not possible, an EHE that reflects final site conditions should be used to document the extent and magnitude of remaining contamination as well as potential environmental hazards in the absence of institutional or engineered controls. This “as built” EHE serves as the basis for an *Environmental Hazard Management Plan* (EHMP) that describes ongoing measures to be taken to ensure that the contamination is properly managed in the future.

The Tier 1 ESLs presented in the lookup tables are NOT regulatory "cleanup standards". Site-specific screening levels and cleanup levels are, however, subject to the approval of the overseeing regulatory agency. The ESLs presented for chemicals that are known to be highly biodegradable in the environment may be excessively conservative for use as final cleanup levels (e.g., many petroleum-related compounds). Stand alone use of the Tier 1 ESLs may be inadequate in some cases. Examples include sites with a high public profile that cannot be fully cleaned up and require a detailed discussion of potential risks to human health. Other examples include sites where physical conditions differ drastically from those assumed in development of the ESLs (e.g., mine sites, landfills, etc., with excessively high or low pH) and sites where impacts pose heightened threats to sensitive ecological habitats. Use of the ESLs as stand alone screening criteria or final cleanup levels should be evaluated in terms of overall site conditions and potential environmental hazards, the cost/benefit of developing site-specific cleanup levels or preparing a more detailed risk assessment, as well as the pros and cons of full site cleanup versus long–term management.

The *Environmental Hazard Evaluation* approach described in this guidance is applicable to any site where contaminated soil and groundwater are identified, including sites that fall under the purview of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The guidance will be of particular benefit to small-business owners and property owners with limited time and financial resources, for whom the preparation of traditional, Superfund-type risk assessments is generally not feasible or even necessary. The guidance is particularly useful as a rapid and cost-effective tool for the evaluation of brownfield or potential brownfield properties. This guidance will be updated as needed, in order to incorporate changes in the referenced sources as well as lessons gained from site investigation and response actions. Comments and suggestions are welcome at any time and should be submitted to the contacts noted at the beginning of this document.

1

Introduction

1.1 Environmental Hazard Evaluation

Environmental Hazard Evaluation (EHE) is the link between the discovery of contaminated soil or groundwater during the *site investigation* and *response actions* taken to address this contamination (Figure 1-1). Note that the term "hazard" is used in a generic fashion to indicate any potential threat to human health or the environment and not in the strict sense of a noncancer "hazard" used in human health risk assessments. During this step of the overall environmental response process, the significance of potential environmental hazards associated with the contamination is determined. This is carried out initially by comparison of soil, groundwater and/or soil vapor data to pre-approved, Environmental Screening Levels (ESLs) presented in Tables A through H at the end of this volume. If potential concerns are confirmed then the specific hazards posed by the contamination are identified, the need for additional data to complete the site investigation is determined and the preparation of appropriate remedial actions is recommended.

Once the site has been adequately characterized, the most appropriate remedial action is determined. For sites where the extent of contamination is minimal or time is of the essence, the most cost-beneficial response may be the immediate removal of the contaminated media. In other cases, the potential cost of remediation or difficulty in accessing the contamination could preclude a complete cleanup. An advanced evaluation of specific environmental hazards is usually warranted at such sites. This may involve the development of site-specific cleanup levels and remedial actions to address the most pressing hazards (e.g., discharges of free product into storm sewers or vapor intrusion into overlying buildings). The extent and magnitude of the remaining contamination and the specific environmental hazards posed by the contamination is then documented in final site investigation and environmental hazard evaluation report. This is then used to prepare an *Environmental Hazard Management Plan* (EHMP) that presents guidelines for long-term management of the contamination and associated institutional and engineered controls.

Environmental Hazard Evaluations are therefore an integral part of site investigations and remedial actions. Site investigations and remedial actions carried out in the absence of a basic understanding of the environmental hazards posed by contaminated soil or groundwater run the risk of being incomplete. This can result in later, unanticipated requirements for additional actions and unnecessary delays and costs needed to bring the property back into productive use. The guidance presented in this document is intended to help avoid such surprises and make the investigation, evaluation and remedial action process as effective and efficient as possible.

1.2 Targeted Environmental Hazards

A basic understanding of environmental hazards associated with contaminated soil and groundwater is critical in the overall environmental response process (see Figure 1-1). Common environmental hazards that should be initially screened for at all contaminated sites include:

Soil:

- Direct-exposure threats to human health;
- Intrusion of subsurface vapors into buildings;
- Leaching and subsequent threats to groundwater resources;
- Gross contamination and general resource degradation concerns;

Groundwater:

- Threats to drinking water resources;
- Threats to aquatic habitats;
- Intrusion of subsurface vapors into buildings;
- Gross contamination and general resource degradation concerns.

For use in this document, the term "soil" refers to any unconsolidated material found in the subsurface, including actual soil, saprolite, sediment, fill material, etc. Soil data should be reported on dry-weight basis (see Appendix 1, Section 7.2). Tier 1 Environmental Screening Levels (ESLs) for soil presented in this guidance are *not* directly applicable to soil that is situated within the capillary fringe zone or below the water table (refer to following section and Section 2.2.4).

The soil screening levels are also not applicable to samples of rock or other solid media. If little to no soil is present within a targeted area then no further action with regards to soil contamination is required (e.g., contaminated soil removed down to bedrock to the extent practicable, with less than a few cubic yards/meters of soil left in place in isolated low areas or fractures).

For comparison, the minimum Decision Unit volume of soil recommended for characterization is 20 cubic yards (HDOH 2016). Although proper management might still be required, for example disposal of grossly contaminated soil disturbed during construction projects, smaller volumes of contaminated soil are not anticipated to pose a significant, long-term risk to human health and the environment under typical site scenarios and no further action under direct, HDOH oversight is warranted. Potential exceptions include the use of contaminated soil in small play areas used by young children. This does not necessarily imply that small volumes of heavily impacted soil do not pose a potential environmental concern, since the presence of isolated “hot areas” within a larger DU can cause the DU as a whole to fail EALs.

Past editions of the EHE guidance included soil screening levels for potential impacts to terrestrial flora and fauna, published by various environmental agencies. Screening levels were available for common metals as well as a short list of pesticides and polynuclear aromatic hydrocarbon compounds (PAHs). Use of the screening levels was discontinued in the 2012 edition of the guidance. Studies used to develop the screening levels also did not reflect typical flora and fauna of the tropical Pacific area. The screening levels also did not take into account naturally occurring metals in soil with very low bioavailability. Site-specific, ecological risk assessments are now recommended when contamination at a site threatens a sensitive, ecological habitat.

A brief description of each environmental hazard incorporated into the ESLs is provided in Figure 1-2a. A schematic of common, potential environmental hazards associated with contaminated soil and groundwater is depicted in Figure 1-2b. Detailed discussions of each hazard are provided in Chapters 3 and 4 and in Appendix 1. Additional site-specific environmental hazards that may need to be reviewed on a site-specific basis include the uptake of contaminants in garden produce and the erosion and runoff of contaminated soil into nearby surface water bodies.

Note that several of the environmental hazards listed above are not necessarily “risk-based,” at least in the traditional regulatory use of this term. For example, soil that is grossly contaminated with petroleum may not pose a toxicological risk to future residents, but it could pose significant odor and nuisance concerns and in some cases even result in explosive levels of vapors in soil vapor. Although it may seem counterintuitive, it is quite possible (and unfortunately common) for traditional, human health risk assessments to conclude that soil is “nontoxic,” even though the soil would ignite if a match was dropped on it. Nevertheless, the fact that the soil is flammable is clearly important to identify and discuss in the environmental hazard evaluation. Gross contamination can also complicate future construction or subsurface utility activities that require disturbance of heavily contaminated soil or groundwater. Leaching of contaminants from soil into groundwater is also important to consider, even though this is often neglected in traditional risk assessments. Discharges of contaminated groundwater or free product into surface water bodies, either naturally or via seepage into storm sewers or via discharge during construction-related dewatering activities, can likewise pose significant environmental hazards to aquatic habitats.

The environmental hazard that drives the potential need for remedial action at a contaminated site depends on the toxicity and mobility of the targeted contaminants (refer to Appendix 1). Soil contaminated with chemicals that are that are highly toxic to humans and relatively immobile (e.g., arsenic, lead, PCBs, etc.) will generally be flagged as posing potential direct exposure hazards. Soil contaminated with volatile chemicals that are potential carcinogens (e.g., benzene, PCE, TPH gasoline, methane, etc.) are typically identified as posing potential vapor intrusion hazards. Soil contaminated with petroleum, solvents or highly mobile pesticides (e.g., TPH gasoline or diesel, BTEX, PCE, atrazine, etc.) will often be identified as posing potential leaching hazards. Soil contaminated with pesticides or metals that are relatively non-toxic to humans (e.g., barium, copper, nickel, etc.) can pose significant toxicity hazards to terrestrial flora and fauna.

Drinking water toxicity hazards are almost always identified for aquifers contaminated with hazardous chemicals. As is the case for soil, vapor intrusion hazards will often be identified for groundwater contaminated with carcinogenic, volatile chemicals. A number of chemicals pose potential aquatic toxicity hazards at relatively low concentrations, if the groundwater were to discharge into a sensitive aquatic habitat. Free product on groundwater poses gross contamination hazards that could lead to sheens or odor in surface water if allowed to migrate offsite (as well as vapor hazards). Gross contamination hazards could also be identified for drinking water contaminated with chemicals that have a low taste and odor threshold (e.g., TPH, ethylbenzene, toluene, xylenes, MTBE).

1.3 Tier 1 Environmental Screening Levels

Tier 1 *Environmental Screening Levels* (Tier 1 ESLs) are concentrations of contaminants in soil, soil vapor and groundwater above which the contaminants could pose a potential adverse threat to human health and the environmental. Figure 1-3 summarizes the use of the Tier 1 ESLs. Exceeding the Tier 1 ESL does not necessarily indicate that contamination at the site poses environmental hazards. It does, however, indicate that additional evaluation is warranted. This can include additional site investigation and a more detailed evaluation of the specific, tentatively identified hazards. The screening levels, or approved alternatives, can be used to delineate specific areas of the site that require remedial actions. These actions can vary, depending on the hazard present and site conditions. An overview of the development of the Tier 1 ESLs is provided in Chapter 2. A detailed discussion of the compilation and development of the ESLs is provided in Appendix 1.

1.3.1 ESL Surfer

The ESL Surfer, an Excel-based version of the lookup up tables, makes use of the ESLs and the identification of potential environmental hazards at contaminated sites especially easy. The ESLs should be rounded to two significant digits for comparison to site data. A link to this guidance document as well as the Surfer and related material is provided on the Hawai‘i DOH web page. Use of the Surfer in Environmental Hazard Evaluation reports is highly recommended. Guidance on use of the Surfer and example printouts are provided in Chapter 3.

1.3.2 Use of ESLs in Site Investigations

One of the most basic uses of the ESLs is to identify potential contaminant of concern (COPCs) and guide completion of the site investigation. The initial list of COPCs established during a review of past site operations can be quickly narrowed down by direct comparison of soil and groundwater data to the Tier 1 ESLs. Further consideration of contaminants that do not exceed Tier 1 ESLs is not necessary. This assumes of course that existing data are representative of overall site conditions.

The lateral and vertical extent of contamination should be determined for COPCs that exceed the Tier 1 ESLs (or approved, alternative screening levels). Delineation of the extent of contamination to laboratory reporting or detection limits is often impracticable and, from a hazard evaluation standpoint, unnecessary. The investigation can be considered complete once the extent of contamination in excess of Tier 1 ESLs (or approved alternatives) is accomplished. The use of field screening methods, mobile labs and quick turnarounds in laboratory analyses will help expedite the completion of site investigation activities.

Conservative, Tier 1 screening levels for future, unrestricted land use, should be used to initially determine the extent of contamination on a property, even if the property will be used for commercial/industrial purposes for the foreseeable future. Long-term management of contaminated soil that exceeds ESLs for unrestricted land use but not commercial/industrial landuse will be required to avoid inappropriate removal and offsite reuse in the future, even if the soil is not included in active remediation. Refer to the HDOH document *Guidance for Soil Stockpile Characterization and Evaluation of Imported and Exported Fill Materia*l (HDOH 2017b) for additional information.

The identification of potential environmental hazards should begin as soon as the first data are received. This will help identify the need for alternative types of data that will be required for more detailed evaluations of specific hazards and completion of the site investigation. For example, if arsenic is reported in soil at concentrations above 20 mg/kg then laboratory bioaccessibility tests should be run on the same sample (refer to Chapter 4). If the reported concentration of volatile contaminants exceed screening levels for vapor intrusion concerns then soil vapor data should be collected. Incorporating these decisions rules in the sampling and analysis plan will help expedite completion of the site investigation as well identify potentially significant environmental hazards at the site that could require immediate action.

1.3.3 Use of ESLs in Environmental Hazard Evaluations

The most important use of the Tier 1 ESLs is the rapid identification of potential environmental hazards associated with contaminated soil and groundwater (refer to Section 3.1). With the exception of gross contamination, most of the environmental hazards noted earlier are not obvious in the field. An initial comparison of site data to the Tier 1 ESLs provided in Tables A through H will only indicate if a potential hazard is present (i.e., “yes” or “no”). If the Tier 1 ESL is exceeded, site data should be compared to the detailed screening levels used to develop the Tier 1 ESL. The specific, potential environmental hazard(s) associated with the contaminant can then be identified. This process is described in more detail in Chapter 3. As discussed above, use of the ESL Surfer will significantly expedite this process.

Potential environmental hazards identified in a Tier 1, screening level Environmental Hazard Evaluation can be evaluated on a more site-specific basis as needed (refer to Chapters 3 and 4). The information gained can be used to better define the need for additional site investigation as well as to help develop appropriate remedial options. The level of effort required for advanced evaluations can vary greatly. For example, only a minimal level of effort may be needed to rule out potential hazards to terrestrial ecological habitats at a highly developed commercial or industrial site that does not contain significant natural habitat. Vapor intrusion is typically a potential hazard at VOC contaminated sites where occupied structures are present (or proposed). The collection of soil vapor data at these sites can be highly useful and in some cases required. A detailed review of groundwater data can replace soil screening levels for leaching hazards at sites that have remained uncapped for a sufficiently long period of time for worst-case groundwater impacts to take place. Soil vapor data can also be used as an alternative to soil data for evaluation of leaching hazards posed by volatile chemicals in leachate. This is especially useful in cases where leachate or actual product has entered bedrock and soil samples cannot be collected (see Chapter 4).

1.3.4 Use of ESLs in Remedial Actions

In cases where contamination is limited, easily accessible and time is of the essence, it can be more cost-effective to aggressively remediate the impacted soil or groundwater to the Tier 1 ESLs. The Tier 1 ESLs are not strict cleanup standards, however, and should not be used as such. In cases where cleanup costs could be significant or complete cleanup is not practicable, the choice is not so clear and a more advanced evaluation of specific environmental hazards is usually warranted (refer to Chapters 3 and 4). Use of the detailed ESLs presented in Appendix 1 of this guidance and, in particular, use of the accompanying *ESL Surfer*, makes the identification of specific, potential environmental hazards relatively quick and easy. The information gained can then be used to evaluate specific environmental hazards in more detail and develop more efficient remedial actions.

Long-term management will be required for sites where contaminated soil and groundwater cannot be remediated in a relatively short time frame. In such cases, the detailed screening levels presented in this guidance (or acceptable alternatives) should be used to delineate areas of contaminated soil and groundwater that will require long-term management as well identify as the specific environmental hazards posed by the contamination under uncontrolled site conditions. Specific actions required to address these hazards should then be described in an *Environmental Hazard Management Plan* (EHMP). An overview of EHMPs is presented in Chapter 5.

1.4 Decision Unit and Multi Increment Investigation Strategies

The use of *Decision Unit* (DU) and *Multi Increment Sample* (MIS) site investigation strategies in conjunction with the ESLs is strongly encouraged. Discrete soil investigations, where decisions are often made on only a few grams of soil tested from a single location, are highly prone to under estimate the average concentration of contaminants within targeted areas as well as the lateral and vertical extent of contamination above levels of potential concern. Properly implemented, DU and MIS investigation approaches provide much more useful and defensible data for the assessment and ultimate remediation of contaminated sites over traditional, discrete sampling approaches.

A detailed overview of the background and field implementation of DU-MIS approaches is provided in the Hawai'i Department of Health *Technical Guidance Manual* (HDOH 2016). Related guidance on incremental sampling approaches has been published by the Interstate Technology and Regulatory Council guidance document *Incremental Sampling Methodology* ("ISM," ITRC 2012). The Hawai'i guidance provides a more detailed discussion of implementation of DU-MIS approaches in the field.

1.4.1 Decision Units

A Decision Unit (DU) is an area where a decision is to be made regarding the extent and magnitude of contaminants with respect to the potential environmental hazards posed by the existing or anticipated future exposure to contaminants (Ramsey and Hewitt 2005). Establishing decision units early in the site investigation design helps develop an effective sampling approach and ensure that adequate data are available to prepare an Environmental Hazard Evaluation report (see Chapter 3). In simple terms, a DU represents the area and volume of soil that you would send to the lab for analysis as a single sample if you could. This isn't usually practical in the field, so a subsample of the soil must be collected. This is carried out by the collection of a Multi Increment sample. Strictly speaking, a decision unit is really a volume rather than area of soil (or water), since the resulting data will necessarily apply to a specific depth as well as area of soil.

Designation of DUs is not dependent on the sampling method used to characterize the targeted area and volume of soil and is necessary for both Multi Increment and discrete sampling approaches. The selection of DUs is unique to each site and is dependent in part on the specific type of environmental hazard under investigation (refer to Section 1.2). Decision units generally fall into two categories: 1) Exposure Areas and 2) Spill Areas (referred to as “source areas” in the 2012 ITRC guidance). The appropriate type, size, shape and number of DUs for a given project is necessarily site-specific and must take into consideration the historical, current and future use of the site.

1.4.1.1 DUs Associated with Exposure Areas

The most appropriate decision unit for relatively immobile contaminants that primarily pose direct-exposure, toxicity-based hazards is the assumed exposure area (e.g., lead, arsenic, dioxins or PCBs or PAHs, etc.; refer to Section 1.2). “Exposure areas” are open, unpaved areas of a property frequented by residents or workers who may come in contact with contaminants in soil on a regular basis. Examples residential yards, schoolyard, playgrounds, gardens, open areas on commercial/industrial properties, etc. For these types of DUs, the primary question is “What is the representative concentration of target contaminants across the exposure area as a whole?” The DUs could be based on current property use (e.g., an open area of a commercial or industrial site) and/or or future use of the property (e.g., assumed hypothetical residential lots).

The size of exposure-area DUs for commercial or industrial sites should be based on the location of exposed areas of soil and use of the site by workers. DUs based on exposure areas for residential properties usually encompass the entire yard and/or open, unpaved common areas in high-density developments. For future redevelopment projects that involve single-family homes, the size of a hypothetical residential lot is generally assumed to be 5,000 ft^2 or less (see HDOH 2016). A site should be investigated and remediated in a manner that allows unrestricted, future land use (e.g., residential; refer to Section 2.8). This may not be practical if the additional costs would be significant or if the site is located in an area that will remain highly industrialized for the foreseeable future.

The concentration of contaminants in small spill areas or “hot spots” within the DU itself is not important, nor is the exact location of these areas. This is an important point. The objective of the investigation is estimate the *mean* contaminant concentration for the targeted area and volume of soil as a whole. The object is never to identify the “maximum” contaminant concentration within the DU, which at some aliquot size (e.g., a few micrograms) will be either “zero” or “one-million-parts-per-million” and has no bearing on the assessment of chronic health risks. It is essential, however, to incorporate a representative range of potential contaminant concentrations in the sample data collected for the DU in order to estimate the mean. As discussed in Section 4.3, this is best accomplished by the collection of a

Multi Increment (versus discrete) sample or samples across the DU. Examples of DUs based on exposure areas are included in later parts of this section.

Decision units based on exposure areas can also be established for ecological risk assessments. Detailed guidance for the preparation of ecological risk assessments is not included in this guidance at this time.

1.4.1.2 DUs Associated with Spill Areas

Spill areas are localized areas where the release of a contaminant is known or suspected to have occurred. Examples include areas with obviously contaminated and stained soils, unpaved areas used to store or mix hazardous chemicals, known waste disposal areas, areas immediately adjacent to transformer pads or other types of equipment that may have contained hazardous chemicals, releases from pipelines, etc.

The isolation and evaluation of individual spill areas is generally necessary to evaluate environmental hazards associated with soil leaching, vapor intrusion and gross contamination hazards (refer to Section 1.2). This applies to most releases of petroleum, solvents and highly mobile pesticides like atrazine and ametryn. In these cases, the appropriate question is “What is the representative concentration of the contaminant(s) within the spill area itself?”

If the target contaminant at the site poses one or more of these potential concerns, then the spill area itself should be established as a separate decision unit. For example, a spill area associated with a petroleum release around an aboveground storage tank should be identified as a separate DU and appropriate investigated. This is because petroleum contamination can pose a multiple of environmental hazards, included leaching of contamination of subsurface groundwater resources, intrusion of vapors into overlying buildings and nuisance or even explosion hazards associated with grossly contaminated soil. It is inappropriate to incorporate data outside of the spill area in the evaluation of these types of hazards.

Consideration of individual spill areas as separate DUs may also be important if the target contaminant poses potential direct exposure hazards and there is a chance that contaminated soil could be excavated and spread out during future construction activities. For example, PCB-contaminated soil in the immediate vicinity of a transformer pad may not in itself pose direct exposure hazards to workers given the current, assumed exposure area. Under a future redevelopment scenario, however, the soil could feasibly be excavated and spread out over a much larger area. This could result in a dramatic increase in the representative concentration of a contaminant across a DU. Other examples of DUs based on spill areas are described later in this section.

1.4.1.3 Evaluation of DU Data

Data collected from DUs are evaluated in an Environmental Hazard Evaluation report (refer to Chapter 2). When using a decision unit strategy, the entire area of a decision unit is acted upon as a single entity based on the data collected from that unit, regardless of internal variation. If the data indicate that remediation is required, then this applies to the entire decision unit. If the decision outcome is "contaminated", then the entire area of the DU is treated as being contaminated. If the outcome is "not contaminated", then the entire area of the DU is treated as being not contaminated. As discussed above, this makes it important during the selection of decision units to segregate areas of obvious, heavy contamination into DUs separate from areas presumed to be uncontaminated in order to reduce the volume of soil or groundwater that may be identified as "contaminated" and therefore require treatment.

Alternative approaches for the use of decision unit strategies at very large sites (e.g., >50 acres) are discussed in the HDOH guidance for pesticide-contaminated sites provided in Appendix 8 and the HDOH *Technical Guidance Manual* (HDOH 2016). For example, testing of every lot in a very large residential development project on former industrial or agricultural land can be very expensive. To reduce sampling costs, initial screening of the area on the scale of large, neighborhood-scale decision units is recommended. More detailed investigation can then be carried out on randomly selected decision units the size of hypothetical residential lots. This approach can expedite the investigation and clearance of large tracts of land while also providing a relatively high degree of confidence in the data collected.

1.4.2 Multi Increment Samples

Multi Increment samples should be collected from selected decision units whenever practicable (see HDOH 2016 and updates). This sampling approach reduces the variability and improves the reliability of decision unit data in comparison to conventional, discrete sampling strategies. Thirty to fifty small *increments* of soil (typically 10 to 50 grams per increment) are collected from each specific decision unit of interest (see previous section). A greater number of increments is necessary to characterize sites where the contaminant may be present in small, highly concentrated "nuggets." This is often the case for explosives, lead associated with firing ranges or chips of lead-based paint and for chemicals such as PCBs that tend to form clumps when the parent media evaporates or degrades.

The increments are collected in a stratified-random manner (e.g., by collecting increments while walking up and down adjacent rows) and physically combined into one sample. The combined sample is analyzed to obtain a representative contaminant concentration for the entire decision unit. Multi Increment sampling data typically have low variability and high reproducibility, which results in a high level of confidence for decision-making. Three Multi Increment samples, referred to as field replicate samples or *triplicates*, should be collected in 10% of the decision units being tested (minimum one set of triplicate samples per site). Data for the replicate samples can be statistically compared, if necessary, in order to evaluate the precision of the field sampling methodology used at the site.

The mass of a Multi Increment sample needed to adequately represent a targeted area and volume of soil is based a number of factors, including the range of particle sizes, and generally ranges from 500 to 2,000 grams (see HDOH 2016, ITRC 2012). The laboratory dries the sample, and sieves it to <2mm particle size (this may also be done in the field). To obtain a representative subsample, the field sample must be processed so that the entire "population" of soil particles is accessible for collection. Sub-sampling can be accomplished with a sectoral splitter or by collecting a Multi Increment sample using the same approach as used to collect the field sample but with smaller tools and increment masses. A minimum subsample mass of ten grams is recommended in order to reduce lab fundamental error due to the range of particle sizes being tested. Note that this is greater than typically called for in some USEPA laboratory methods, especially for metals. Handling and analysis of a larger subsample mass should be discussed ahead of time with the laboratory. Replicates can be used to verify accurate subsampling and analysis by the laboratory.

Multi Increment samples can be collected for both nonvolatile and volatile contaminant analyses. When collecting samples for volatile contaminants, increments must be placed into an extraction solution in the field (e.g. methanol) in order to prevent VOC loss. Alternative methods are also allowable. Refer to Section 4 of the HDOH Technical Guidance Manual for addition information on the collection of MI samples to be tested for VOCs (HDOH 2016).

1.5 Guidance Organization

Volume 1 of this guidance document is kept intentionally brief and as non-technical as possible. The scope and use of the Tier 1 ESLs is summarized in Chapter 2. Chapter 3 discusses the preparation of basic *Environmental Hazard Evaluations*. Chapter 4 presents mode advanced approaches for the evaluation of specific environmental hazards. The final chapter provides guidance for the long-term management of contaminated sites that cannot be easily remediated, with a focus on petroleum-related contamination. Technical details regarding the compilation and development of the Tier 1 ESLs are discussed in a series of appendices presented in Volume 2. The ESL Surfer and advanced models that accompany this guidance document are available for download from the Hawai‘i DOH website (see also contact information for CNMI DEQ and Guam EPA at front of document).

1.6 Limitations

The Tier 1 ESLs presented in the lookup tables are NOT required, regulatory "cleanup standards". Use of the ESLs as actual cleanup levels should be evaluated in view of the overall site investigation results and the cost/benefit of performing a more detailed environmental risk assessment. The ESLs are intended to be conservative for use at the vast majority of impacted sites in developed areas. As discussed in Chapter 4, however, stand-alone use of the EHE approach may not be appropriate for final assessment of all sites. Examples include:

- High profile sites that cannot be fully cleaned up and warrant a detailed, traditional human health or ecological risk assessment;

- Sites where more than ten known or suspected carcinogens or more than five chemicals with similar noncarcinogenic health effects have been identified (potential cumulative risk concerns even if no individual EAL exceeded; see section 2.9 for details);

- Sites with very thin soil covers and sites with deep, vadose-zone volatile contamination (refer to additional soil and soil vapor screening levels for leaching concerns in Tables E and F);

- Sites where inorganic chemicals (e.g., metals) are potentially mobile in leachate due to soil or groundwater conditions different than those assumed in leaching models used to develop the lookup tables (e.g., very low or very high pH conditions at mine or landfill sites; laboratory batch tests recommended to evaluate leaching of metals from soil);

- Sites where contaminated soil that might otherwise not be remediated poses a risk to sensitive, terrestrial ecological habitats; and

- Sites affected by tides, rivers, streams, heavy rainfall, etc. where there is a potential for erosion of soil and concentration of contaminants in aquatic habitats through transport and deposition of contaminated soil particles (runoff of contaminated soil to aquatic habitats not considered in ESLs).

The need for detailed human health or ecological risk assessments in these cases should be discussed with the overseeing regulatory agency on a site-by-site basis. Consideration of cumulative risk for petroleum-contaminated soil or groundwater is not required unless specifically requested by HDOH, since cumulative risk is directly incorporated into action levels for TPH.

Soil ESLs do not consider potential water- or wind-related erosion and deposition of contaminated particles in a sensitive ecological habitat. This may especially be of concern for contaminants that are known to be bioaccumulative in aquatic organisms (e.g., mercury, PCBs and organochlorine pesticides) or heavy metals that are only moderately toxic to humans but highly toxic to aquatic and terrestrial biota (e.g., copper). At sites that pose an elevated threat to sensitive aquatic habitats, measures should be taken to mitigate potential erosion and runoff concerns.

Evaluation of landfills and sites impacted by mine wastes may in particular require a more detailed evaluation of contaminant fate and transport in soil and groundwater, as well as groundwater-surface water interactions, due to low pH issues. Screening levels for leaching of metals in soil are not considered reliable and are not included in the Tier 1 ESLs. Lab-based methods to evaluate this potential hazard are discussed in Chapter 4.

It is conceivable that soil, groundwater and soil vapor screening levels developed to address the emission of chlorinated volatile organic compounds to indoor air may not be adequately conservative in some cases. This is most likely to occur in enclosed buildings sites with poor ventilation designs or buildings with flooded basements. In all likelihood, however, health risks posed by contamination f indoor air by sources within the subject building (e.g., cleaners, glues, furniture, etc.) will far outweigh the risk posed by intruding vapors under these circumstances. Additional guidance on the site-specific evaluation of vapor intrusion hazards is provided in Chapter 4.

The groundwater screening levels presented in the lookup tables do not directly address the impact of long-term discharges of contaminated groundwater on sediment quality. The accumulation of potentially toxic metals in sediment over time could require a more detailed evaluation at some sites. The buildup of highly-sorptive (lipophilic), organic contaminants in sediment over time could likewise be a concern for petroleum-contaminated sites that are immediately adjacent to sensitive aquatic habitats (e.g., PAHs and other heavy petroleum compounds).

Direct-exposure action levels for construction and utility trench workers are presented in Appendix 1, Table K-3.. The action levels consider ingestion and dermal contact with contaminated soil as well as the inhalation of vapors and dust for 120 days a year over several years (see Appendix 1, Section 4.2 and Appendix 2). Construction/Trench Worker action levels are consistently higher than direct-exposure action levels for unrestricted land use, which consider long-term exposure of young children to contaminants in soil (see Appendix 1, Table K-1). Action levels for numerous metals and in some cases VOCs are lower than comparative action levels for commercial/industrial land use and take precedence over the latter for screening of commercial/industrial sites (see Appendix 1, Table I-2). This is due to an assumed greater exposure to dust and vapors posed to construction and trench workers during work activities, even though exposure is assumed to occur over a fewer number of days per year. In addition, *the model used to evaluate inhalation of vapors does not fully consider soil that is being disturbed during excavation or exposed in trenches, however.* **Actions to minimize exposure of workers to volatile contaminants in soil during construction or trench-related activities should be included in a properly prepared health and safety plan.**

2

Environmental Screening Levels

2.1 Introduction

Tier 1 *Environmental Hazard Evaluations* are based the use of pre-approved, *environmental screening levels* (Tier 1 ESLs) to screen soil, soil vapor and groundwater data for potential environmental hazards. Tier 1 ESLs for soil and groundwater are summarized in Tables A through D. Additional soil screening levels for leaching of contaminants at sites with very thin (<1m) soil cover over bedrock are presented in Table E. Soil vapor screening levels for evaluation of vadose-zone, leachate condition and potential threats to groundwater from migrating, volatile contaminants are presented in Table F. Soil vapor and indoor air for potential vapor intrusion hazards are presented in Table G. Surface water screening levels are presented in Table H. A detailed discussion of the Tier 1 ESLs is provided in Appendix 1.

The presence or absence of potential environmental hazards is determined by the direct comparison of representative site data to the Tier 1 ESLs. Exceeding the Tier 1 ESL for a specific chemical does not necessarily indicate that the contamination poses a significant threat to human health or the environment, only that additional evaluation is warranted. The level of detail required for the additional evaluation will vary. In some cases it may be more cost-beneficial to simply remediate the site to the Tier 1 ESLs than to conduct an advanced evaluation. A more detailed evaluation of specific environmental hazards is generally warranted in cases where significant cleanup costs may be incurred, where public sensitivity of the site is high or where long-term, *in-situ* management of the contamination is being considered.

More advanced approaches for evaluating specific hazards are presented in Chapter 4. The advanced approaches range from relatively simple methods that do not require significant expertise in the specific hazard under investigation to very complex methods that will require a high level of technical expertise. It is anticipated, however, that only a very small number of sites will warrant highly technical and detailed environmental hazard evaluations.

The ESL Surfer (Excel-based electronic lookup tables) included with this guidance provides a quick and easy method to screen site data and, as needed, identify specific, potential environmental hazards. Sample printouts from the Surfer are included in the appendices of the EHE report for reference. **Use of the ESL Surfer to prepare *Environmental Hazard Evaluations* is strongly recommended.**

2.2 Default Conceptual Site Models

The Tier 1 ESL lookup tables are organized to reflect three of the most important factors that control the magnitude of environmental hazards posed by contaminated soil and groundwater:

- Accessibility of the impacted soil (e.g., currently or potentially exposed at the ground surface versus isolated in the subsurface);
- Beneficial use of the groundwater immediately underlying the site or otherwise potentially threatened by the release (e.g., drinking water resource threatened versus no drinking water resource threatened);
- Current and anticipated future use of the site (e.g., residential land use permitted or commercial/industrial land use only).

These factors are incorporated into a total of eight *conceptual site models* (CSM) that describe default site conditions used to develop the Tier 1 ESLs. The CSM and associated Tier 1 ESLs that most directly applies to the site under investigation are selected to screen for potential environmental hazards. The CSMs are based on four initial site scenarios:

	Drinking Water Resource Threatened	Drinking Water Resource NOT Threatened
Shallow soils	A	B
Deep soils	C	D

A. Contaminated soil within three meters of ground surface ("Shallow Soils"), groundwater is a current or potential source of drinking water;

B. Contaminated soil within three meters of ground surface ("Shallow Soils"), groundwater is *not* a current or potential source of drinking water;

C. Contaminated soil *not* within three meters of ground surface ("Deep Soils"), groundwater is a current or potential source of drinking water; and

D. Contaminated soil *not* within three meters of ground surface ("Deep Soils"), groundwater is *not* a current or potential source of drinking water.

The lookup tables for soil and groundwater Tier 1 ESLs are organized with respect to the same site scenarios (refer to Tables A-D). Separate soil screening levels are then provided in each table for unrestricted (e.g., residential) versus commercial/industrial land-use scenarios. Note that the final Tier 1 ESL will not vary for differing land uses if the driving environmental hazard is tied soil leaching of contaminants from soil and contamination of underlying groundwater resources (refer to Section 1.2). For deep soils (Tables C and D), the Tier 1 ESLs only vary if vapor intrusion is the driving environmental hazards. Screening levels for other environmental hazards are otherwise identical (refer to Appendix 1).

The Tier 1 ESLs for exposed (shallow) soils assume that contaminated soil is present at the ground surface or could be excavated and spread out at the ground surface at some time in the future. The ESLs further assume that there are no restrictions on current or future use of the property, including potential use as residential housing, schools, day care, health care, etc. This approach minimizes the need for restrictions on future site use, including the export of soil for reuse in offsite areas, and highlight soils that must be properly managed if complete remediation to unrestricted future use is not feasible (refer to HDOH 2017b).

Alternative soil screening levels for sites that will be restricted to commercial/industrial use only are included in Appendix 1 and included in the ESL Surfer (refer to Chapter 3). Use of these screening levels for final site closure should be discussed with the overseeing regulatory agency on a case-by-case basis, however, and could require the implementation of formal engineered and institutional controls.

The presence of a very thin soil cover over an unconfined, bedrock aquifer exacerbates the vulnerability of the groundwater (defined as <1m thick; e.g., soil over northern, carbonate platform area of Guam.). With respect to the default, Tier 1 ESLs, this is primarily of concern for moderately sorptive chemicals that are essentially immobile in thick soils. Examples include organochlorine pesticides such as aldrin and dieldrin. In order to address this concern, additional and more stringent screening levels for potential leaching of these chemicals from thin soils over bedrock are presented in Table E. These screening levels may be particularly useful at sites where demolition of structures underlain by soil that has been treated with termiticides is being carried out. Immediate removal or recapping these soils is critical to prevent migration of contaminated leachate into the underlying bedrock. More stringent screening levels for TPH and cleanup of petroleum spills in areas of thin soil covers are also included in Table E (e.g., TPHg and TPHd screening levels reduced from 100 mg//kg to 50 mg/kg).

Volatile organic chemicals (VOCs) also pose an increased risk to groundwater in areas where a thick sequence of vadose-zone bedrock overlies an unconfined aquifer. The carbonate plateau area of northern Guam again offers a prime example. These chemicals are not highly sorptive, and the thickness of the soil cover is not a driving factor in the development of soil screening levels for leaching concerns. The collection and analysis of “soil” samples from bedrock, however, is both impractical and unlikely to yield an accurate characterization of leachate conditions in the bedrock. The ability to collect and analyze actual leachate samples (e.g., infiltrating surface water) for VOCs is also likely to be very limited and impractical.

Soil vapor samples offer the most accurate method for the identification of VOCs in leachate that is migrating through bedrock. The data can also be used to evaluate potential impacts to groundwater by downward migrating vapor plumes. Soil vapor screening levels for potential leaching concerns are presented in Table F. The presence of a VOC in soil vapors above its respective screening level suggests that the concentration of the VOC in soil moisture or leachate could exceed the target groundwater screening level and pose a threat to underlying groundwater. For example, a concentration of 5 ug/L benzene in vadose zone leachate would in theory yield a equilibrium concentration in soil vapor of 1,200 ug/m^3. The soil vapor screening levels do not take into account attenuation and dilution as the leachate migrates downward and mixes with groundwater. Whether or not the leachate (or even the vapors) poses a true threat to groundwater depends on site-specific factors, including the size of the source area and the mass of contaminant present, the rate and amount of downward moving leachate, the distance to the water table, and the rate of groundwater flow and the thickness of the leachate-groundwater mixing zone. Additional information on the site-specific evaluation of potential leaching hazards is provided in Section 4.3.3.

Alternative soil screening levels for sites that will be restricted to commercial/industrial use are included in the ESLs. Use of these screening levels for final site closure should be discussed with the overseeing regulatory agency on a case-by-case basis, however, and could require the implementation of formal engineered and institutional controls.

Additional discussion of factors used to develop the Tier 1 ESL lookup tables is presented in the following sections. Compilation of the Tier 1 ESLs is discussed in more detail in Section 2.4 and Appendix 1.

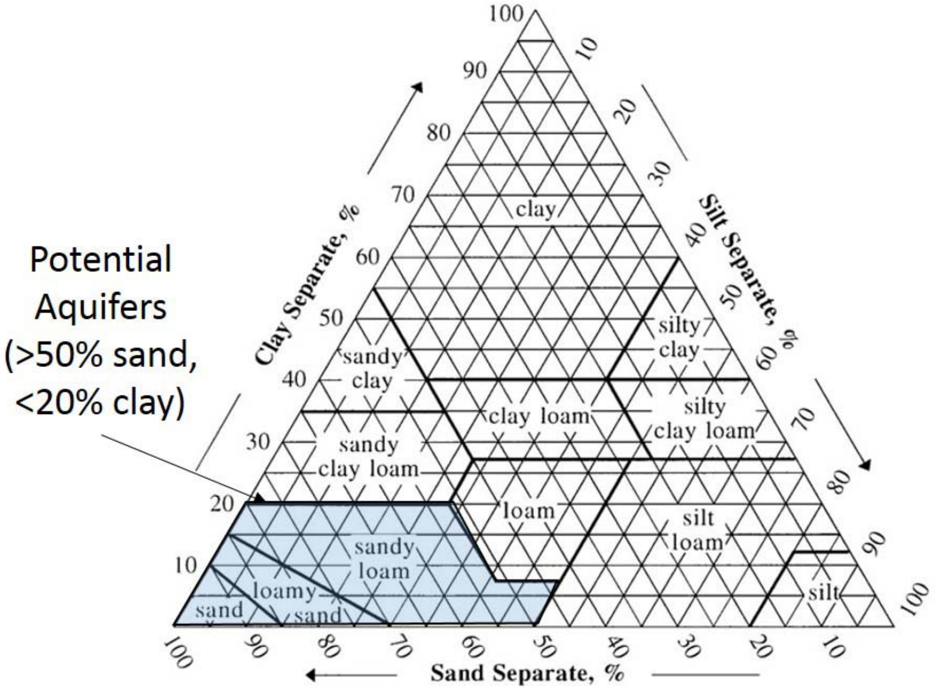
2.2.1 Groundwater Beneficial Use

Groundwater in areas designated for use as a source of public water supply should be treated as a potential source of drinking water unless otherwise approved by the overseeing regulatory agency. **All groundwater should be considered a potential source of drinking water unless otherwise approved by the overseeing regulatory agency.** Drinking water standards published by the USEPA are incorporated by reference into CNMI DEQ and Guam EPA Administrative Rules (CNMI 2002, 2005a, GEPA 1997a,b). The selection of drinking water screening levels for contaminants that lack promulgated standards is discussed in Appendix 1.

Hydrogeologic criteria for exclusion of a given occurrence of groundwater from consideration as a potential source of drinking water could include (CalEPA 2013):

- Total dissolved solids in groundwater is greater than or equal to 3,000 mg/L; OR
- Water bearing unit is not sufficiently permeable to produce an average, sustained yield of 200 gallons of water per day.

Groundwater in coastal areas, geothermal fields, etc., can contain levels of dissolved solids that make the water unsuitable as a potential source of drinking water. In addition, the permeability of soils and caprock sediments that lack a significant amount of coarse-grained material can be too low to allow for an adequate, sustained yield of groundwater. The hydraulic conductivity of an unconsolidated formation must in general be greater than 10^{-6} to 10^{-7} meters per second for the formation to be considered a potential aquifer (Freeze and Cherry 1979). This is equivalent to a “silty sand” under the Unified Soil Classification System (ASTM 1985) and similar to a “sandy loam” under the US Department of Agriculture soil classification (USDA 1987). In combination, unconsolidated geologic units that are comprised of less than 50% sand-size ($\leq$2mm) material or more than 20% clay-size material ($\leq$0.002 mm) are typically not considered to be viable "aquifers" or potential sources of useable groundwater. The relation of soil (or more likely sediment) type versus potential aquifer potential is summarized in the following diagram (after USDA 1987):



The potential for a given unit of bedrock to serve as a viable source of groundwater similarly depends on the primary and secondary porosity in the rock and the quality of the groundwater. Consideration must also be made for the potential migration of groundwater out of a geologic unit that is insufficiently permeable to be considered an aquifer and into a more permeable unit that could serve as a viable source of drinking water.

For the purposes of this document, it is also assumed that all shallow groundwater will ultimately discharge to a body of surface water and potentially impact aquatic organisms (see Section 1.2). Soil and groundwater ESLs were therefore developed to be protective of both drinking water resources and aquatic habitats. This is discussed in greater detail in Chapters 2 and 3 of Appendix 1.

Site-specific factors may render some groundwater unsuitable for potential drinking water purposes (e.g., elevated Total Dissolved Solids in a groundwater management zone located in an industrialized area). Environmental Screening Levels presented in Tables B (shallow soils) and D (deep soils) of this document are intended for use at such sites. The ESLs presented in these tables consider the potential discharge of groundwater to surface water but do not consider potential impacts to sources of drinking water. The ESLs also consider vapor intrusion and “gross contamination” concerns such as the presence of free product or odor concerns if contaminated groundwater were to discharge into a nearby surface water body. This is a common problem at petroleum contaminated sites adjacent to bays and rivers.

In general, soil and groundwater screening levels are more stringent for sites that threaten a potential source of drinking water (see Tables A and C). This is particularly true for chemicals that are highly mobile in the subsurface and easily leached from impacted soil. This requires that soil to be excavated from a property and used in an offsite area be screened against Tier 1 action levels applicable to areas that overlie a source of drinking water, even if groundwater beneath the site of origin is not considered as such (refer to HDOH 2017). For chemicals that are especially toxic to aquatic life, however, screening levels for sites that threaten drinking water resources may be driven by surface water/aquatic habitat protection concerns rather than by drinking water concerns. Many of the metals and pesticides listed in the lookup tables fall into this category (see Section 1.2). Refer to the detailed, F-series lookup tables in Appendix 1 or simply use the ESL Surfer.

As discussed in Appendix 1, Tier 1 soil screening levels for potential leaching and contamination of underlying groundwater assume the presence of at least one meter (three feet) of clean soil between contaminated soil and underlying bedrock. The soil serves to limit the mobility of contaminants in downward migrating leachate and the risk they pose to groundwater. Default screening levels for individual chemicals are assumed to also be adequate for thin soil covers, based on batch tests that indicate significantly stronger sorption to soil that otherwise predicted by leaching models (see Section 4.3.3). More stringent soil screening levels for leaching of petroleum from soil (represented by "TPH") are, however, included in Appendix 1 for use at sites with thin soil covers. Soil vapor screening levels for evaluation of VOCs in vadose-zone leachate are also provided (see Table F and Section 4.4 of Appendix 1). These screening levels should be especially useful at sites with thin soil cover over bedrock, where soil samples cannot be collected.

Groundwater action levels should be normally compared to dissolved-phase chemical concentrations unless instructed by the overseeing regulatory agency. This may require filtering of turbid samples. Filtering should not be carried out on samples to be tested for volatile chemicals. Filtering of samples might also not be acceptable for groundwater in a karst aquifer with direct connections to a surface water body.

2.2.2 Land Use

Land uses are categorized based on the assumed length, duration, and magnitude of potential human exposure. The category "Unrestricted Land Use" is intended for use at sites where future land-use restrictions are not desirable or allowed. This includes sites used as residences, hospitals, day-care centers, and other sensitive purposes (e.g., see CalEPA 2002, HDOH 2011). ESLs listed under this category use conservative assumptions regarding long-term, daily exposure of children and adults to impacted soils in a residential setting (see Appendix 1, Section 4.2 and Appendix 2). It is assumed that the greatest human health impacts posed by a site would result from residential land use exposures. Therefore, sites meeting residential-use ESLs would not pose hazards under any other land uses.

By contrast, the land-use category "Commercial/Industrial Use Only" assumes that only working-age adults will be present at the site on a regular basis, and only during working hours. Direct-exposure assumptions incorporated into commercial/industrial use soil ESLs are less conservative than assumptions used for residential land-use soil ESLs.

Land use should be selected with respect to the current and reasonably anticipated future use of the site in question. Reference to zoning maps and local redevelopment plans is an integral part of this process. Use of the lookup tables for sites with other land uses (e.g., agriculture, parkland, etc.) should be discussed with and approved by the overseeing regulatory agency. As the category heading implies, use of the soil ESLs listed under "Commercial/Industrial Use Only" places implicit land-use restrictions on the affected property. The short-term cost savings of limiting site cleanup to meet only commercial/industrial-use ESLs rather than unrestricted land use should be carefully weighed against potential restrictions on future property use. In addition to land use restrictions, cleanup to commercial/industrial-use ESLs may also encumber the site with long-term environmental monitoring requirements and requirements for future subsurface excavation activities. Implications for land-use restriction are discussed in more detail in Section 2.8.

2.2.3 Exposed Versus Isolated Soils

Tier 1 ESLs for shallow, exposed soils are presented in Tables A and B. Tier 1 ESLs for deep or otherwise isolated soils are presented in Tables C and D. For the purposes of this document, a depth of three meters (approximately 10 feet) was used to delineate between shallow soils, where a potential exists for regular direct exposure of residents and/or office workers, and deep, isolated soils where only periodic exposure during construction and utility maintenance work is considered likely. Three meters is assumed to be the maximum depth that impacted soil could be excavated and left exposed at the surface during typical redevelopment activities (e.g., for swimming pools, utilities, etc.; CalEPA 1996). A minimum, default depth of one-meter is recommended for commercial/industrial properties to distinguish between shallow and isolated soils. Subsurface activities below this depth are likely to be closely supervised by the property owner, who will presumably be aware of contaminated soil at depth on the property and manage the soil appropriately. Landscaping and other less supervised activities could disturb and expose soils shallower than this depth.

An evaluation of vapor emissions from deep soils to outdoor air may be required for sites that are heavily contaminated with volatile chemicals. The potential intrusion of vapors from both deep and shallow sources into overlying buildings and to outdoor air must also be considered, regardless of the depth of the contaminated soil (refer to Chapter 4 and Appendix 1). In some cases, contaminated soil may be left in place at shallower depths with appropriate institutional controls, upon review and approval by the overseeing regulatory agency.

The full suite of environmental hazards noted in Figure 1-2 was considered in development of ESLs for shallow soils. For deep soils, regular exposure of residents or commercial/industrial workers and impacts to terrestrial flora and fauna was not considered. As a result, deep-soil ESLs for low-mobility chemicals are generally much higher than corresponding shallow-soil ESLs (e.g., compare PCB ESLs in Tables A and C). However, for chemicals that are highly mobile, e.g., easily leached from soil or potentially emitted to the air as a volatile gas, groundwater and indoor-air protection concerns usually drive selection of the final ESL regardless of the depth of the impacted soil. This is the case for several of the highly volatile, chlorinated organic compounds. As a result, corresponding shallow and deep soil ESLs for high-mobility chemicals are identical (e.g., compare benzene ESLs in Tables A and C).

If contamination is present in both shallow soil and deep soil, it may be appropriate to use a separate set of screening levels for each zone (e.g., Table A for the shallow soils and Table C for the deep soils). Soil that is located under paved areas or buildings can also be considered to be isolated if appropriate, long-term management actions are implemented. This is most applicable to commercial/industrial sites where activities on the property are closely controlled. This isolation of contaminated soil under properties to be used for more sensitive purposes is generally not recommended but can be discussed with the overseeing regulatory agency on a case-by-case basis. For example, the isolation of easily recognizable, petroleum-contaminated soil under the parking lot of a high-density residential development would be more acceptable than the isolation of soil heavily contaminated with dioxins or other persistent chemicals that are difficult to recognize in the field. Controls for long-term management of contaminated soil that is left in place at a site must be document in a site-specific *Environmental Hazard Management Plan*. This is discussed in Chapter 5.

The pros and cons of remediating all soil on a property to criteria for unrestricted reuse should be evaluated on a site-by-site basis. While potentially more costly in the short term, doing so would eliminate concerns regarding future disturbance and reuse of deeper soils. This includes future excavation and offsite reuse of soil from the property (HDOH 2017).

2.2.4 Threat to Surface Water Habitats

The conceptual site models used to develop the Tier 1 ESLs assume that contaminated groundwater at all sites could at some time migrate offsite and discharge into a body of surface water (refer to Section 2.2.4). This discharge could occur due to the natural downgradient migration of groundwater or to human activities such as dewatering of excavations at construction sites.

Promulgated water quality standards and correlative screening levels for contaminants that lack promulgated standards are presented in Table H. Water quality standards published by the USEPA for the protection of aquatic habitats are incorporated by reference into Guam EPA Administrative Rules (GEPA 1997a). The selection of screening levels for contaminants that lack promulgated standards is discussed in Appendix 1. Tidally influenced portions of creeks, streams and rivers and the bays they flow into are considered to be *estuarine* environments. Screening levels for estuarine environments are based on the more stringent of screening levels for marine (saltwater) versus freshwater environments but do not consider drinking water standards or screening levels. Chronic surface water standards (or equivalent) are incorporated into the groundwater screening levels to address potential aquatic habitat protection concerns.

In freshwater environments, screening levels (or promulgated standards) for most chemicals for drinking water concerns are generally much lower than corresponding standards for toxicity to aquatic organisms. For many pesticides and heavy metals, however, aquatic habitat goals are more stringent than drinking water toxicity goals and therefore drive the selection of final Tier 1 ESLs (e.g., dieldrin, endrin and endosulfan). This is reflected in the final groundwater screening levels for these contaminants (refer also to Appendix 1 and the ESL Surfer).

The groundwater ESLs for potential impacts to aquatic habitats do not consider dilution of groundwater upon discharge to a body of surface water. Benthic flora and fauna communities situated below or at the groundwater/surface water interface are assumed to be exposed to the full concentration of chemicals in impacted groundwater. Use of a generic dilution factor to adjust the surface water protection screening levels with respect to dilution of groundwater upon discharge to surface water is therefore not generally acceptable. Consideration of alternative groundwater screening levels for the protection of surface water quality may, however, be appropriate on a site-specific basis (e.g., use of acute aquatic screening levels for groundwater in highly developed, harbor areas, refer to section 4.4.3).

The groundwater ESLs also do not consider surface water standards for bioaccumulation concerns. As discussed above, the use of chronic surface water standards to screen contaminants in groundwater is considered to be adequately protective of benthic habitats at most sites.

The soil and groundwater screening levels presented in the lookup tables also do not directly address long-term impacts of contaminated groundwater on sediment quality. Site-specific concerns could include the accumulation of highly sorptive chemicals in sediment over time due to long-term discharges of impacted groundwater. This may be especially true for groundwater impacted with metals or highly sorptive (lipophilic) chemicals, including PAHs and other heavy petroleum compounds.

Potential erosion and runoff of contaminated surface soils from impacted sites may also need to be considered on a site-by-site basis, particularly at sites impacted with metals, PCBs, organochlorine pesticides and similar compounds that are situated near a sensitive aquatic habitat. The need for a more detailed, ecological risk assessment of impacts to sediment should be evaluated on a site-by-site basis and discussed with the overseeing regulatory agency (refer to Chapter 4).

2.3 Use of Lookup Tables

The step-by-step use of the Tier 1 ESL lookup tables and preparation of an *Environmental Hazard Evaluation* is summarized below and in Figure 1-3. A detailed discussion of *Environmental Hazard Evaluation* reports is provided in Chapter 3.

Step 1: ESL Updates and Applicability

Check the overseeing agency (or HDOH) web page listed at the beginning of this guidance to ensure that the most up-to-date version of this document is being used. Review the limitations discussed in Section 1.6 to determine if the ESLs are applicable to the subject site.

Step 2: Identify All Chemicals of Potential Concern

An *Environmental Hazard Evaluation* (EHE) must be based on the results of a thorough site investigation, where all chemicals of potential concern have been identified. A summary of the site investigation results should be included in the EHE in order for it to be reviewed as a "stand alone" document. An outline of the information that should be included in an EHE is provided in Section 3.2.

Step 3: Select Lookup Table(s)

Initially compare site data to ESLs for surface soils and unrestricted (e.g., residential) land use in order to minimize the need to future land use controls. Defer to ESLs for commercial/industrial land use and/or screening levels for subsurface soils as needed due to limitations on future remedial actions (EHMP required for long-term management). Data for soil to be excavated and used for offsite fill material should be compared to the most stringent ESLs to determine potential limitations on reuse (HDOH 2017b). Determine the beneficial use of impacted or threatened groundwater beneath the site and the distance to the nearest surfaced water body from the downgradient edge of the release site (refer to Figure 2.1). In general, **all groundwater should initially be treated as a current or potential source of drinking water unless otherwise approved by the overseeing regulatory agency.**

Step 4: Select Soil, Soil vapor and/or Groundwater ESLs

Select appropriate soil ESLs from the appropriate lookup table. ESLs for groundwater are provided in the adjacent column of each table and are not necessarily dependent on land use or depth to impacted soil. Replace ESLs with naturally occurring, background concentrations of chemicals of concern (e.g., assumed background arsenic = 20 mg/kg) or laboratory method reporting levels if higher (see Section 2.7).

Step 5: Determine Extent of Impacted Soil and/or Groundwater

Using the selected ESLs, determine the extent of impacted soil or groundwater and areas of potential environmental hazard at the site and offsite, as required. Soil vapor screening levels can be used to determine the extent of subsurface vapor plumes. Soil data should be reported on a dry-weight basis. While this is not likely to affect final cleanup decisions, it is more in line with assumptions used to develop direct-exposure screening levels for human health concerns (see also Appendix 1, Section 7.2).

Step 6: Evaluate the Need for Additional Investigation or Corrective Actions; Submit EHE Report

A detailed discussion of EHE reports is provided in Chapter 3. Based on a comparison of available site data to the ESLs, evaluate the need for additional action at the site (e.g. additional site investigation, remedial action, preparation of a more site-specific risk assessment, etc.). For sites where sample data are limited, it will be most appropriate to compare the maximum-detected concentrations of chemicals of concern to the ESLs to initially evaluate potential environmental concerns.

The collection of Multi Increment sample (MIS) data is recommended when possible (refer to Section 1.4). Statistical methods can be used to estimate representative contamination concentrations in individual decision units at sites where only discrete sample data are available. This is generally selected as the lesser of the maximum-detected concentration and the 95% upper confidence interval of the arithmetic mean of sample data. Additional guidance on the estimation of representative contamination concentrations from MIS and discrete sample data is included in the Hawai‘i DOH *Technical Guidance Manual* (HDOH 2016) Guidance on the statistical evaluation of environmental data is also provided in the California EPA documents *Preliminary Endangerment Assessment Guidance Manual* (CalEPA 1994) and *Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities* (CalEPA 1996), among other sources.

This evaluation should be summarized in the EHE report and workplans for additional actions prepared as needed (see Section 3). Decisions for or against additional actions should be made in conjunction with guidance from the overseeing environmental agency. Adjustment of Tier 1 screening levels in a more advanced, environmental hazard evaluation is discussed in Chapter 4.

2.4 Compilation of Environmental Screening Levels

2.4.1 Tier 1 ESLs

A detailed discussion of the compilation of all screening levels is provided in Appendix 1. Approximately 150 chemicals are listed in the lookup tables. For each chemical, a screening level was compiled or generated to address each of the environmental hazards noted in Figure 1-2, as applicable and available. The lowest of the individual screening levels for each hazard was selected for inclusion in the summary lookup tables. This ensures that the final, Tier 1 ESL for an individual chemical is protective of all potential environmental concerns and allows for rapid and comprehensive screening of site data. Where ESLs are exceeded, the ESL Surfer (electronic lookup tables) or the detailed tables provided in Appendix 1 can be used to identify the specific environmental concerns that could be present at the site.

A summary of the sources used to compile screening levels for individual environmental hazards is provided in Figure 2-1. A detailed discussion of each source and associated models is provided in Appendix 1. In most cases, the screening levels were drawn from published references (e.g., direct exposure screening levels for soil, published drinking water and surface water standards, etc.). In other cases, published models were used to develop screening levels for the subject environmental hazard (e.g., vapor intrusion screening levels).

An example of the selection of final, Tier 1 ESLs for benzene in soil and groundwater is presented in Figure 2-2 (surface soils, drinking water resource threatened, residential land use). In this case, the screening level for leaching hazards (0.30 mg/kg) is lower than the screening levels for each of the other environmental hazards. This screening level is therefore selected as the Tier 1 ESL presented in Table A of the summary lookup tables. For groundwater, the screening level for drinking water toxicity (5 ug/L) drives potential environmental hazards and is selected as the Tier 1 ESL (i.e., is lowest; see Table A). A more detailed discussion of this example is provided in Appendix 1.

The driving environmental hazard for a specific chemical depends largely on the toxicity and mobility of the chemical. This is evident from a review of the detailed lookup tables in Appendix 1 or by using the ESL Surfer to browse through various chemicals under different site scenarios. Tier 1 ESLs for highly mobile (e.g., volatile and/or not significantly sorptive) or highly toxic chemicals in soil are typically driven by leaching or vapor intrusion concerns (e.g., see selection process for benzene Tier 1 ESL in Figure 2-2). Tier 1 ESLs for chemicals that are relatively immobile in soil but highly toxic to humans are typically driven by potential direct-exposure concerns (e.g., PCBs and lead). In contrast, Tier 1 ESLs for heavy metals that are relatively non-toxic to humans are typically driven by ecological concerns or ceiling levels for general resource degradation (e.g., copper and total chromium). Tier 1 ESLs are typically driven by gross contamination concerns for chemicals that have particularly strong odors, pose explosive hazards or could cause sheens on surface water the selection of (e.g., cyanide, phenols or Total Petroleum Hydrocarbon). The consideration of gross contamination becomes especially important in the selection of ESLs for relatively immobile chemicals in deep or otherwise isolated soils (refer to Section 4.3.5)

Driving environmental hazards are similar for groundwater. Tier 1 ESLs for contaminants that are carcinogenic or otherwise highly toxic to humans tends to be based on drinking water toxicity concerns (e.g., PCE), assuming the groundwater is a potential source of drinking water. Screening levels for taste and odor concerns drive the selection of Tier 1 ESLs for less toxic chemicals in drinking water (e.g., xylenes). The fact that a specific area of groundwater is not suitable for drinking water does not imply that contamination of the groundwater does not pose potential environmental hazards. Vapor intrusion into buildings or discharges into aquatic habitats typically drive the selection of Tier 1 ESLs for highly volatile chemicals in groundwater that is not a source of drinking water (e.g., PCE and vinyl chloride). Chronic surface water standards for contaminants that are highly toxic to aquatic organisms can be significantly lower than drinking water standards (e.g., DDT and dieldrin).

2.4.2 Comparison of Organochlorine Pesticide Data to EALs

Toxicity factors and associated screening levels for several organochlorine pesticides are based on “technical” products that can include mixtures of multiple chemicals or multiple isomers of the same chemical. Reported concentrations of the mixtures and isomers must be summed for comparison to the EALs. Examples are provided below.

Technical Chlordane

Soils adjacent to or under buildings that are known or suspected to have been treated with termiticides should be tested for organochlorine pesticides before reuse in open exposed areas (refer also to the HEER *Technical Guidance Manual*, HDOH 2016 and updates). For “chlordane,” the laboratory should report the total concentration of the *technical chlordane* mixture rather than individual chlordane isomers and related compounds found in the mixture (e.g., heptachlor). This must be specifically requested on the Chain of Custody form and discussed with the laboratory in advance. Laboratories should also be instructed to report any additional organochlorine pesticides that are not typically found in technical chlordane (e.g., DDT, dieldrin, endrin, etc.).

Technical chlordane is not considered to be significantly mobile in soil due to its relatively strong sorption to organic carbon and clay particles (koc >5,000 cm^3/g; refer to Section 4.4 in Appendix 1). Technical chlordane mixtures contain multiple compounds with differing degrees of potential mobility, however. Laboratory batch tests are therefore recommended to evaluate potential leaching hazards for soil that is to be left in place at a site with a representative concentration of technical chlordane that exceeds 29 mg/kg. Refer to Section 4.3.3 for additional information.

Other Organochlorine Pesticides

Individual isomers of organochlorine pesticides and related compounds tested using Method 8081a or similar method should be summed for comparison to action levels unless listed separately in the lookup tables. Examples of groupings include:

- Total Dichlorodiphenyltrichloroethane (DDT): isomers of DDT similar for DDE and DDD);
- Total Endosulfan: Endosulfan I, Endosulfan II, Endosulfan Sulfate;
- Total Endrin: Endrin, Endrin Aldehyde, Endrin Keytone; and
- Total Hexachlorobenzene (BHC): alpha, beta and gamma BHC (Lindane);

Alpha and beta BHC are assumed to be minor components of Lindane and do not need to be assessed separately, even if reported separately by the laboratory. Heptachlor and heptachlor epoxide should be evaluated separately if not associated with mixtures of Technical Chlordane (see above).

2.5 Contaminants of Potential Concern at Petroleum Release Sites

2.5.1 TPH and Targeted Individual Compounds

Refer to Section 6 of Appendix 1 for a detailed review of the chemistry and toxicity of petroleum compounds. . Staff from the HDOH HEER Office are active participants in a document currently under preparation by the Interstate Technical and Regulatory Council (ITRC) that discusses risk-based approaches for the evaluation of “Total Petroleum Hydrocarbons (TPH)” in soil, water and air as part of a site investigation (ITRC 2017). Case studies included in the document are based on large part on experience gained from Hawaii’s ten-plus years of experience with risk-based approaches for TPH.

Recommended, target analytes for petroleum contaminants in soil, soil vapor and groundwater are provided in Figure 2-3. Refer also to Section 9 of the Hawai‘i DOH *Technical Guidance Manual* (HDOH 2016; see also HDOH 2012).

Petroleum is a complex mixture of hundreds of different compounds composed of hydrogen and carbon or “petroleum hydrocarbon” compounds (API 1994). The bulk of these compounds are evaluated collectively under the all-inclusive category of “Total Petroleum Hydrocarbons (TPH).” The term “TPH” is defined for use in this guidance as the sum total of parent petroleum hydrocarbons as well as petroleum hydrocarbon-related metabolites and other degradants. The latter includes alcohols, phenols, ketones, aldehydes and organic acids (Mohler et al. 2013; Zemo et al. 2013, 2016). The toxicity of parent, petroleum hydrocarbon compounds and related degradants is assumed to be similar for initial screening purposes. A detailed overview of the chemistry and toxicity of petroleum-related metabolites is provided in the document *Petroleum Metabolites Literature Review and Assessment Framework* (CalEPA 2016b). This issue will be reviewed in the ITRC document noted above, with examples provided in the Case Studies appendix to that document (ITRC 2017). Methane, a product of anaerobic, biologic respiration that is commonly identified at petroleum-release sites, is assessed separately and is not included under the definition and measurement of TPH.

Laboratory analytical methods for TPH were designed to report the total concentration of petroleum hydrocarbons in a sample with respect to a gasoline, diesel or residual fuel standard (e.g., Method 8015; USEPA 2007). It has traditionally been assumed that these test methods are also adequate to quantify petroleum-related, degradation compounds in the samples. This assumption has recently been called into question, however, and the need for analytical methods more specific to degradation compounds is currently under review (Bekins 2016; ITRC 2017). Silica gel cleanup methods can be used to separate and quantify non-polar, parent compounds from polar, degradation compounds (see HEER TGM Section 9; HDOH 2016; see also Mohler et al. 2013; Zemo et al. 2013, 2106). Petroleum-related, polar compounds are considered to have similar toxicities as the parent compounds, however, and TPH action levels are applicable to both the nonpolar and polar fractions for initial screening. The use of alternative toxicity factors and physiochemical constants for metabolites can be proposed in a site-specific Environmental Hazard Evaluation.

Gasoline-range TPH is a petroleum mixture characterized by a predominance of branched alkanes and aromatic hydrocarbons with carbon ranges of C6 to C12 and lesser amounts of straight-chain alkanes, alkenes, and cycloalkanes of the same carbon range (see also NEIWPCC 2003, included in Appendix 7). Vapor-phase compounds are dominated by C5-C8 aliphatics (see Brewer et al. 2013).

Total Petroleum Hydrocarbon associated with middle distillates (e.g., kerosene, diesel fuel, home heating fuel, jet fuel, etc.) is characterized by a wider variety of straight, branched, and cyclic alkanes, PAHs (especially naphthalenes and methylnaphthalenes), and heterocyclic compounds with carbon ranges of C5 to C25. Liquid fuels are characterized by a dominance of C9-C25 aliphatics with a lesser amount of C9-C10+ aromatics. Vapor-phase compounds are characterized by a mixture of C5-C8 aliphatics and C9-C12+ aliphatics with only minor amounts of aromatics (see Section 6 of Appendix 1). Although still potentially significant, vapor emissions from middle distillate release sites tends to be an order of magnitude lower than for gasoline-contaminated for the same volume and magnitude of contamination due to the lower volatility of these fuels.

Residual fuels (e.g., Fuel Oil Nos. 4, 5, and 6, lubricating oils, mineral oil, used oils, and asphalts) are characterized by complex polar PAHs, naphthenoaromatics, asphaltenes, and other high-molecular-weight saturated hydrocarbon compounds with carbon ranges that in general fall between C24 and C40. With the exception of waste associated with manufactured gas plants, vapor emissions associated with residual fuels releases are significantly lower than emission associated with middle distillate or gasoline releases and generally do not pose significant vapor intrusion hazards. Soil vapor data may be warranted to document a lack of vapor problems, however, as well as to evaluate potential methane buildup.

Due to the complex nature of petroleum mixtures, petroleum contamination should be evaluated in terms of both Total Petroleum Hydrocarbon (TPH) and target "indicator chemicals" for the specific type of petroleum product released (see Figure 2-3; e.g., benzene, toluene, ethylbenzene and xylenes [BTEX], methyl tertiary butyl ether [MTBE], polynuclear aromatic hydrocarbons [PAHs], etc.). Target indicator chemicals typically make up only a small fraction of the total petroleum present but are important players in the assessment of environmental hazards posed to human and the environment.

Eighteen priority pollutant PAHs are listed in the USEPA Regional Screening Level (RSL) guidance (USEPA 2017):

- acenaphthene
- acenaphthylene
- anthracene
- benzo(a)anthracene
- benzo(b)fluoranthene
- benzo(g,h,i)perylene
- benzo(a)pyrene
- benzo(k)fluoranthene
- chrysene
- dibenzo(a,h)anthracene
- fluoranthene
- fluorene
- indeno(1 ,2,3)pyrene,
- methylnaphthalenes (1 & 2)
- naphthalene
- phenanthrene
- pyrene

The suite of PAHs that should be tested for at a given site depends on the type of the petroleum product released (after MADEP 2002a). As indicated in the Figure 2-3, only naphthalene needs to be tested for at gasoline release sites. Soils impacted with middle distillates should be tested or both methylnaphthalenes and naphthalene (e.g., diesel, JP-8 jet fuel, etc.). The full suite of PAHs should be considered at sites with releases of heavier petroleum fuels and waste oil, unless site-specific information on the product released can be used to justify elimination of specific PAHs.

Understanding the potential source of PAHs in soil is important for decision making. Anthropogenic, background concentrations of PAHs in urban area soils due to auto exhaust and other sources can easily exceed risk-based screening levels based on a conservative, excess cancer risk of 10^{-6} (e.g., MADEP 2002b). Samples of soils impacted with waste oil can have concentrations of benzo(a)pyrene and related PAHs in the range of one to ten-plus parts-per-million - well above Tier 1 ESLs for potential direct-exposure concerns. Correlative concentrations of TPH up to approximately C40 are usually in the thousands of parts-per-million range. Soils impacted with asphalt can express similar concentrations of PAHs. An asphalt source of the PAHs is usually readily identifiable by relatively low concentrations of TPH, usually in the low hundreds of parts-per-million range, however. The bioavailability of PAHs in asphalt is relatively low and their presence at these levels does not pose a significant health risk. Asphalt is also usually regulated as an inert waste that can be used for fill material. Relatively low concentrations of TPH are also often reported for soils impacted with coal tar, including petroleum-based patching material for roads or roofing. The concentration of PAHs associated with these materials is often in the hundreds of parts-per-million range, however, highlighting coal tar or similar material as the likely source of the PAHs. Concentrations of PAHs in soil at these levels could pose potential direct-exposure concerns, even if the bioavailability of the PAHs is relatively low.

Volatile components of petroleum that are not specifically identified as target indicator compounds in Figure 2-3 but reported as separate compounds by the laboratory using Method 8260 or similar methods can in general be ignored (e.g., hexane, methylbenzenes, alkanes, alkenes, alkyl benzenes and other aromatics not specifically identified as target indicator compounds; refer to Section 2.10 and NEIWPCC 2003). These compounds are included under the umbrella analysis for TPH in general and do not need to be evaluated (or even reported) separately. This is based on the assumption that the toxicity factors selected for TPH are adequately conservative for the mixture of compounds present in fuels beyond the target compounds noted in Figure 2-3 (refer to Appendix 1, Chapter 6).

Soil, groundwater and soil vapor samples must always be tested for TPH (or equivalent) in addition to targeted, individual chemicals. Laboratory analysis for TPH as gasolines and middle distillates is generally carried out using gas chromatography, modified for "gasoline-range" organics ("Volatile Fuel Hydrocarbons") and "diesel-range" organics ("Extractable Fuel Hydrocarbons"), respectively (e.g., EPA Method 8015). Refer to the Hawai‘i DOH *Technical Guidance Manual* for additional information on laboratory methods. Analysis for TPH as residual fuels up to the C40 carbon range can be carried out by gas chromatography, infrared absorption, or gravimetric methods. The latter methods are rarely used, however, due to their inability to discriminate the type of the petroleum present and interference with organic material in the soil. Analysis of soil vapor for TPH is also sometimes reported as “Total Volatile Hydrocarbons” or “TVH.” Consult a laboratory with expertise in analysis of total hydrocarbon fractions in soil vapor for additional information.

As discussed in Appendix 1, environmental screening levels for TPH were developed by assigning representative fate and transport properties and toxicity factors to surrogates for each TPH category and applying the same models and approaches as used for the target, indicator compounds (refer to Appendix 1). The following carbon range fractions were targeted:

- C5-C8 aliphatics;
- C9-C18 aliphatics;
- C19+ aliphatics; and
- C9+ aromatics.

Note that the lower end of reported light aliphatics can range range from C3 to C6, depending on the laboratory. This is unlikely to make a significant difference to the total TPH reported. Any starting point within this range is acceptable for comparison to the EALs. A more in-depth analysis of the specific carbon range makeup of TPH can be carried out in a site-specific environmental hazard assessment as needed. This may be especially useful for cases where the reported concentration of TPH in soil vapor exceeds the Tier 1 screening level. Carbon range data are less useful for soil, since gross contamination concerns generally outweigh direct-exposure concerns under residential or commercial scenarios for exposed soil.

From an environmental hazard standpoint, cleanup of releases of gasoline is usually driven by a combination of TPH and benzene, with fuel oxygenates such as MTBE playing an important role in some cases. The cleanup of middle distillate fuel releases is usually driven by TPH, rather than individual VOCs or PAHs. Naphthalene and methylnaphthalenes are two potential exceptions, since they can be present in middle distillate fuels at relatively high concentrations and are moderately more volatile and mobile than TPH in general.

Soil and groundwater contaminated with middle distillate fuels should also be tested for BTEX (refer to Figure 2-3). Although BTEX rarely drives cleanup for releases of middle distillate fuels, their presence or absence is a useful indicator of past gasoline releases at the site or the migration of gasoline-contaminated groundwater onto the property from offsite sources. Testing for naphthalene at gasoline release sites is recommended for the same reason (refer to Figure 2-3).

The chemical composition of gasolines and middle distillates in soil or groundwater with respect to individual VOCs and other chemicals can be estimated with reasonable confidence (see Section 6 in Appendix 1). In contrast, the chemical composition of residual fuels, used oils, coal tar, asphalt, and other heavy petroleum mixtures in soil or groundwater is less predictable. Engine combustion processes may add PAHs, VOCs, and metals to used motor oils. Cleaning solvents, PCB transformer oils or pesticides that use a petroleum-based solute are sometimes inadvertently disposed of with waste oil. Due to this potential for additional contaminants, the list of analytes for residual fuels is quite large. The need to test for certain analytes can be ruled out on a site-by-site basis, however, if it can be documented with confidence that the product released was fresh or otherwise uncontaminated. For example, releases of unused lube oil, transformer oils, mineral oils, virgin hydraulic oils and similar products do not require testing for PAHs and other chemicals if it can be demonstrated that product released was never heated to high temperatures (potentially producing PAHs) and not likely to be contaminated with solvents or metals.

2.5.2 Ethanol

Ethanol should be tested for at release sites where it is a known or suspected fuel additive or where it was stored or transferred. Toxicity factors are not available for ethanol (refer to Appendix, Table J). Ethanol is not believed to be significantly toxic at concentrations likely to be found in contaminated soil or groundwater and not easily detectable by taste or odors. It is also readily biodegradable under both aerobic and anaerobic conditions and not anticipated to persist in the environment for longs periods of time. Tier 1 soil, groundwater and indoor air screening levels presented in this guidance are therefore based on gross contamination hazards only (odors in soil, taste and odor in drinking water supplies, generation of explosive vapors, etc., refer to Appendix 1).

In addition to gross contamination hazards, ethanol's high rate of biodegradability may result in additional adverse impacts, including (after MADEP 2002a):

- Increased levels of gasoline constituents in groundwater, including the MTBE, benzene, toluene, ethylbenzene and xylenes due to cosolvency effects in the presence of high concentrations of ethanol; and

- Longer plumes of petroleum-contaminated groundwater and other dissolved gasoline hydrocarbons due to the high biochemical oxygen demand exerted by ethanol and the depletion of oxygen and nutrients available for the degradation of other constituents. This has implications for natural attenuation considerations as a long-term cleanup remedy.

2.6 Contaminants of Potential Concern for Former Agricultural Lands

Testing of soils is recommended for sites where long-term application of pesticides may have occurred before they are developed for unrestricted (e.g., residential) or commercial/industrial use. This is especially pertinent to large tracts of former agricultural land, golf courses and nurseries. This also includes military bases where housing complexes that may have been treated with organochlorine-based termiticides are being demolished and redeveloped with new homes (refer to discussion of technical chlordane in Section 2.2).

In the case of former agricultural lands, contamination is likely to be heaviest in former pesticide mixing and staging areas, seed dipping areas and storage areas, although heavy contamination could occur in association with bagasse piles, settling ponds, former plantation camp areas, etc. (see HDOH 2011). Residual contamination in former fields is likely to be much lower, although significant arsenic contamination has been identified in some areas of former sugar cane fields in Hawai'i.

Types of pesticides commonly used in agricultural lands are discussed in Section 9 of the Hawai‘i DOH *Technical Guidance Manual* (HDOH 2016, see also HDOH 2011, 2016). The list chemicals provided in that guidance is not intended to be comprehensive, nor is it intended to represent a required list of target analytes. Specific pesticides of concern should be based on a review of the historical use of the site with a focus on pesticides that may be persistent in soil above Tier 1 ESLs. Soil and groundwater screening levels for the majority of commonly used, persistent pesticides in are included in this document. To obtain screening levels for pesticides not listed in the lookup tables, contact the overseeing regulatory agency or follow the guidelines used to develop the Tier 1 ESLs in Appendix 1.

Refer to Section 9 of the Hawaii *Technical Guidance Manual* for guidance on testing of pesticides in former agricultural lands (HDOH 2016). Organochlorine pesticides are known to be very persistent in soils, as are arsenic and lead. Organophosphate pesticides, chlorinated herbicides, triazines, carbamates and pentachlorophenol are susceptible to biological and chemical breakdown over time and are more likely to be persistent above levels of potential concern in heavily contaminated, pesticide mixing areas than in fields. As discussed in Chapter 4, significant levels of arsenic (associated with the use of lead arsenate or arsenic trioxide) and dioxins/furans (associated with the use of pentachlorophenol, 2,4,5 TP, etc.) can remain in soil even though the parent pesticide has degraded below levels of concern. Fumigants are not likely to persist in shallow soils more than one year after use due to a propensity to volatilize into the atmosphere and degrade or be carried downward in leachate. The collection of shallow soil vapor data (e.g., 1.5m/five ft bgs) in additional to soil data is recommended if fumigant contamination is suspected (refer to Section 4.5). Areas of past fumigant storage, mixing and distribution points should be targeted. Testing of large field areas for fumigants more than a year after the last application is generally considered unnecessary.

2.7 Laboratory Reporting Limits and Ambient Background

In cases where an ESL for a specific chemical is less than the standard, method detection limit for a commercial laboratory (as agreed upon by the overseeing regulatory agency), it is acceptable to consider the method detection limit in place of the screening level. Potential examples include groundwater screening levels that are in the parts-per-trillion range for PCBs, PAHs and organochlorine pesticides. Most of the contaminants involved are highly sorptive and not significantly mobile in groundwater. Lower reporting limits could be required in rare cases where discharges of groundwater known to be contaminated with these chemicals poses a significant threat to an aquatic habitat.

In the case of both soil and groundwater, sample analyses that are below the method reporting limit for the subject chemical should be reported in summary tables as “ND” (“non-detect”) with the laboratory method reporting level noted in parentheses (e.g., “ND (<0.5 ug/L)”). An alternative is to simply note “ND” in the cell for the chemical and sample number and note the method reporting limit table at the bottom of the table for each chemical.

Natural background concentrations of metals in soils should be used in place of risk-based screening levels to evaluate sites for possible contamination if higher than the latter (see Appendix 1, Table M; includes arsenic, cadmium and thallium). For example, background concentrations of arsenic in soils typically range from 1 mg/kg to 20 mg/kg, with some soils containing in excess of 50 mg/kg. Purely risk-based screening levels presented in Appendix 1 can be significantly lower (Table K series). These screening levels assume, however, that 100% of the metal in the soil is bioavailable or potentially toxic. This is rarely the case for naturally occurring metals in soils. For arsenic, site-specific bioaccessibility tests are recommended when the total concentration of arsenic in the soil exceeds the default, background concentration of 20 mg/kg (refer to Chapter 4).

Background metals concentrations tend to be higher in soils developed over volcanic rocks and can exceed risk-based screening levels in some cases. This is especially true for arsenic, but can also occur for heavy metals such as antimony, cadmium, chromium (in comparison to screening levels for hexavalent chromium), thallium and vanadium associated with soils developed over volcanic bedrock. If a release of one of these chemicals is suspected at a site then additional evaluation may be warranted (e.g., testing of soil specifically for hexavalent chromium) and more stringent, risk-based screening levels.

Risk-based screening levels are no longer published for total chromium in soil (USEPA 2017). As an alternative, an assumed background concentration of 1,000 mg/kg is incorporated into the ESL lookup tables for initial site screening (see Appendix 1, Table M). Background total chromium concentrations could be higher in areas not underlain by carbonate rocks. Testing of soil for Cr III and CrVI should be carried out at sites where expected background levels of total chromium are exceeded.

2.8 Land-Use Restrictions Inherent in Tier 1 ESLs

Allowing the option to tie screening levels or cleanup levels to site-specific land use and exposure conditions can save considerably in investigation and remediation costs. For example, the screening level for polychlorinated biphenyls (PCBs) in surface soils is 1.1 mg/kg in residential areas but up to 7.4 mg/kg for commercial/industrial areas (based on a target cancer risk of 10^{-5} and noncancer hazard quotient of 1.0). Higher levels can potentially be safely left in place if proper institutional and engineered controls are implemented and an adequate Environmental Hazard Management Plan is prepared (refer to Chapter 5).

The use of cleanup levels less stringent than those appropriate for unrestricted land use may place significant restrictions on future use of the property. For example, if a site is remediated to meet ESLs (or alternative criteria) intended for commercial/industrial land use then the site could not be used for residential purposes in the future without additional evaluation. This will noramlly require that a formal covenant to the deed be recorded to restrict future use of the property to commercial/industrial only. Deed covenants are generally not necessary for petroleum-release sites unless significant vapor intrusion hazards are present (refer to Chapter 4). Residual petroleum contamination will naturally degrade once the source of the release and gross contamination are removed. Petroleum-contaminated soil or groundwater is also easily recognized at levels that pose potential direct exposure hazards in the field.

The use of alternative screening levels for deep or otherwise isolated soils assumes that the impacted soil will remain isolated below the ground surface "for eternity" (refer to Section 4.3). For single-family residential areas, future disturbance of soil situated deeper than three meters is generally considered to be unlikely (CalEPA 1996). The use of alternative ESLs for soil located below this depth is reasonable (see Section 2.2.3 and Chapter 4). For commercial/industrial sites, soils situated below a depth of one meter are assumed be “isolated” and not likely to be exposed during authorized subsurface activities. For persistent contaminants, preparation of an EHMP and placement of formal institutional controls on the property is recommended to clearly document the presence of isolated contamination and prevent inadvertent disturbance in the future (refer to Chapter 5).

During the redevelopment of properties for commercial/industrial or high-density residential use, excavation and removal of soils from depths up to five or greater is possible (e.g., for underground parking garages, elevator shafts, utilities, etc.). The need to impose enforceable institutional controls for proper management of deep or otherwise isolated, contaminated soils at commercial/industrial properties where screening levels for isolated soils are applied should be discussed with the overseeing regulatory agency on a site-by-site basis.

Land-use restrictions inherent in the selection of ESLs from the Tier 1 lookup tables (or assumptions used in site-specific risk assessments) should be kept as minimal as possible (e.g., commercial/industrial land use, current isolation of soil at depth, etc.). **When preparing EHEs for commercial/industrial sites, concentrations of chemicals in impacted soils left in place should always be compared to screening levels for both unrestricted land use and commercial/industrial land use.** If the soils in fact meet ESLs for unrestricted land use after cleanup then this should be clearly stated in the site closure report. There is no need to compare confirmation data to screening levels for commercial/industrial land use only. Recognizing this upfront will help avoid unnecessary delays should the site be considered for more sensitive uses in the future (e.g., residential, school day care, health care, etc.).

The long-term isolation of contaminated soil under pavement, buildings or some other type of caps should be avoided when possible in order to minimize future land-use restrictions and controls. This may be unavoidable, however, for soil contaminated with chemicals that require treatment and disposal at off-island, hazardous waste facilities (e.g., dioxins). If done, actions to prevent future disturbance of the soil should be clearly described in an *Environmental Hazard Management Plan* prepared for the site (refer to Chapter 5). The need for a formal covenant to the property deed should be also discussed with the overseeing regulatory agency (generally not required for petroleum-contaminated soil or groundwater). A foresighted approach in the use of Tier 1 ESLs or alternative, site-specific cleanup levels will allow more flexibility in future use of a site, help avoid unexpected complications during site redevelopment, and minimize the liability of future land owners.

2.9 Cumulative Risks at Sites with Multiple Chemicals of Concern

Risks posed by direct exposure to multiple chemicals with similar health affects are considered to be additive or "cumulative." For example, the total risk of cancer posed by the presence of two carcinogenic chemicals in soil is the sum of the risk posed by each individual chemical. The same is true for chemicals that cause noncarcinogenic health effects. A summary of example target health effects for the chemicals listed in the lookup tables is provided in Appendix 1 (Table L).

The Tier 1 ESLs are considered to be adequately protective provided that no more than ten carcinogenic COPCs and no more than five noncarcinogenic COPCs, are present at a site. This is based on a combination of conservative exposure assumptions and target risk factors in direct-exposure models. Refer to Chapter 4 and Appendix 1 for additional discussion of this subject. The cumulative health risk may need to be calculated for sites where additional contaminants are present. Refer to Chapter 4 and Appendix 1 for additional information. Note that the USEPA Regional Screening Levels do not directly consider the potential or multiple chemicals with similar health affects (i.e., RSLs based on target noncancer Hazard Quotient of 1.0; see USEPA 2017). Use of RSLs, especially those based on noncancer hazards, requires calculation of cumulative health risks (see Section 2.11.1).

2.10 Chemicals Not Listed in Lookup Tables

Compilation of screening levels for chemicals not listed in the current lookup tables is a relatively straightforward process, provided that adequate supporting data are available. A detailed discussion of the development of screening levels presented in this guidance is provided in Appendix 1. A summary of the approaches used to develop the screening levels is provided in Figure 2-1. To compile screening levels for chemicals not listed in the lookup tables, the interested party should use the same approaches or contact the overseeing regulatory office for assistance.

With the exception of the target, indicator compounds noted in Figure 2-3 and discussed in Section 2.5, individual petroleum-related compounds that are captured and included in TPH analyses do not need to be evaluated separately in an EHE. Screening levels for these compounds do not need to be developed. This includes a host of alkanes, alkenes, alkyl benzenes and other aromatics not specifically identified as target indicator compounds that could be reported separately in analytical methods for volatile organic compounds (e.g., refer to NEIWPCC 2003, included in Appendix 7).

Screening levels must be developed for all applicable, potential hazards (refer to Sections 1.2 and 2.3). **In particular, the USEPA Regional Screening Levels (RSLs) should not be used as stand-alone criteria for screening of contaminated soil or water (USEPA 2017) cannot be used as stand-alone criteria for the evaluation of contaminated soil** (refer also to Section 2.12.1)**.** This is because the RSLs do not consider all potential environmental hazards posed by contaminated soil. In particular, the RSLs do not address potential leaching, vapor intrusion, ecotoxicity and gross contamination hazards (see Section 2.11.1). Proposals for use of alternative, site-specific screening levels must be inclusive of all potential environmental concerns incorporated in the ESLs presented in this guidance unless otherwise supported and presented for review by the overseeing regulatory agency.

2.11 Comparison to Other Published Screening Levels

This Tropical Pacific edition of the EHE guidance document represents an update and expansion of guidance published by the California Environmental Protection Agency (CalEPA 2016a), the Hawai'i Department of Health (HDOH 2017a) and the Commonwealth of the Northern Mariana Islands (CNMI 2005b). These documents represent a progressive compilation of approaches developed by various environmental agencies in the USA, Canada and other countries. As discussed below, the documents incorporate and significantly expand on the early USEPA *Preliminary Remediation Goals* (PRGs) and more recent *Regional Screening Levels* (USEPA 2017). Differences and similarities between this guidance document and guidance prepared by the other agencies are summarized below.

[Dr. Roger Brewer, the primary author of this document, oversaw preparation of the California (CAlEPA 2005b), Hawai'i (HDOH 2017a) and CNMI documents (CNMI 2005b).]

2.11.1 USEPA Region RSLs

The U.S. Environmental Protection Agency (USEPA) *Regional Screening Levels* (RSLs; USEPA 2017, and updates) replaced *Preliminary Remediation Goals* (PRGs) previously published by individual, USEPA regional offices. Like the PRG guidance, the RSL guidance presents risk-based soil, air and tapwater screening levels for a long list of contaminants.

The RSL and PRG models used are essentially identical, with the exception that the 2008 and later RSLs utilize Unit Risk Factors (cancer concerns) and Reference Concentrations (noncancer concerns) for inhalation of vapors and particulates, rather than Cancer Slope Factors and Reference Doses derived from the former as done in previous editions of the USEPA Region IX PRGs. This does not make a significant difference in the final screening levels. The USEPA RSL guidance also includes soil screening levels for potential leaching hazards, although the model used and the resulting screening levels are considered to be overly simplistic and excessively conservative by most risk assessors and they are rarely used, including by staff within the USEPA.

The USEPA RSL direct-exposure models for soil and for tapwater were retained for use in this document. With the exceptions noted below and in Appendix 1, target risks, toxicity factors and physiochemical constants included in the RSL guidance were also retained for development of the ESLs.

The ESLs represent a significant expansion of the USEPA RSLs to address a more comprehensive suite of environmental hazards potentially associated with contaminated soil and groundwater (refer to Section 1.2). Specific differences include (see Appendix 1 for details):

- Adjustment of soil direct-exposure RSLs for noncarcinogens to a target hazard quotient of 0.2, rather than 1.0, to address potential cumulative health concerns at sites where multiple contaminants are present;
- Use of alternative target cancer risk for some chemicals, based on confidence in the toxicity studies and/or the need to screen out ubiquitous, low-level contamination in urban soils (e.g., PAHs, PCBs, etc.);
- Extrapolation of inhalation toxicity factors from oral toxicity factors for volatile chemicals in cases where the former are not included in the RSLs (follows approach used in previous editions of the USEPA Region IX PRGs);
- Focus on noncancer health risks for TEQ dioxin soil screening levels and consideration of dioxin bioavailability in soil;
- Addition of direct-exposure screening levels for construction and trench worker exposure to contaminated soils;
- Addition of soil, groundwater and soil vapor screening levels for vapor intrusion (indoor-air impact) hazards;
- Addition of groundwater screening levels for the protection of aquatic habitats and surface water quality (discharges of contaminated groundwater to surface water);
- Use of a more rigorous leaching model to develop soil screening levels for protection of groundwater quality (soil leaching hazards);
- Addition of soil and groundwater "ceiling levels" to address gross contamination hazards, including explosion hazards, odors, sheens and

general nuisance and resource degradation concerns;
- Inclusion of soil screening levels for arsenic and total chromium based on natural background; and
- Addition of soil and groundwater screening levels for Total Petroleum Hydrocarbons (TPH).

Use of the USEPA RSL direct-exposure models in the ESLs presented in this guidance is discussed further in Chapter 3 of Appendix 1**. As previously stated, the USEPA RSLs cannot be used as stand-alone screening levels to evaluate potential environmental hazards posed by contaminated soil and groundwater.** This is clearly stated in the User's Guide to the RSLs and includes sites that fall under Federal rather than State jurisdiction in Hawai'i. The RSLs can be referred to assess direct-exposure concerns, as they are intended. Cumulative risk should be evaluated is RSLs based on a noncancer Hazard Quotient of 1.0 are referred to (consideration of cumulative risk directly incorporated into ESLs). An additional, comprehensive assessment of potential environmental hazards must be included, however, including leaching, vapor intrusion and gross contamination concerns. Refer to Section 4 for additional guidance.

2.11.2 Hawai'i DOH EALs

The Hawai'i Department of Health document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (HDOH 2017a) is almost identical is a companion document to the Tropical Pacific ESL guidance and was prepared by the same author. The Hawai'i Department of Health worked in co-ordination with the USEPA in the early 1990s to publish one of the first guidance documents for the preparation of expedited environmental risk assessments (HDOH 1995). The guidance is periodically updated since that time. Lookup tables of soil and groundwater "Environmental Action Levels (EALs)" included in the document addressed soil direct-exposure hazards (similar to the earlier, USEPA Region IX "PRGs") as well as soil leaching and groundwater protection concerns.

The updated document is modeled largely after the California EPA document originally prepared by the same author (CalEPA 2016a). The Hawai'i action levels incorporate local drinking water and surface water standards when available. Risk-based action levels presented in the Hawai'i document also reflect USEPA toxicity factors for human health hazards, as do the ESLs presented in this guidance.

Note that an alternative and slightly less conservative, noncancer Reference Dose published by the World Health Organization is used to develop TEQ dioxin action levels the Hawai‘i guidance (HDOH 2017a). This was done in order to more efficiently identify potential high-risk sites, due to widespread but still relatively low levels of dioxins in former sugarcane fields across the islands. Dietary exposure to dioxins is also discussed in the Hawai‘i document.

Unlike this guidance document, the Hawai’i guidance does not at this time present a separate set of action levels for commercial or industrial properties in their summary, Tier 1 lookup tables. Instead, only action levels for residential use of a property are presented. Separate, Tier 1 action levels are also not presented for “deep”, isolated soils versus “shallow” soils as included in both this guidance and the California EPA document (see below). Action levels that can be applied to both nonresidential land use and deep soils are, however, included in the appendices of the Hawai’i EAL document. Use of these action levels is permitted in more site-specific, Tier 2 and Tier 3 risk assessments. Hawai’i chose not to include action levels for these site scenarios in their Tier 1 lookup tables in part because in-house risk assessment support was adequate to address these issues on a site-by-site basis as needed.

2.11.3 CNMI DEQ ESLs

The Tropical Pacific ESLs presented in this document represent an update and expansion of guidance originally prepared for the Commonwealth of the Mariana Islands, Division of Environmental Quality (CNMI 2005b). Primary differences include:

- Significant revision of the text to better define and describe the role of *Environmental Hazard Evaluation* in site investigations;
- Enhancement of the ESL Surfer (electronic lookup tables);
- Addition of approximately 30 pesticides and explosives-related contaminants to the ESL lookup tables; and
- Addition of guidance on the following topics (published by Hawai’i DOH):
    - Soil action levels and categories for bioaccessible arsenic (HDOH 2010b);
    - Pesticides in former agricultural lands and related areas (HDOH 2016a, 2011);

- Use of laboratory batch tests to evaluate potential leaching of contaminants from soil (HDOH 2007a); and
- Long-Term management of petroleum-contaminated soil and groundwater (HDOH 2007b; see also HDOH 2016).

The ESLs presented in the 2005 CNMI guidance have subsequently been replaced with the ESLs presented in this guidance (Tropical Pacific Edition) and are no longer in use.

2.11.4 TSCA PCB Standards

Risk-based soil screening for polychlorinated biphenyls (PCBs) are included in the lookup tables of this guidance (refer to Table K series in Appendix 1). The final, residential soil ESL of 1.1 mg/kg is based on a noncancer Hazard Quotient of 1.0. This is essentially equal to the TSCA residential screening level of 1.0 mg/kg discussed below. The screening levels are calculated based on the same approach used to develop the USEPA Region IX RSLs, with the exception of the use of a target excess cancer risk of 10^{-5} rather than the default of 10^{-6} (refer to Section 4.2.2 in Appendix 1).

The treatment, storage and disposal of PCBs is also regulated under the Toxics Substance Control Act (TSCA), as described in Title 40, Part 761 of the Code of Federal Regulations. Reviews of TSCA regulations are provided in the USEPA documents *Guidance on Remedial Actions for Superfund Sites with PCB Contamination* (USEPA 1990a) and *PCB Site Revitalization Guidance Under the Toxics Substances Control Act* (USEPA 2005). TSCA cleanup regulations are primarily targeted to address spills from operating electrical equipment. TSCA requirements are applicable to materials that contain PCBs in concentrations equal to or great than 50 mg/kg, including soil. Impacted soils containing less than 50 ppm PCBs are not regulated under TSCA, provided that the concentrations are "as found" at the site and the impacted soil has not been mixed with clean soil to reduce total concentrations. *Soils containing PCBs at a concentration greater than 50 mg/kg must be treated and disposed of in accordance with TSCA regulations.*

TSCA regulations present several cleanup standards for PCBs in soil. These cleanup standards are not applicable to sites that are not regulated under TSCA. The cleanup standards primarily apply to spills within and around electrical substations and should not be applied to residential or commercial/industrial sites that are found to be contaminated with PCBs. For example, a TSCA cleanup standard of 1.0 mg/kg is often quoted for PCBs in residential areas. This “cleanup level,” presented in 40CFR761 Subpart G for “high occupancy areas” (defined as

>6.7 hours exposure per week) is based primarily on laboratory detection levels for PCBs in the 1980s and not strictly risk-based, nor does it reflect currently used toxicity factors for PCBs. Although almost identical to the residential screening level for PCBs in soil of 1.1 mg/kg presented in the ESLs (refer to Table K-1 in Appendix 1), *the TSCA cleanup level of 1.0 mg/kg is not technically supportable and should not be referred to for use in residential soil cleanup actions outside of TSCA-directed investigations.*

TSCA regulations also present a soil cleanup of 25 mg/kg PCBs in "low occupancy areas" (defined as <6.7 hours exposure per week). This cleanup level is presented under "Requirements for decontaminating spills in other restricted access areas." TSCA defines a "restricted access area" as a "...fenced or walled in area" associated with the spill of PCBs in or around an electrical substation or similar area ((40 CFR 760.125(c)(3)). If this doesn't apply to your site, neither does the TSCA cleanup level of 25 mg/kg. *For commercial/industrial sites in general, the TSCA soil cleanup level of 25 mg/kg is not applicable.*

The TCSA cleanup levels for low-occupancy are intended to prevent the buildup of high concentrations of PCBs in small, localized areas where electrical workers may be exposed to spills on a regular basis (e.g., around transformers and other electrical equipment). They were not intended for use as cleanup levels in residential or commercial/industrial areas where PCB containing equipment is no longer being used or was never used. As described in the Toxics Substances Control Act (TSCA) regulations (40 CFR 761.120(e)(2)), the PCB cleanup levels presented were developed assuming "...(worker) exposures associated with ...typical, electrical equipment-type spills..." This can reasonably be interpreted to refer to isolated and localized leaks and spills related to the normal operation of transformers and other electrical equipment.

TSCA regulations also clearly state that "EPA foresees the possibility of exceptional spill situations in which site-specific risk factors may warrant additional cleanup to more stringent numerical decontamination levels than are required by (the TSCA) policy (40 CFR 761.120(b))." For this reason and as summarized above, *the ESLs for PCBs presented in the lookup tables of this guidance document take precedence in all soil cleanup actions not associated with the normal, ongoing operation of transformers and other electrical equipment.*

2.11.5 Hazardous Waste TCLP Standards

Waste is classified as either “hazardous” or “nonhazardous” in part based on Toxicity Characteristic Leaching Procedure (TCLP) analysis for solids and associated TCLP leachate standards (USEPA 1990b). The TCLP leachate standards are intended to determine the type of landfill a waste material must be sent to (USEPA Title 22, Section 66699 - Persistent and Bioaccumulative Toxic Waste). If TCLP standards are exceeded, the waste must be sent to a Class I, hazardous waste landfill (see HDOH 2017). Collection of TCLP data is not required for soil that meets Tier 1 EALs, provided that samples were collected in accordance with the HEER TGM (HDOH 2016).

The TCLP test and associated leachate standards **cannot** be used screen soils for potential environmental hazards, including potential leaching hazards. The criteria, developed in the 1980s, are only loosely based on human health and environmental considerations and apply only to soil (and other materials) placed in a lined, regulated landfill. The TCLP test was not intended or designed to model leaching of contaminants from soil in the natural environment. Dilution attenuation factors assumed in the TCLP standards may not be applicable to settings outside of a landfill setting.

The TCLP test itself is very similar to the Synthetic Precipitation Leaching Procedure (SPLP) test recommended for a more site-specific evaluation of leaching hazards (HDOH 2007a, see Section 4.3.3). Refer to Section 1.2 and Appendix 1 for guidance on appropriate methods for screening of contaminated soil and approaches for evaluation of potential leaching hazards.

2.11.6 OSHA Permissible Exposure Limits

The National Institute for Occupational Safety and Health (NIOSH) is the US Federal agency responsible for conducting research and making recommendations for the prevention of work-related disease and injury, including exposure to hazardous chemicals in air (NIOSH 2007). NIOSH develops and periodically revises Recommended Exposure Limits (RELs) for hazardous substances in the workplace. The RELs are used to promulgate Permissible Exposure Limits (PELs) under the Occupational Safety and Health Act (OSHA).

In most cases, OSHA PELs are not appropriate for health risk evaluations for commercial settings where the chemical is not currently being used as part of a regulated, industrial process. This includes sites affected by the migration of offsite releases (e.g., via emissions from a moving plume of contaminated groundwater). OSHA PELs are derived for an occupational setting, where the chemical in question is used in the industrial process, i.e., workers and others who might be exposed to the chemical have knowledge of the chemical's presence, receive appropriate health and safety training, and may be provided with protective gear to minimize exposures. OSHA PELs are derived for adult, healthy workers and are not intended to protect children, pregnant women, the elderly, or people with compromised immune systems.

As one example, the current OSHA PEL for tetrachloroethylene (PCE) is 678,000 $\mu g/m^3$ (100 ppmv, NIOSH 2007). Comparable risk-based screening levels for commercial/industrial exposure settings included in this document fall between 0.68 $\mu g/m^3$ and 10 $\mu g/m^3$ (carcinogenic effects vs noncarcinogenic effects, respectively; refer to Table E-3 in Appendix 1). The PEL is applicable to regulated work areas where PCE is being used and the employees have been properly trained to minimize exposure. The risk-based screening levels for indoor air presented in this guidance document are applicable to all other areas.

3

Environmental Hazard Evaluations

3.1 Steps to Environmental Hazard Evaluation

Environmental Hazard Evaluation (EHE) ties site investigation activities to remedial actions (refer to Figure 1-1). During this stage of the environmental response process, data collected at the site are reviewed and potential environmental hazards posed by contaminated soil and groundwater are identified and evaluated (Figure 3-1). In most cases this will be a relatively simple task and the text of the evaluation itself will be very brief. Although not required, preparation of the EHE is greatly simplified by comparison of the site data to Tier 1 Environmental Screening Levels (Tier 1 ESLs) and in particular by use of the ESL Surfer.

It is important to begin to identify potential environmental hazards at a site as soon as initial soil, groundwater and other data are received. This is used to guide completion of the site investigation as well as initiate discussions regarding the need for remedial actions. Questions that should be considered as part of the EHE include:

1) Of the initial list of contaminants of potential concern, which contaminants pose potential environmental hazards under uncontrolled site conditions?
2) What are the specific environmental hazards posed by these contaminants?
3) Are additional site data needed to better define the extent and magnitude of contamination or the potential environmental hazards identified?
4) Is an advanced evaluation of a specific environmental hazard warranted?
5) What is the distribution of potential environmental hazards across the site?
6) Are remedial actions required to address the hazards?

Answering these questions is not as difficult as it may at first seem and does not require a significant amount of technical expertise in the field of "risk assessment." Approaching the EHE in a step-wise fashion will ensure that all potential environmental hazards are adequately considered and that the most cost-effective and appropriate remedial actions are selected.

3.1.1 Identify Contaminants of Potential Concern

Contaminants of potential concern (COPCs) are selected based on the known or assumed past use of hazardous chemicals at the site. This is an important part of the Phase I assessment of the site and the subsequent preparation of a sampling and analysis plan. For example, if gasoline was stored at the site then the target COPCs should be TPHgasoline, BTEX, lead and fuel oxygenates. If the site was used to mix pesticides then the specific types of pesticides should be identified. Related contaminants such as arsenic, lead, mercury and dioxins should also be considered COPCs. Chapters 2 and 4 provide additional guidance for petroleum- and pesticide-contaminated sites.

The list of contaminants of potential concern can be quickly narrowed down once representative initial data are obtained by comparing the data to the Tropical Pacific Tier 1 Environmental Screening Levels (Tier 1 ESLs, refer to Chapter 2). If the representative concentration of a contaminant does not exceed the corresponding Tier 1 ESL then it can be reasonably assumed the contaminant does not pose a significant environmental hazard. If the Tier 1 ESL *is* exceeded, then additional evaluation of that contaminant is warranted. Contaminants that exceed the Tier 1 ESLs should continue to be considered COPCs and carried through the environmental hazard evaluation process, as described below.

3.1.2 Identify Potential Environmental Hazards

A summary of common environmental hazards posed by contaminated soil and groundwater is provided in Chapter 1 (see also Figure 1-2a,b). A detailed evaluation of each environmental hazard on a site-specific basis would be an arduous and time consuming task. Fortunately, this level of effort will rarely be necessary. As discussed in Chapter 1, a simple comparison of site data to the Tier 1 ESLs offers a relatively rapid and cost-effective alternative to detailed environmental hazard evaluations and related risk assessments. Use of the ESL Surfer included with this guidance to identify potential environmental hazards and expedite Tier 1 EHEs is highly recommended.

Example printouts of the ESL Surfer are provided in Figures 3-2a (data input form), 3-b (detailed environmental hazards) and 3-2c (EHE summary report). To use the Surfer, select the appropriate site scenario information from the pulldown list (groundwater utility, depth to top of contaminated soil and land use), select the target contaminant, and (optional) input the representative concentration of the contaminant in soil or groundwater (Figure 3-2a). Note that soil screening levels for direct exposure, vapor intrusion and gross contamination hazards are higher (i.e., less stringent) for commercial/industrial land use than for unrestricted ("residential") land use. Soil (and soil vapor) screening levels for leaching hazards are unchanged since, in the absence of required, engineered controls (e.g., pavement over contaminated areas), use of the land for residential versus commercial purposes in itself does not necessarily alter the threat to groundwater.

The Surfer will generate Tier 1 ESLs for the selected chemical and site scenario. If included, the Surfer will also indicate if the input soil and/or groundwater concentration exceeds the Tier 1 ESLs. The input concentrations are compared to screening levels for specific environmental hazards in the second worksheet (Figure 3-2b). The Surfer flags hazards where the screening level is exceeded. A separate, summary report is generated that can be printed and included in the *Environmental Hazard Evaluation* report for the site (Figure 3-2c).

The example presented in Figures 3-2a, b and c is based on an assumed residential land use scenario with contaminated soil situated less than three meters below the ground surface ("shallow soils"). Groundwater is a current or potential source of drinking water. In the example, the input concentrations of benzene in soil (5.1 mg/kg) and in groundwater (150 µg/L) cause the Tier 1 ESLs for both media to flagged (Figure 3-2a). A look at the detailed screening levels worksheet (Figure 3-2b) indicates that benzene in soil at the input concentration could pose soil direct exposure, vapor intrusion and hazards. Groundwater contaminated with 150 µg/L benzene poses drinking water toxicity concerns but no other potential hazards. Note that this concentration also does not exceed the taste threshold (gross contamination), so in the absence of other petroleum chemicals (unlikely) it would not be easily detectable. The input concentration of benzene in soil vapor (34,000 ug/m^3) exceeds the soil vapor screening level for potential vapor intrusion concerns (310 ug/m^3). This also exceeds the soil vapor screening level that indicates the concentration of the chemical in leachate exceeds the groundwater screening level (1,200 ug/m^3, see Figure 3-2b). The presence of a volatile chemical in soil vapors above the screening level implies that downward migration of leachate over time could adversely impact groundwater and should be evaluated in more detail. These potential hazards are summarized in the Summary EHE Report worksheet of the Surfer. This worksheet can be printed and included in the appendices of the formal EHE, with a brief discussion of the potential environmental hazards flagged and recommended followup actions included in the text of the report. Recall that this does not necessarily mean that the contamination does in fact pose the hazards indicated, only that the potential exists and that additional evaluation is warranted.

3.1.3 Complete the Site Investigation

The objective of the site investigation is to determine the extent and magnitude of contamination to the degree needed for adequate identification of potential environmental hazards. Determining the extent of contamination to “non-detect” levels of targeted COPCs is rarely necessary. Site investigation activities can be considered complete when the vertical and lateral extent of contamination above Tier 1 ESLs is determined. In some cases (e.g., investigation of commercial/industrial areas with land use restrictions), the delineation of contamination to higher screening levels is acceptable. Be aware that the distribution of contamination could be discontinuous. For example, irregular pulses of releases over time can result in groundwater plumes that taper off to less than ESLs with increasing distance from the source and then rise again, as an older slug of contaminants is encountered.

The identification of potential environmental hazard(s) and completion of the site investigation is an iterative process. For example, if direct exposure to contaminated soil is flagged as a potential hazard then site data should be reviewed to ensure that the limits of contamination are adequately identified. Estimating representative contaminant concentrations across exposure areas (e.g., residential yards, commercial lots) rather than specific spill areas is generally acceptable. This is because a person is assumed to have equal access (and therefore equal exposure) to all parts of the site, not just the contaminated areas. For large industrial complexes, the property may need to be divided into smaller decision units based on specific exposure areas (e.g., specific work areas at an industrial site). The collection of Multi Increment sample data in specific exposure areas to better estimate exposure point concentrations should also be considered.

If soil leaching hazards are identified either by soil data or soil vapor data then specific spill areas should be identified and treated as separate decision units. Unlike direct exposure hazards, data collected outside of contaminated areas should *not* be considered when estimating representative soil concentrations to assess leaching hazards. This is because the decision unit is the spill area, not the site as a whole, and the target “receptor” of concern is the groundwater that directly underlies the contaminated soil. If Tier 1 soil screening levels for leaching concerns are exceeded then laboratory batch leaching test data can be collected for the target contaminants and a more advanced evaluation of leaching concerns carried out (refer to Chapter 4). Batch tests can also be used to confirm the cleanup of soils contaminated with chemicals that could threaten groundwater resources. Keep in mind that soil data are *not* necessarily good indicators of potential groundwater contamination. This is especially true for chlorinated solvents. Releases of wastewater contaminated with solvents may not leave an identifiable smear zone in vadose-zone soil due to the low sorptive capacity of the solvent compounds.

Soil vapor data are a more reliable indicator of VOCs in vadose-zone leachate than soil data. A soil vapor sample represents a significantly larger area and mass of soil than a traditional soil sample (e.g., one- to six-liter soil vapor sample versus five gram soil aliquot typically analyzed for VOCs). There is also significantly less uncertainty in the use of soil vapor data to estimate VOC concentrations in vadose-zone leachate based on the chemicals Henry’s Constant in comparison to soil data. This is due to very error-prone assumptions regarding sorption and desorption of VOCs to organic carbon and clay that must be incorporated into soil-based screening levels. Only five grams of soil are typically analyzed by the laboratory for VOCS for a single, discrete sample (less than one teaspoon). This is unlikely to be representative of the surrounding soil. Soil vapor data are less useful than soil data for estimation of the actual mass of contaminant present, however, since the estimation of the sorbed-phase mass of contaminant based on vapor data is likewise very prone to error (likely to be underestimated). A combination of both data types may be desirable at sites where potential leaching hazards are initially identified and remediation could be required. Multi Increment soil sampling approaches combined with the use of methanol in the field offer the most defensible and useful type of soil data (see HDOH 2016).

Soil data alone are not considered to be adequate to rule out vapor intrusion hazards at sites where significant releases of volatile chemicals have occurred. The collection of concurrent, soil vapor data will generally be necessary. The collection of methane data is also useful at sites with heavy petroleum contamination.

3.1.4 Evaluate Targeted Environmental Hazards

Potential environmental hazards flagged by comparison of site data to Tier 1 ESLs (or approved alternative screening levels) may or may not in fact exist at the site. The ESLs intentionally assume uncontrolled current and future site conditions in order to minimize future restrictions on use of the property (i.e., unpaved, soil exposed at the surface, contaminants not strongly bound to soil, nearby aquatic habitats, etc.). Actual site conditions could differ, causing the contaminants to pose a much lower threat to human health and the environment than a simple, screening level evaluation might imply. In these cases a more advanced and site-specific evaluation of targeted hazards is advisable and in some cases could even be required. Example approaches for evaluation of specific environmental hazards are provided in Chapter 4.

3.1.5 Identify Potential Additional Environmental Hazards

The ESLs are intended to address common environmental hazards at sites where contaminated soil and groundwater are identified. The majority of these sites will be located in industrialized or urbanized areas where the threat to sensitive ecological habitats is limited. Additional, potential environmental hazards should be identified and evaluated as appropriate on a site-by-site basis (refer to discussion of ESL limitations in Section 1.6). This could include the runoff of contaminated soil into aquatic habitats and impacts on sediment quality, bioaccumulation of contaminants aquatic organisms, uptake of contaminants in produce, explosive hazards associated with methane buildup, etc. (refer also to Chapter 4 – *Advanced Environmental Hazard Evaluations*).

3.1.6 Prepare Environmental Hazard Maps

Question Five asks about the distribution of environmental hazards across the site. Instead of thinking in terms of contaminants and contaminant concentrations, it is now important to start thinking in terms of the actual hazards posed by the contaminants at the site. What areas of the site pose potential direct exposure or vapor intrusion hazards? What areas of the site pose potential leaching hazards? In what areas will grossly contaminated soil likely be encountered during future subsurface activities?

Understanding the site in terms of environmental hazards rather than just contaminant concentrations is important, since this understanding serves as the basis for cleanup decision-making as well as long-term management plans. For the latter, the post-cleanup, “as-built” *environmental hazard maps* can be especially useful. As discussed in the previous sections, this can be accomplished by comparison of site data to ESLs (or acceptable alternatives) for targeted hazards. While not necessarily required to complete a project, such maps can help guide completion of and summarize the results of a site investigation, as well as assist those tasked with the preparation of remedial actions. A combination of contaminant distribution maps and environmental hazard maps may, however, be required for sites where contamination above screening levels for unrestricted future use of the property is to be left in place and managed over time.

An example soil environmental hazard map (based on a former pesticide mixing area) where soil is contaminated with dioxin, arsenic, chlorinated pesticides, and heavy oil is presented in Figure 3-3. Areas of specific hazards were delineated by comparison of soil data to detailed environmental screening levels (e.g., refer to Tropical Pacific ESL Surfer). Remedial options could vary with respect to the specific environmental hazard(s) posed in a given area. As an interim measure, contaminated soil that poses direct exposure hazards can be consolidated and placed under a well-managed soil cap. Areas of contaminated soil that pose leaching concerns will, in contrast, require some type of impermeable cap. Immediate removal of soil that is grossly contaminated with petroleum is recommended.

An example groundwater environmental hazard map is presented in Figure 3-4 (based after a former gasoline bulk fuel terminal). Contaminated soil has been removed. Remaining groundwater contamination poses several potential hazards, including vapor intrusion, toxicity to aquatic habitats, and gross contamination along the shoreline (odors and sheens). Areas of specific hazards were delineated by comparison of groundwater data to detailed environmental screening levels (e.g., refer to Tropical Pacific ESL Surfer). The site was to be redeveloped for residential use. Soil vapor data confirmed potential vapor intrusion hazards. Aggressive treatment of the area of groundwater that posed vapor intrusion hazards was required prior to redevelopment. Aggressive remediation of groundwater that posed acute aquatic toxicity hazards and gross contamination (odors and sheens) within 50 meters of the shoreline was also required. Long-term monitoring of remaining groundwater contamination was required.

As described above, property owners, developers, and their consultants can utilize environmental hazard maps to help prioritize aggressive (and often costly) site cleanup actions by focusing resources on the most pressing hazards first. In many cases this may permit redevelopment of the site prior to the completion of final cleanup actions and the generation of funds to address remaining environmental hazards through less aggressive and presumably less costly measures (e.g., focused treatment of spill areas, in situ treatment of remaining groundwater contamination, long-term monitoring, institutional and engineering controls, etc.).

3.1.7 Recommend Followup Response Actions

Determining the most appropriate response to address environmental hazards at contaminated sites depends on a number of factors, including the presence or absence of hazards under current conditions, the planned future use of the site, the cost-benefit of postponing cleanup until a later time, natural attenuation of contaminants over time, regulatory requirements, etc. A partial list of potential recommendations is provided under Item 7 in Section 3.2. Refer also to advanced environmental hazard evaluation approaches discussed in Chapter 4, as well as the Hawai‘i TGM (HDOH 2016).

Preparing a simple summary of environmental hazards posed under current site conditions versus unrestricted site conditions can aid in the selection of appropriate response actions. What types of environmental hazards could the contamination pose under uncontrolled (unrestricted) site conditions? What controls are currently in place to eliminate or reduce these hazards? What types of additional actions are needed to address existing hazards? What type of response actions are needed to fully eliminate the environmental hazards and allow unrestricted, future use of the site? What type of hazards will still be present at the site following the recommended response action in the absence of engineered or institutional controls? Do recommended controls need to be formally implemented at the site (e.g., via a covenant to the deed)? An example format for summarizing these issues is provided in Figure 3-5a (contaminated soil) and Figure 3-5b (contaminated groundwater).

When practical, full cleanup of contaminated soil and groundwater to permit future unrestricted use of a property is desirable. If full cleanup will not be carried out, the extent and magnitude of remaining contamination must be summarized and the potential environmental hazards posed by the contamination under uncontrolled conditions clearly described. The need for institutional and engineering controls must then be evaluated. These controls could include restrictions on activities such as excavation or well drilling, installation of vapor mitigation systems under buildings, capping of contaminated soil to prevent exposure or leaching, long-term monitoring of groundwater, etc. These actions must be described in a site-specific, *Environmental Hazard Management Plan*. The preparation of *Environmental Hazard Management Plans* is discussed in more detail in Chapter 5.

3.2 Preparation of Environmental Hazard Evaluation Reports

The *Environmental Hazard Evaluation* (EHE) should serve as "stand alone" report that provide a good summary of environment impacts at a site and the existing or potential hazards posed by the contamination. The report should include the following information:

1. Site Background
    - Describe past and current site uses and activities.
    - Describe reasonably anticipated future site uses and activities. (*Always* include a comparison of site data to ESLs for unrestricted (“residential”) land use to evaluate need for formal land use restrictions and other institutional and engineered controls; see Section 2.8).
2. Summary of investigations (including to-scale maps with a north arrow):
    - Identify all types of impacted media (soil, groundwater, surface water, etc.).
    - Identify all sources of chemical releases.
    - Identify initial chemicals of potential concern.
    - Identify magnitude and extent of impacts that exceed ESLs to extent practicable and applicable (include maps of site with isoconcentration contours for soil and groundwater as practicable).
    - Identify nearby groundwater extraction wells, bodies of surface water and other potentially sensitive ecological habitats.
    - Ensure data are representative of site conditions.
3. Applicability of Tier 1 ESLs or alternative screening levels:
    - Do Tier 1 ESLs exist for all chemicals of concern?

- Does the site have a high public profile and therefore require a higher degree of decision confidence (including preparation of a detailed, human health risk assessment)?
- Do soil and groundwater conditions at the site differ significantly from those assumed in development of the lookup tables (e.g., low pH at mine sites)?
- Do impacts pose a heightened threat to sensitive ecological habitats (e.g., presence of endangered or protected species)?
- Have more than ten carcinogens or five chemicals with similar noncarcinogenic health effects been identified (excluding petroleum, see Section 2.9)?
- Other issues as applicable to the site.

4. Selection of soil and groundwater categories:
    - State the regulatory beneficial use of impacted or potentially impacted groundwater beneath the site; discuss the actual, likely beneficial use of groundwater based on measured or assumed quality of the groundwater and the hydrogeologic nature of the soil or bedrock containing the groundwater.
    - Characterize the soil type(s) and location of impacted soil as applicable to the lookup tables (e.g., soil stratigraphy, soil texture and permeability, depth to and thickness of impacted soil, etc.).
5. Selection of ESLs and comparison to site data.
    - Summarize how Tier 1 ESLs were selected with respect to the information provided above and additional assumptions as applicable.
    - Compare site data to the selected summary Tier 1 ESLs (see Tables A-H or use EAL Surfer) and identify areas of soil or groundwater that pose potential environmental hazards.

6. Identification of potential environmental hazards:
    - Identify specific, potential environmental hazards by comparison of site data to detailed ESLs for individual hazards (use the ESL Surfer; detailed tables presented in Volume 2, Appendix 1).
    - Identify any additional, potential environmental hazards not specifically addressed by the ESLs (refer to Section 3.1.5).
    - Discuss specific, potential environmental hazards present at site.
    - Include environmental hazard maps in the EHE to help guide followup remedial actions and long-term site management plans.
7. Conclusions and recommendations for followup actions, such as:
    - Recommendation for more advanced evaluation of specific, environmental hazards (e.g., direct exposure, vapor intrusion or leaching hazards);
    - Recommendation for an evaluation of remedial alternatives, including site-specific human health or ecological risk assessments;
    - Recommendation for land-use restrictions and/or institutional controls based on the identified environmental hazards and in the absence of full site cleanup (e.g., requirements for caps, need for covenant to deed to restrict land use to commercial/industrial purposes only, etc.).
    - Recommendation for preparation of an *Environmental Hazard Management Plan* (required for all sites where contamination above Tier 1 EALs left in place)..

The conclusions and recommendations of the EHE should be incorporated into the remedy selection process.

The above elements are not intended to be exhaustive or representative of an exact outline required for all Tier 1 EHEs. The level of detail required for an EHE will vary depending on the complexity of the site and the ease at which contamination concerns can be addressed. For relatively simple sites, the EHE can be included as a separate chapter in the post-remediation report with ESL Surfer printouts for target COPCs included in the appendices. As discussed above, both maps that summarize the extent and magnitude of contamination as well as maps that depict areas of specific environmental hazards (or some combined form of the maps) are very useful components of EHEs. This information may then be passed on to persons developing remediation action plans for active cleanup of contaminated areas and/or Environmental Hazard Management Plans for long-term management of sites that cannot be fully cleaned up.

Conditions that pose immediate or short-term environmental hazards should be addressed as quickly as possible. This includes exposure of residents or workers to potentially harmful levels of contaminants in soil ("direct exposure"), impacts to water supply wells, intrusion of vapors or methane into overlying structures (including explosion hazards) and discharges of free product to surface water.

Note that the approach described above is referred to as Environmental "Risk" Assessment in previous guidance documents (e.g., CNMI 2005b). The term "risk" is replaced with the term "hazard" in this guidance document. This was done to emphasize the fact that some environmental concerns are not necessarily toxicological in nature, as the term "risk" is often interpreted to indicate. Examples include explosion hazards, leaching of contaminants from soil to groundwater, and even general gross contamination concerns. Human health and ecological risk assessments are of course important components of an *Environmental Hazard Evaluation*, but they cannot be used as stand-alone tools to determine the need for potential cleanup actions at sites where petroleum-contaminated soil and groundwater are identified (refer to Section 1.2). Additional information on human health and ecological risk assessments is provided in Chapter 4.

4

Advanced Environmental Hazard Evaluations

4.1.1 Tier 1 Screening Level Assumptions and Flexibility

The Tier 1 ESLs presented in this guidance incorporate a large number of conservative assumptions about the toxicity of a chemical and the potential exposure to that chemical. These assumptions can be reviewed on a site-specific basis as needed. This will be most common (though still rare) for soil screening levels in general and for soil, soil vapor and groundwater screening levels intended to flag potential vapor intrusion hazards.

The Tier 1 soil screening levels are based on an assumed current or future unrestricted land use (e.g., residential) and an assumption that the soil is currently exposed at the ground surface, or could be in the future (see Section 1.2 and Appendix 1, Chapter 4). Alternative screening levels for commercial/industrial land use versus residential land use and subsurface versus surface or near surface soils are provided in Appendix 1. These screening levels can be referred to in a site-specific Environmental Hazard Evaluation if desired. This allows for more flexible use of the EHE guidance without the time and cost of independently developing similar, alternative screening levels on a case-by-case basis. Note that use of alternative site assumptions could, however, impose land use restrictions on the property (e.g., commercial use only and/or long-term management of subsurface contaminated soil).

It is important to understand that the screening levels presented in this guidance are optional for use and intentionally conservative for the majority of sites where investigations are carried out. As discussed in the previous sections, concentrations of chemicals above the screening levels do not necessarily indicate that the chemicals pose a potential risk to human health and the environment, only that additional evaluation is warranted. The screening levels in general denote the *lowermost concentration* of a range of potentially acceptable contaminant concentrations in the targeted media (i.e., indoor air, soil vapor, soil and groundwater). Potentially acceptable contaminant concentrations in soil could be significantly higher than the Tier 1 ESLs and still be protective human health and the environment. In most cases it will be more time- and cost-beneficial to simply refer to the screening levels for final decision making purposes, however, rather than develop site-specific screening levels. In other cases, adjustment of the screening levels on a site-specific basis may be desirable or even required by the overseeing regulatory agency (e.g., to address cumulative risk at sites with a large number of contaminants).

Site-specific screening levels for indoor air and groundwater that is a source of drinking water are the least flexible, discounting consideration of natural background. This is because there are relatively few site-specific variables for these media, other than target risk (see Appendix 2). For example, exposure models assume that the average person inhales 10-20 m^3 of air and drinks one-two liters of water a day. Many of the drinking water screening levels are also promulgated standards that cannot be adjusted. With the exception of target risk for indoor air, these assumptions cannot be significantly altered on a site-specific basis.

Groundwater screening levels for potential discharges into an aquatic habitat or for vapor intrusion hazards could, in theory, be adjusted on a more site-specific basis. This will rarely be practical or beneficial, however (see Section 4.4). For the former the next step is more likely to be characterization and monitoring of the groundwater plume and a closer look at potential groundwater-surface water interactions if an aquatic habitat is indeed threatened. The next step for potential vapor intrusion hazards will be the collection of soil vapor data, rather than additional modeling.

Development of site-specific soil screening levels will be more common. Soil screening levels are much more complicated and dependent on a long list of site-specific and chemical-specific factors. This is reflected by a wide range of potentially acceptable screening levels and one reason why the USEPA and individual states rarely promulgate soil screening levels as legally required, “cleanup standards.” When they do, allowances are almost always made for development of more site-specific screening levels when necessary. Factors considered to generate the Tier 1 soil screening levels presented in this guidance include (see Appendix 1):

- Land use;

- Area, thickness and volume of impacted soil;
- Number of contaminants present;
- Chemical bioavailability/bioaccessibility
- Biodegradation;
- Groundcover (e.g., pavement vs grass vs barren soil);
- Depth to contaminated soil;
- Distance from slab of building to top of impacted soil (VOCs);
- Fraction organic carbon in soil;
- Soil density;
- Particle density;
- Soil porosity;
- Soil air-filled porosity;
- Soil water-filled porosity;
- Soil temperature;
- Rainfall;
- Evapotranspiration;
- Soil pH and Redox potential; and
- Groundwater depth, utility, flow rate and proximity to a surface water body.

Conservative assumptions about these site characteristics are incorporated into the models used to generate the soil screening levels (described in the appendices). Each of these parameters could in theory be evaluated in an advanced, site-specific EHE, although in most cases this will have only a minor effect on the original screening level and not be time- or cost-beneficial. Potential common exceptions include a consideration of land use, area and volume of contaminated soil, potential exposure at the ground surface, bioaccessibility of arsenic in contaminated soil and the use of laboratory batch tests to provide a more accurate evaluation of potential soil leaching hazards.

The range of potentially acceptable cancer and noncancer health risks that could be used to develop soil screening levels is also a very important controlling factor. Target risks used to develop the Tier 1 soil screening levels generally assume the presence of multiple contaminants with similar, potential health effects at a site (see Appendix 1). This is done in order to ensure that potential cumulative health effects are taken into account upfront and minimize the time and cost required to do this on a site-by-site basis. For example, a target, excess cancer risk of one-in-a-million is used to generate screening levels for most carcinogens. This is the most stringent of the potentially acceptable excess cancer risk range of one-in-a-million (10^{-6}) to one-in-a-ten-thousand (10^{-4}). This in itself reflects a potential upward adjustment of site-specific soil screening levels by up to two orders of magnitude. Screening levels for noncarcinogens similarly incorporate a default, conservative assumption that up to four other chemicals with similar health effects could be present in the soil (see Appendix 1). If only a single chemical were present then based on this factor alone the soil screening level could be safely increased five-fold and still be protective of direct-exposure concerns.

As discussed in Section 4.2 and Appendix 1, adjustment of target cancer and noncancer risks to more reasonable levels was made upfront for several chemicals, based on a better understanding of the occurrence and nature of the chemicals at sites investigated in developed areas well as a more detailed review of toxicological studies. This includes chemicals that are ubiquitous in trace amount in soil, such as arsenic, PAHs and dioxins. This also includes chemicals that do not usually co-occur with other chemicals in significant amounts, such as organochlorine pesticides in termite-treated soils around and under buildings (e.g., Technical Chlordane and aldrin, with its breakdown product dieldrin). In these cases less stringent, but still protective, target health risks were used to develop Tier 1 soil screening levels upfront in order to minimize the need to so on a site-by-site basis. Cumulative risks may need to be evaluated in more detail if multiple contaminants are indeed present at a site, however.

Site-specific exposure assumptions such as exposure duration and frequency and soil ingestion rates can likewise be evaluated on a case-by-case basis, although this could lead to a requirement for land use restrictions or engineered controls. Potential variations in these assumptions generally affect soil screening levels by less than a factor of three to five. Published toxicity factors used to develop the soil screening levels incorporate another host of assumptions and safety factors that can be reviewed on a case-by-case basis if warranted. As described in the next section, however, this process is much more time consuming and will require significant input from an experienced toxicologist and approval by the overseeing regulatory agency.

4.1.2 Direct-Exposure Screening Level Safety Factors

It is important to understand the significance of safety factors incorporated into direct-exposure screening levels for soil (and other media). The majority of these built-in safety factors are left untouched in a site-specific EHE or risk assessment.

Screening levels presented in this document are, for example, presented to two significant digits (see Appendix 1). Calculation of site-specific cancer risk noncancer hazard is rounded to the nearest, whole number, however, due in part to uncertainty already built into the toxicity factors (e.g., see USEPA 1989a). This implies that a concentration of 149 mg/kg of Chemical X in soil adequately satisfies a target screening level of 100 mg/kg, since the ratio of the two is less than 1.5 and thus rounds to the target, acceptable hazard quotient of 1 (cumulative risk not considered in this example). While it is still useful to remediate a contaminated site to the target screening level, these types of risk-based considerations should be taken into account in terms of feasibility and the cost-benefit of additional remediation.

Table 4-1 and Figure 4-1 illustrate an example of the development of soil screening levels for typical chemical, modeled after dieldrin (see USEPA 1990c; for example only and not intended to be comprehensive). The process begins with the development of noncancer toxicity factors and selection of a *Lowest Observed Adverse Effects Level* (LOAEL), usually from animal studies. In the case of dieldrin the selected LOAEL is 0.05 mg/kg-day (i.e., 0.05 mg of dieldrin ingested per kilogram of body weight per day (USEPA 1990c). Health effects were identified in the laboratory animals after long-term, chronic (e.g. several years) exposure this level of dieldrin. Much higher levels would have been required to see acute health effects within days or weeks (or even minutes).

Next, a *No Observed Adverse Effects Level* (NOAEL) is estimated. As the name implies, this is the level where no adverse health effects were observed in laboratory studies. A NOAEL of 0.005 mg/kg-day was selected for dieldrin, in this case assumed to be 1/10th of the LOAEL since a clear threshold was not identified in the studies (i.e., the lower the noncancer toxicity factor the more conservative; USEPA 1990c).

For the purpose of this example, the LOAEL and NOAEL are converted to equivalent dieldrin concentrations in soil, following the same models and exposure assumptions used to develop the residential, direct exposure soil screening levels presented in Appendix 1 (see Table 4-1 and Figure 4-1). A LOAEL of 0.05 mg/kg-day corresponds to an equivalent, risk-based concentration in soil of 3,100 mg/kg (based on target noncancer Hazard Quotient of 1.0). The more conservative NOAEL of 0.005 mg/kg-day equates to a correspondingly lower, equivalent concentration in soil of 310 mg/kg.

Laboratory-based LOAELs and NOAELs are almost always further adjusted downwards (i.e., made more conservative) before use in human health risk assessment. The NOAEL is then further adjusted downwards (i.e, made more stringent) by a series of safety and uncertainty factors in order to generate a noncancer Reference Dose (RfD) for use in human health risk assessments or for the development of risk-based screening levels. In the example, the NOAEL is first divided by an uncertainty factor of ten to take into account the extrapolation of laboratory animal data to human exposure. This is then divided by an additional uncertainty factor of ten to take into account the lack of a reliable threshold dose below which no adverse health effects will occur. The initial NOAEL based on animal studies is therefore divided by a total uncertainty factor of 100 in order to generate an RfD for use in human health risk assessment. This generates a final RfD of 0.00005 mg/kg-day (see Table 4-1). This similarly reduces the equivalent soil screening level by a factor of 100, to 3.1 mg/kg (see Figure 4-1).

For development of an initial, Tier 1 screening level, the soil screening level for noncancer health risk is further reduced by a factor of up to five (i.e., reduction in target Hazard Quotient from 1.0 to 0.2) to take into account the potential presence of other chemicals in the soil with similar health effects and associated cumulative health risks (see Figure 4-1; see also Section 2.9). This generates a final, residential soil screening level for potential noncancer, direct-exposure hazards of 0.60 mg/kg. Note that this step is not considered in the USEPA RSLs (USEPA 2017). The USEPA guidance instead recommends that cumulative risk be evaluated at sites with multiple contaminants, although in practice this is rarely done (see Section 2.11.1).

Additional considerations such as potential cancer risks (if applicable) are then taken into account to determine if further reduction of the soil screening level is warranted. In the case of dieldrin, potentially acceptable, cancer-based soil screening levels range from 0.03 mg/kg to 3.0 mg/kg, reflecting the potentially acceptable excess cancer risk (ECR) range of 10^{-4} to 10^{-6} (see Table 4-1 and Figure 4-1; see also Appendix 1, Table K-1).

The final, Tier 1 soil screening level for dieldrin could therefore be set anywhere between 0.03 mg/kg and 3.0 mg/kg in order to address both cancer and noncancer risk (see Figure 4-1). Where the level is ultimately set depends on the target risks used and the assumed number of other chemicals present. In the case of dieldrin, a final, Tier 1 screening level for unrestricted land use of 1.5 mg/kg was selected, based on a target noncancer Hazard Quotient of 0.5 (see Figure 4-1; see also Table A and Appendix 1, Section 4.2.2). The target Hazard Quotient takes into consideration the likely co-occurrence of dieldrin with its parent chemical, aldrin. This screening level also takes into consideration weaker evidence of carcinogenicity for dieldrin and meets the upper limit to the acceptable excess cancer risk of 10^{-4}. Cumulative health risks would need to be evaluated if other chemicals with similar health effects were identified in soil at concentrations that approach their respective, direct-exposure screening levels.

Consideration of alternative exposure assumptions in a site-specific EHE could further increase the maximum-acceptable concentration of a chemical in soil (e.g., commercial/industrial use, exposure duration, assumed soil ingestion rate, etc.). Doing so may impose land use restrictions and even engineered controls on the property, however. A closer evaluation of the studies and assumptions used to develop toxicity factors could also be carried out in a more formal, human health risk assessment. This would be more time consuming and require input from an experienced toxicologist, as well as approval by the overseeing regulatory agency. In the case of dieldrin, leaching concerns and other potential environmental hazards would also need to be evaluated in more detail (e.g., by SPLP batch tests; see Section 4.3.3).

This example is intended to demonstrate the range of potentially acceptable soil screening levels that could be developed on a site-specific basis. The actual range of acceptable levels will vary from chemical to chemical. Again note that the large safety factors built into the conversion of the dieldrin Lowest Observed Affects Level to the final Reference Dose are not affected by the site-specific adjustment of target risk or exposure assumptions (see Table 4-1 and Figure 4-1).

4.2 Tentatively Identified Environmental Hazards

Potential environmental hazards posed by contaminated soil and groundwater can be identified by direct comparison of site data to Tier 1 Environmental Screening Levels (Tier 1 ESLs) or approved, alternative screening levels (refer to Chapter 3). The Tier 1 ESLs assume uncontrolled and unrestricted current and future site conditions. Conservative assumptions are also made about mobility, persistence and toxicity of the target contaminants. This approach allows sites with minimal contamination to be quickly cleared for unrestricted use, without the need for time consuming and costly investigations and assessments.

A more detailed review of specific environmental hazards should be considered when costly remedial actions could be required. A summary of advanced evaluation approaches is provided in Figures 4-2a (soil) and 4-2b (groundwater). For example:

- At arsenic sites, relatively inexpensive bioaccessibility tests often indicate that the majority of arsenic in pesticide-contaminated soil is so tightly bound to the soil that it is essentially nontoxic. This can significantly reduce or even eliminate the need for capping or aggressive treatment of contaminated soil.

- Long-term monitoring of petroleum-contaminated groundwater is likely to indicate that the groundwater contaminant plume will rapidly shrink once the source of the release and gross contamination is removed (see Chapter 5). This can be used to support a remedy of focused, aggressive treatment in the immediate release area and natural attenuation as the selected remedy in outer areas of the plume.

- Soil vapor data provide a much more realistic idea of vapor intrusion hazards initially flagged by a comparison or soil or groundwater data to Tier 1 screening levels for this concern. Collection of soil vapor data and comparison to screening levels for potential vapor intrusion hazards will expedite the identification of buildings or even specific areas of buildings at high risk for potential indoor air impacts (see Table G).

- If direct-exposure to contaminated soil is the driving environmental hazard at a site and the contamination cannot be cost-effectively removed, then placement of a restriction on future land use can reduce or even eliminate the need for aggressive remedial actions (e.g., commercial/industrial land use only).

Although "advanced," these and other approaches for a more site-specific review of potential environmental hazards flagged during the Tier 1 environmental hazard evaluation are not necessarily costly and do not necessarily require a significantly greater amount of technical expertise.

These and other example approaches for more advanced evaluations are outlined below. These evaluations can be relatively simple, such as the use of groundwater monitoring data to evaluate leaching and plume migration hazards or soil vapor data to better evaluate vapor intrusion hazards. Other approaches can be very time-consuming and do require more technical expertise, such as the preparation of a human health or ecological risk assessment.

A brief overview of human health risk assessments and ecological risk assessments are provided at the end of this section. Although the nomenclature and intent of the two types of documents is often confused, it is important to understand that a traditional human health risk assessment *cannot* be used in place of an *Environmental Hazard Evaluation*. Human health risk assessment focuses on toxicological risks to humans associated with direct exposure to contaminated soil, groundwater, or air. While these risks are important, direct exposure is only one of several potential environmental hazards that are addressed in a more comprehensive EHE (refer to Section 1.2). Screening levels specifically developed to screen for potential direct-exposure concerns are incorporated in the Tier 1 ESLs (based on USEPA RSLs, see below). Preparation of a traditional, human health risk assessment is generally only necessary at sites where exposure of residents or workers to contamination above target, risk-based screening levels is taking place and cannot be immediately remedied or where significant contamination is to be managed in place in residential or other sensitive use developments (schools, day care centers, medical facilities, etc.; refer to Section 4.3.1). In some cases, legal needs on the part of the responsible party could also require preparation of a detailed human health risk assessment.

4.3 Advanced Evaluations of Contaminated Soil

Example approaches for advanced evaluation of environmental hazards posed by contaminated soil are presented in Figure 4-2a. A brief discussion of highlighted topics is provided below.

4.3.1 Direct Exposure

4.3.1.1 Tier 2 Direct Exposure Model

This guidance document includes an easy-to-use, Excel-based spreadsheet model (available for download from Hawai‘i DOH EHE webpage; HDOH 2017a) that calculates site-specific, Tier 2 direct-exposure screening levels for soil based modifications to default site conditions and human exposure assumptions. The model uses the same equations used to develop the USEPA RSLs and the Tier 1 screening levels for direct-exposure hazards (USEPA 2017; refer to Appendix 1). Printouts of the model input pages (first two worksheets, two pages) should be included in the Environmental Hazard Evaluation. All changes made to default input parameter values must be discussed and supported in the text of the report.

A copy of the first page of the model is provided in Figure 4-3. To use the model, simply select the contaminant of concern, select the land use exposure scenario, and adjust the soil parameter values as appropriate based on site data. Assumed soil properties typically have very little effect on calculated direct-exposure screening levels. An exception is the input thickness of contaminated soil for volatile chemicals. The USEPA source model assumes that the emission of a volatile chemical from contaminated soil remains constant over the entire 30-year exposure period (USEPA 2002a, 2016). This constant emission progressively depletes the mass of the chemical in the soil over time. For highly volatile chemicals such as vinyl chloride and even benzene, maintaining the model's theoretical vapor emission rate over 30 years would require the volume of contaminated soil to be tens of meters thick. This is not realistic for most sites.

The Tier 2 direct-exposure model includes an alternative, "mass-balanced" volatilization factor that establishes a maximum, long-term vapor emission rate based on the mass of contaminant present and the assumed exposure duration (default exposure duration = 30 years, USEPA 2017). To adjust the soil screening levels simply input the site-specific thickness of soil above Tier 1 ESLs. The spreadsheet automatically generates an adjusted, Tier 2, direct-exposure screening level for the selected land use. A screening level is also generated for construction worker exposure. If the latter is lower than the Tier 2 screening level for the selected exposure scenario then it is selected as the final, screening level. Risk-based soil screening levels for construction workers can in particular be more stringent than those for commercial workers at sites where soils are contaminated with metals that are highly toxic via inhalation in dust (e.g., beryllium, Cr VI, cobalt, etc.; refer to Table K-2 in Appendix 1).

Changing the input site parameters beyond the assumed exposure scenario will have very little effect on screening levels for nonvolatile chemicals. This is because the thickness of contaminated soil at a site (or more correctly the mass of the contaminant present) does not play a significant role in estimating the risk or calculating soil screening levels for nonvolatile contaminants. Exposure assumptions (exposure duration, target risk etc.) can be adjusted in the spreadsheet. However, most of these assumptions are essentially "fixed" for the noted exposure scenario and will require review by a toxicologist for approval.

4.3.1.2 Screening Levels for Arsenic

Direct exposure soil screening levels for arsenic are based on guidance published by the Hawai‘i DOH (HDOH 2011). A copy of the Hawai‘i technical memorandums is provided in Appendix 8. An overview of the basis of the screening levels is provided below (see also Appendix 1).

A summary of soil screening levels and guidance for arsenic is provided in Figures 4-4. A detailed discussion of the background of the soil screening levels and guidance for arsenic as published by Hawai'i is provided in Appendix 7. The reported concentration of total arsenic should be used to initially screen soils for potential contamination concerns. If the reported total concentration of arsenic exceeds 20 mg/kg in the 2mm fraction (assumed upper limit of natural background), then the samples should be tested for *bioaccessible* arsenic and compared to the screening levels noted in Figure 4-4. The screening levels apply to bioaccessible arsenic in the <250µm fraction of the soil.

Bioaccessible arsenic is the fraction of the total arsenic in ingested soil that could be available for absorption by a person's digestive tract and pose health risks. Equivalent concentrations of bioaccessible arsenic in soil are calculated by multiplying the reported total concentration of arsenic by the fraction that is determined to be bioaccessible by site-specific bioaccessibility tests.

Use of the Solubility/Bioavailability Research Council (SBRC) gastric-phase bioaccessibility method is recommended (Drexler and Brattin 2007; refer to Section 9 of the HEER office Technical Guidance Manual, HDOH 2016; see also Diamond et al. 2016). As an alternative, the USEPA default bioaccessibility for arsenic in soil of 0.6 (60%) can be applied to total arsenic reported for the <250 micron soil fraction (USEPA 2012a). If the adjusted concentration of arsenic is less than the target action level then no further action is necessary.

If other contaminants are present at or near their screening levels for direct-exposure concerns then the cumulative health risk should be evaluated in a more site-specific, human-health risk assessment. The arsenic screening levels do not consider potential leaching of arsenic from soil and subsequent impacts to groundwater. The use of laboratory batch tests to evaluate this potential hazard is recommended. Refer to Section 4.3.3 for additional information

4.3.1.3 Soil Screening Levels for Lead

The current, USEPA residential RSL of 400 mg/kg is intended to reflect a target blood-lead level in children of 10 ug/dl (USEPA 2017). It is anticipated that the USEPA will reduce the residential soil lead RSL in the near future. This value was used in past editions of this guidance. A screening level of 200 mg/kg was selected for use in the Fall 2017 update to the TPESL guidance (see Table K-1), identical to the action level used in Hawaii since 2005 (HDOH 2017a). This in part reflects upcoming USEPA recommendations to reduce the target blood level to 5 µg/dl (USEPA 2011a; USCDC 2012a,b).

The model used to calculate soil screening levels for lead is not linear, however (USEPA 2007). A reduction in the soil action level for lead below 200 mg/kg is not practical for heavily developed, urban areas, however. Background, anthropogenic levels of lead in urban soils from past auto exhaust and other sources is estimated to average 75-200 mg/kg and in places far exceed these values (USEPA 1994, 1998). The use of an action level below 200 mg/kg can complicate the identification and characterization of localized contamination that could conceivable be remediated.

The inclusion of soil that exceeds anticipated, natural background for lead in remediation plans is recommended when practicable and when the contamination can be attributed to a specific release. Capping, landscaping (including a well-maintained lawn) or other efforts to minimize exposure of young children should be considered where area-wide impacts above 200 mg/kg lead are identified, regardless of the suspected source.

4.3.1.4 Screening Levels for TEQ Dioxins

A detailed discussion of Tier 2 action levels and guidance for dioxins and furans (“dioxins) is provided in Appendix 8 (HDOH 2010b). A summary of HDOH Tier 2 action levels for dioxins is provided in Figure 4-5. **Remediation of sites to the HDOH default soil background level of 20 ng/kg TEQ dioxins should be considered to the extent practicable for residential sites where contamination in excess of 240 ng/kg is initially idenitified (refer to HDOH 2010b).** Note that the Reference Dose used to develop the dioxin action levels incorporates an assumed bioavailability of 50%. The residential action level therefore reflects an equivalent concentration of bioavailable TEQ dioxin in soil of 120 ng/kg.

Dioxins are contaminants of potential concern in former agricultural areas due to their presence as manufacturing-related impurities in pesticides, especially pentachlorophenol, 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), and 2,4,5-trichlorophenoxypropionic acid (2,4,5-TP or Silvex). These pesticides were commonly used in sugar cane and other operations (see Section 9 of the HEER office Technical Guidance Manual; HDOH 2016 and updates). Dioxins can also be created when organic material is burned in the presence of chlorine.

Quantification of dioxins in soil for use in human health risk assessments requires conversion of congener-specific GC/MS data to Toxicity Equivalent (TEQ) dioxin concentrations by use of Toxicity Equivalence Factors (TEFs; WHO 2005). The TEQ concentrations for individual congeners are then added together to calculate a total TEQ dioxin concentration for the sample. Tier 2 soil action levels presented in the HDOH guidance are applicable to adjusted TEQ dioxin data. A value of ½ of the laboratory Method Detection Limit (MDL) should be used for calculation of a TEQ dioxin concentration if the subject isomer was detected above the MDL in one or more samples from the same area.

Laboratory bioassay methods offer a cheaper alternative for dioxin analysis in comparison to standard GC/MC methods (typically 50% or less than GC/MS; HDOH 2007c). Methods currently available include CALUX and Cape Technology's DF1 kit, with CALUX currently in most use. Laboratory method procedures for CALUX have also been formalized (USEPA 2008). A Bioassay data are reported directly in terms of TEQ concentrations and do not require conversion using congener-specific TEFs. Ten percent of the samples (minimum two per site) should be tested using GC/MS to confirm bioassay-based TEQ dioxin data. The GC/MS analyses should be conducted on samples with the highest-reported bioassay TEQ dioxin results.

Dioxins (and furans) are not considered to be significantly mobile in soil due to their strong sorption to organic carbon and clay particles (default koc 250,000 cm^3/g; refer to Section 4.4 in Appendix 1). Consideration of soil leaching hazards is therefore not considered to be necessary. Pesticides associated with dioxins could pose potential leaching and groundwater contamination hazards, however, and should be included in testing and evaluation.

Note that the HDOH action levels for TEQ dioxins are based on a review of dioxin toxicity published by the World Health Organization, with a focus on noncancer risk (WHO 2001, 2002; refer to Appendix 6). The USEPA published a final review of dioxin toxicity in 2012 (USEPA 2012b; see also ATSDR 2007). Drafts of this document, which were consistent with the final, were reviewed for preparation of the 2010 HDOH technical memorandum. A detailed comparison of the WHO and USEPA toxicity factors is included in the memorandum. As discussed in the 2010 HDOH technical memorandum, reference to the WHO study was based in part on preference for the body burden approach to evaluate potential health risks posed by chronic exposure to dioxins. The WHO "Permissible Tolerable Intake (PTI)" of 3.3 pg/kg-day) used to develop soil action levels is somewhat higher (less conservative) than the equivalent "Reference Dose" of 0.7 pg/kg-day selected by USEPA for development of RSLs (USEPA 2017). This is used to generate a noncancer-based screening level of 51 ng/kg for residential exposure. This compares to a USEPA RSL cancer-based screening level of 480 ng/kg, assuming a target 10^{-4} risk. Noncancer risk to young children thus takes precedence, under this scenario. Similar studies were reviewed by both organizations. The toxicity factors selected represent a range of potential values from those studies. The WHO PTI includes an assumed bioavailability of 50%.

This is consistent with studies carried out for dioxins in soil, as discussed in the HDOH memorandum.

The USEPA toxicity factor does not considered bioavailability. Consideration of a similar bioavailability in the USEPA toxicity factor would generate a noncancer, residential soil screening level of 102 ng/kg (51 ng/kg divided by 0.5). This compares to the HDOH action level of 240 ng/kg. Both USEPA and HDOH soil levels assume a conservative, soil ingestion rate for children of 200 mg/day. This likely overestimates actual soil ingestion rates by a factor of at least four (NZME 2011). Assuming a soil ingestion rate of 50 mg/kg would increase the HDOH residential soil action level to a 960 ng/kg (240 ng/kg times four). The latter is coincident with a soil screening level of 1,000 ng/kg originally utilized to by USEPA for residential properties (ATSDR 1998) and should be considered an upperbound value in terms of risk to human health under a residential exposure scenario.

A residential action level of 240 ng/kg is this considered adequately conservative for initial screening purposes and the identification of impacted areas that will likely require remediation. **As noted above and in Figure 4-5, , in absence of a more site-specific risk assessment, remediation of sites to background (default 20 ng/kg) should be considered to the extent practicable for residential sites when TEQ dioxin concentrations above this level are identified.**

4.3.1.5 Human Health Risk Assessment

The preparation of a traditional, human health risk assessment may be required at heavily contaminated sites that are unlikely to be cleaned up in the near term and/or in cases where contamination is to be managed in place at sites being used for residential or other sensitive land use purposes (see Section 4.3). A detailed risk assessment is rarely required for petroleum-contaminated sites. An in depth review of the preparation of human health risk assessments is beyond the scope of this guidance document. Selected references for additional information are provided below:

- USEPA Regional Screening Levels: (USEPA 2017);
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (USEPA 2002a);

- Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (USEPA 2002b);
- Assessing the Significance of Subsurface Contaminant Vapor Migration to Enclosed Spaces (Johnson et al. 1998, 2003 and updates);
- Exposure Factors Handbook (USEPA 1997a, updated 2011);
- Superfund Soil Screening Guidance: Technical Background Document (USEPA 2002a);
- Supplemental Guidance For Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities (CalEPA 1996);
- Standard Provisional Guide for Risk-Based Corrective Action (ASTM 1995);
- Preliminary Endangerment Assessment Guidance Manual (CalEPA 1994); and
- Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual (Part A) (USEPA 1989a).

As discussed in Section 1.2, it is important to ensure that all potential environmental hazards are adequately evaluated at sites where human health risk assessments are carried out.

4.3.2 Vapor Intrusion into Buildings

Detailed guidance on advanced approaches for evaluation of vapor intrusion hazards is provided in Section 4.5. A more site-specific evaluation usually begins with the collection of soil vapor data once concentrations of volatile contaminants in soil or groundwater exceed Tier 1 screening levels for this potential hazard. The use of site-specific vapor intrusion models in the absence of soil vapor data is strongly discouraged.

4.3.3 Use of Batch Tests to Evaluate Leaching from Soil

Soil leaching hazards drive the selection of final, Tier 1 ESLs for the majority of organic contaminants presented in the lookup tables. That is, screening levels for leaching hazards are lower than screening levels for direct exposure, vapor intrusion, ecotoxicity and gross contamination hazards (refer to Tables A through D in Appendix 1). Leaching and contamination of groundwater resources will therefore be a common concern at most contaminated sites. In addition, screening levels for leaching hazards are not incorporated into the Tier 1 ESL for metals, since the existing models are very unreliable. If metals are suspected to be potentially mobile, this concern must be evaluated a site-by-site basis.

Laboratory batch tests are recommended for more site-specific evaluations of soil leaching hazards. Batch tests can also be used to confirm the cleanup of soils contaminated with chemicals that could threaten groundwater resources. A summary of this approach is provided in the Hawaiʻi Department of Health guidance document *Use of laboratory batch tests to evaluate potential leaching of contaminants from soil* (HDOH 2007b). Four basic questions are posed:

1. "Is the contaminant potentially mobile?"
2. "What is the concentration of the contaminant in leachate in the primary source area?"
3. "What is the concentration of the contaminant in leachate at the point that the leachate reaches the top of the water table?" and
4. "What is the concentration of the contaminant in groundwater after the leachate has impacted the groundwater?"

Each of these questions should be answered in a site-specific evaluation of potential soil leaching concerns.

The approach is relatively simple. As discussed in Chapter 1, decision units for contaminants that pose potential leaching hazards should be defined as specific spill areas (refer to Section 1.4). A representative sample is collected. The sample is tested for the target contaminant of potential concern. If the reported concentration of the contaminant exceeds the Tier 1 screening level for leaching hazards, or if it is a potentially mobile metal, then a split of the sample is also tested using the Synthetic Precipitation Leaching Procedure (SPLP) batch test method. In this method, 100 grams of soil are placed in two liters of buffered, de-ionized water and the mixture is agitated for a set period of time. The ratio of the mass of contaminant that remains sorbed to the soil compared to the mass that goes into solution is the *desorption coefficient,* or K_d. If the K_d value is greater than 20, then the contaminant is considered immobile and no further action is required to address leaching hazards (after Fetter 1988; refer to 2017 update to HDOH 2007b). If the Kd value is less than 20 then the estimated concentration of the contaminant in leachate and ultimately in groundwater is compared to target groundwater screening levels and the need for further action is evaluated. (Note that direct comparison of SPLP data to target groundwater screening levels is not technically correct or appropriate in most cases.)

This test is especially recommended in conjunction with the more conservative screening levels for leaching of PAHs and organochlorine pesticides from thin soils that overlie unconfined, highly vulnerable drinking water aquifers (see Section 2.3 and Appendix 1, Section 4.4.2). A detailed discussion of the approach is provided in the referenced Hawai‘i DOH guidance (HDOH 2007b). The guidance includes an easy-to-use, Excel-based spreadsheet model that can be used to calculate K_d values and estimate contaminant concentrations in leachate and groundwater (available for download from the Hawai‘i DOH EHE webpage; HDPH 2016). A copy of the input page of the model is provided in Figure 4-5. **Use of batch tests to confirm the adequacy of soil screening levels for leaching hazards and final cleanup actions is strongly recommended at sites that overlie highly valued and vulnerable groundwater resources.** Batch tests can be run on confirmation soil samples in conjunction with standard soil analyses at minimal added costs (including TPH).

4.3.4 Use of Soil Vapor to Evaluate Vadose-Zone Leachate

Soil vapor screening levels for potential leaching hazards posed by volatile organic chemicals (VOCs) in vadose-zone soil or bedrock are presented in Table F (see Appendix 1, Section 4.4.3). The screening levels are calculated based on target concentration of the chemical in groundwater times the chemicals Henry’s Law constant and a default, dilution/attenuation factor of twenty. The screening levels focus on potential impacts to immediately unconfined, drinking water aquifers by volatile hydrocarbons, solvents, explosives and fumigants. The evaluation of leachate associated with petroleum fuels focuses on TPHg, TPHmd, BTEX, MTBE and naphthalene. Testing for additional, semi-volatile, PAHs in soil vapors is not necessary to evaluate potential leachate conditions (e.g., acenaphthene or methylnaphthalenes).

The presence of a VOC in soil vapors above its respective screening level suggests that the concentration of the VOC in soil moisture or leachate could exceed the target groundwater screening level. For example, a concentration of soil vapor of 1,200 ug/m^3 benzene in soil vapor would in theory correspond to an equilibrium concentration in soil moisture of 5 ug/L, the drinking water standard for this chemical. The screening levels should be considered very conservative, especially for biodegradable, petroleum compounds. The screening levels do not take into account attenuation as the leachate migrates downward through the vadose zone and are most applicable to vapors from leachate in close proximity to the water table. Progressive reduction in the concentration of a chemical in leachate due to volatilization (e.g., chlorinated solvents) or biodegradation (e.g,, hydrocarbons) could be significant. The latter is likely to be significant for TPH and BTEX, although the resulting, nonvolatile degradation compounds are by default considered to be of equal toxicity to the original, parent hydrocarbon compounds (refer to Section 2.5.1). In such cases vapors emanating from downward migrating leachate might dramatically decrease with depth, even though to total concentration of hydrocarbon-related compounds in the leachate remains roughly the same.

The screening levels also do not consider the actual mobility of the soil moisture. Vapor concentrations could be very high in dry soils with little to no mobile, soil moisture (i.e., leachate). Whether or not the leachate (or even the vapors) poses a true threat to groundwater depends on site-specific factors, including the size of the source area and the mass of contaminant present, the rate and amount of downward moving leachate, degradation and resorption to soil, the distance to the water table, the presence of low-permeability layers between the source and the water table, the rate of groundwater flow and the thickness of the leachate-groundwater mixing zone. Note that USEPA guidance recommends a default, dilution-attenuation factor of twenty (USEPA 2002a).

Soil vapor data collected over several depths can provide information regarding the downward migration of VOCs in soil leachate toward groundwater. The concentration of VOCs in soil vapors immediately beneath a building slab or paved area could, for example, be very high due to the dryness of the soil even though very little mass is present and the leaching threat is minimal. The chemical may not be present in leachate (or soil vapor) a short distance from the source if water is not infiltrating the area and carrying the chemical downward. Removal of the cap, however, or the breakage of an underground water pipeline could lead to a surge of contaminated leachate toward groundwater.

Soil vapor data are not useful for estimation of the total mass of contaminant present in the vadose zone. This is due to the difficulty in estimating the fraction of soil moisture present as well as the sorbed-phase mass of a VOC in soil based on vapor data alone (published sorption coefficients can significantly underestimate sorbed-phase mass due to presence of clays, etc.). Most of the mass is likely to be sorbed to soil particles under normal conditions (an exception being the common presence of vapor plumes in very dry soil under building slabs). The collection of a Multi Increment soil sample(s) from the suspected source area is recommended to evaluate this issue in more detail and better understand the threat to groundwater posed by the VOCs, as well as optimize remedial actions if necessary.

4.3.5 Gross Contamination

Gross contamination of soil includes the presence of potentially mobile free product, offensive odors, unaesthetic appearance, generation of explosive vapors, and general resource degradation. Although it may seem counterintuitive, it is possible for soil to be so heavily contaminated with some chemicals that the soil is flammable but is not considered "toxic" in the classic toxicological sense. Acetone, methyl ethyl ketone, xylenes, and even gasoline (in the absence of significant benzene content) are a few examples. Gross contamination hazards generally drive cleanup of soil contaminated with these chemicals.

When gross contamination hazards are flagged in the Tier 1 Environmental Hazard Evaluation then a check of actual conditions in the field is strongly recommended. Soil heavily contaminated with diesel fuel may not pose a direct-exposure hazard but its presence at or near the surface in a new residential development would most likely not be welcome. Advanced evaluation of gross contamination hazards for potentially flammable or explosive contaminants can be carried out by the comparison of soil vapor data to lower explosive limits for the target contaminants (refer to NIOSH 2007). Note that the OSHA PELs are not appropriate for evaluation of gross contamination hazards (refer to Section 2.11.6).

Both TPH and methane should be included in soil vapor analyses for petroleum-contaminated sites (see Sections 2.4 and 4.4.4). Published guidance on the evaluation of methane hazards includes:

- CalEPA, 2005, *Advisory on Methane Assessment and Common Remedies at Schools Sites* (June 16, 2005) California Environmental Protection Agency, Department of Toxic Substances Control.

A copy of this guidance is provided in Appendix 8. Additional guidance on the investigation and mitigation of methane hazards is presented in the Hawai‘i DOH *Technical Guidance Manual* (HDOH 2016 and updates).

4.3.6 Terrestrial Ecotoxicity

Detailed, ecological risk assessments will not be required for the majority of typical, urban area sites. The need for a detailed evaluation of terrestrial ecotoxicity hazards should be based on an inspection of the site by a qualified individual and the identification of potentially threatened habitats and endangered or threatened species. Among other sources, refer also to the Hawai‘i *Technical*

Guidance Manual for additional guidance on the preparation of ecological risk assessments (HDOH 2016 and updates).

4.4 Advanced Evaluations of Contaminated Groundwater

Example approaches for advanced evaluations of environmental hazards posed by contaminated groundwater are presented in Figure 4-2b. A brief discussion of highlighted topics is provided below.

4.4.1 Drinking Water Resource Contamination

Screening levels for drinking water are not easily adjustable. Toxicity-based drinking water screening levels for approximately 40% of the chemicals listed in the lookup tables are based on promulgated standards and cannot be changed (refer to Appendix 1). Screening levels for the remaining chemicals as based on a USEPA model for tapwater. The latter could in theory be adjusted based on alternative exposure assumptions and toxicity factors but the approach used is relatively straight forward and rigid and adjustment is considered unlikely. The same is true for drinking water screening levels based on gross contamination, taste and odor concerns.

Site-specific evaluations of threats to drinking water resources should instead focus on plume mobility and the long-term persistence of the chemicals released. Nearby groundwater supply wells should be identified. Long-term monitoring should be carried out to assess plume mobility. Groundwater fate and transport models may be useful in some cases, but should not be relied upon in the absence of actual groundwater monitoring data and aquifer data. Petroleum plumes rarely migrate more than a few hundred feet from the release area. Persistent chemicals such as chlorinated solvents, MTBE, pesticides, and other persistent chemicals pose the greatest long-term threat to drinking water resources. In some cases, the installation of sentinel wells between the contaminant plume and a threatened well may be required.

4.4.2 Vapor Intrusion into Buildings

Detailed guidance on advanced approaches for evaluation of vapor intrusion hazards is provided in Section 4.5. A more site-specific evaluation usually begins with the collection of soil vapor data once concentrations of volatile contaminants in soil or groundwater exceed Tier 1 screening levels for this potential hazard.

The use of site-specific vapor intrusion models in the absence of soil vapor data is generally discouraged.

4.4.3 Discharges into Aquatic Habitats

Fewer than 20% of the screening levels for aquatic toxicity are based on promulgated surface water standards. While adjustment of non-promulgated screenings levels based on alternative study data is feasible, it will rarely be required or beneficial.

As discussed for drinking water concerns, site-specific evaluations of threats to nearby aquatic habitats should instead focus on plume mobility and the long-term persistence of the chemicals released. Nearby, surface water bodies should be identified. Storm sewers and other potential conduits that cross through the plume should also be identified. Long-term monitoring with or without the use of fate and transport models (generally not necessary) should be carried out to assess plume mobility. If plumes are discharging into an aquatic habitat then a more detailed evaluation of surface water and groundwater interaction and impacts on aquatic organisms may be required.

Use of a generic dilution factor to adjust screening levels for the protection of aquatic habitats is not recommended (refer to Chapter 2). This is because benthic organisms that live at the groundwater-surface water interface will not be protected by dilution of groundwater in the water column. Consideration of acute aquatic toxicity screening levels may, however, be appropriate on a site-specific basis (e.g., discharges of groundwater into in highly developed, harbor areas without significant benthic habitats).

4.4.4 Gross Contamination

Gross contamination concerns for groundwater are primarily related to petroleum releases. Check for free product if solubility limits for target contaminants are approached or exceeded. Check shoreline or stream bank areas beside areas of heavily contaminated groundwater for sheens, odors and related gross contamination concerns. Monitor soil vapor for methane buildup and potential explosion hazards in areas of heavy petroleum contamination. Be sure to include TPH and methane in soil vapor analyses (see Sections 2.4, 4.2.4 and 4.4.4).

4.5 Advanced Evaluation of Vapor Intrusion Hazards

4.5.1 Overview of Vapor Intrusion

Use of the soil, groundwater and soil vapor screening levels for vapor intrusion concerns presented in this guidance to initially screen sites contaminated with volatile contaminants rather than attempt to develop sites-specific screening levels is strongly recommended. Development of the screening levels is described in Appendix 1. A detailed discussion of vapor intrusion is presented in Section 7 of the Hawaii Department of Health Technical Guidance Manual (HDOH 2014, and updates).

A basic overview of vapor intrusion is provided in Figure 4.7. Potential adverse impacts to indoor air are driven by the concentration of VOCs in the intruding vapors, the vapor entry rate into the structure and the exchange rate of the building with fresh, outdoor air. Wind effects, and in colder areas indoor heating, can cause air to be drawn out of gaps in windows, doors, roof eves and other gaps on the downwind side of a building (USEPA 2004, 2015a,b; CalEPA 2016c; Brewer et al. 2014). This causes the building to become under-pressurized and results in the entry of outdoor air into the structure from similar gaps on the upwind side. Air can be drawn under the slab of the building and up through the floor of the structure if cracks or gaps around utilities are present.

The upwelling of air beneath a building slab or from a crawl space into a building was recognized by building ventilation engineers in the early 1900s, when heating and air conditioning of buildings became more common, as well as by experts studying the intrusion of natural, radon gas into buildings. The operation of an HVAC system for heating inside of house can in particular exacerbate depressurization of the structure and increase vapor entry rates. This can lead to a corresponding exacerbation of impacts to indoor air if not sufficiently offset by equally proportional increase in the leakage of outdoor air into of the upper part of the structure.

This process is referred to as “vapor intrusion” when volatile organic chemicals or “VOCs” in underlying, contaminated soil and/or groundwater become entrained in air entering a building floor. This can lead to adverse impacts to indoor air quality under some conditions. The upward migration of VOCs into a building occurs in three stages (see Figure 4-6). The first stage is characterized by outward, diffusive flow of vapor-phase chemicals from high-concentration source areas. If the strength of the source is adequate, VOCs will migrate into the advective zone underlying a building slab. Once in this zone the VOCs mix with outdoor air being pulled under the slab and into the overlying structure due to depressurization caused by wind or other effects (Stage 2). Upon entering the building, the now contaminated air (vapors) mixes with indoor air (Stage 3). This includes mixing with the much larger volume of outdoor being drawn into the building due to pressure differential-driven leakage through gaps in the upper part of the structure.

For buildings with a crawl space design, subsurface vapors are diluted as they diffuse into and mix with air in the crawl space below the building floor. Additional mixing may or may not occur as the air from the crawl space is pulled into the building. Unless otherwise supported by site-specific data, vapor attenuation factors applied to slab-on-grade design buildings should likewise be applied to crawl space designs.

These processes, well studied in the field by vapor intrusion experts and building design engineers, are expressed quantitatively in the USEPA vapor intrusion model (USEPA 2004) described below and used to develop corresponding soil, groundwater and subslab soil vapor screening levels. The significance of vapor intrusion hazards is closely tied to local climate conditions and building designs. The mild climate, lack of heating in buildings and general improved ventilation of buildings in Hawaiʻi significantly reduces vapor intrusion hazards in comparison to colder areas on the US mainland.

Additional guidance documents on the investigation of vapor intrusion risks include:

- HDOH: Development of Subslab Attenuation Factors (Brewer et al. 2014);
- USEPA: *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (USEPA 2004b; see also USEPA 2015a,b);
- DoD: *Tri-Services Handbook for the Assessment of the Vapor Intrusion Pathway* (DoD 2008);
- California: *Vapor Intrusion Mitigation Advisory* (CalEPA 2016c);
- Massachusetts: *Indoor Air Sampling And Evaluation Guide* (MADEP 2002c);
- Massachusetts: *Vapor Intrusion Guidance* (MADEP 2010);
- New Jersey: Vapor Intrusion Guidance, New Jersey Department of Environmental Protection (NJDEP 2005); and
- New York: *Guidance for Evaluating Soil Vapor Intrusion in the State of New York* (NYDOH 2006).

Note that vapor intrusion attenuation factors presented in the 2015 USEPA guidance documents, in fact finalized several years before publication, have since been determined to be unreliable (Brewer et al. 2014). This information was not incorporated into the general vapor intrusion guidance document published in 2015 (USEPA 2015a) although the Brewer et al. paper is referenced in the guidance specific to petroleum vapor intrusion (USEPA 2015b). Based on discussions with the USEPA vapor intrusion coordinator at the time, this was due to time constraints for completion of the documents (Richard Kapuscinski 2016, personal communication):

> (The Brewer et al. 2014) paper… on subslab attenuation factors was published (Fall 2014) after the intra-agency vetting concluded for the OSWER *Technical Guide For Assessing And Mitigating The Vapor Intrusion Pathway From Subsurface Vapor Sources To Indoor Air* (OSWER Publication 9200.2-154). By contrast, the *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* (EPA 510-R-15-001) was prepared and revised somewhat independently.

The vapor intrusion guidance and screening levels presented in this document reflect a reduced vapor intrusion risk in tropical climates. Cold winters, heating of buildings and less efficient ventilation can significantly exacerbate potential vapor intrusion hazards in colder climates. This could be reflected by an increased rate of vapor flow into buildings in colder climates as well as a decreased potential for attenuation due to lower, indoor air exchange rates. Due to these factors, *vapor intrusion screening levels presented in this guidance for soil, soil vapor and groundwater may not be adequately conservative for use in non-tropical climates. Example modification of the vapor intrusion screening levels for use in other climate zone is included in Section 13 of the HDOH Technical Guidance Manual.*

4.5.2 Collection of Soil, Groundwater and Soil vapor Data

Refer to the Hawai‘i DOH *Technical Guidance Manual* for detailed information on the collection of soil, soil vapor and groundwater samples (HDOH 2016 and updates). A brief overview of sampling approaches specific to potential vapor intrusion hazards is provided below.

4.5.2.1 Stepwise Approach to Vapor Intrusion Evaluation

The direct collection and analysis of indoor air samples may seem to be an easy way to evaluate vapor intrusion concerns. However, identification of the sources of VOCs identified is complicated by the presence of the same chemicals in auto emissions and in many household goods (aerosol sprays, dry-cleaned clothing, cleaners, etc.). For example, ambient levels of benzene in outdoor air in urban areas (related to auto exhaust) typically exceed the indoor air screening level presented in Table G (0.31 $\mu g/m^3$) by an order of magnitude or more. Ambient levels of dry cleaning solvent (tetrachloroethylene) and other chlorinated solvents in indoor air may also exceed the screening levels presented in Table G (see Figure 4.6a).

As an alternative, the sequential collection and evaluation of groundwater data or soil data (see below), soil vapor data and, if needed, indoor air data is recommended. These data can then be compared to screening levels for vapor intrusion concerns presented in this document and areas of elevated concern quickly identified. The following approach is recommended:

1) Compare soil and/or groundwater data to appropriate screening levels for vapor intrusion concerns (see Tables E-1a and E-1b of Appendix 1 or the ESL Surfer); for sites with significant impacts to vadose-zone soils, proceed directly to Step 2;

2) For areas where screening levels for vapor intrusion concerns are approached or exceeded or sites where significant releases to vadose-zone soils have occurred, collect shallow soil vapor samples immediately beneath (preferred) or adjacent to buildings and compare results to soil-gas screening levels (refer to Table G in this volume or Table E-2 in Appendix 1).

3) At buildings where soil-gas screening levels for vapor intrusion concerns are approached or exceeded, further evaluate the need to carry out an indoor air study.

A more detailed discussion is provided below. **Site data should not be averaged over an area greater than the existing or anticipated floor space area of a building for initial evaluation of vapor intrusion hazards.** A denser area of data coverage may be required for buildings with isolated rooms directly above the slab.

The screening levels are based on scientific models for vapor intrusion into buildings as well as a growing body of data from actual field investigations. A detailed discussion of the screening levels is presented in Appendix 1. The use of site-specific vapor intrusion models for soil and groundwater is discouraged, especially in the absence of soil vapor data. The models used are highly sensitive to parameters such as soil vapor permeability and moisture**. If site-specific models *are* carried out then it is imperative to include a 15cm of high-permeability fill material (i.e., "sand") as the soil layer that immediately underlies the slab, as done for the models used to develop screening levels in this guidance (e.g., "sand" in model default soil types, refer to Appendix 1, Chapter 2).** This will help reflect likely site conditions and ensure a realistic vapor flow rate through the floor slab.

4.5.2.2 Collection and Evaluation of Soil Data

Soil data are *not* considered to be highly reliable for detailed evaluation of vapor intrusion hazards. The collection and use of soil vapor data is instead preferred (refer to Section 4.5.2). Vapor intrusion screening levels for soil should only be applied to sites where relatively minor releases of volatile contaminants have occurred and the collection of soil vapor data is not considered to be necessary and/or feasible (see also HDOH 2007b).

4.5.2.3 Collection and Evaluation of Groundwater Data

Groundwater data should be collected at all sites where significant releases of VOCs are known or thought to have occurred and compared to screening levels presented in Appendix 1 of this document (Table E-1a, see also Tables F-1a and F-1b). Vapor emission rates are controlled by the concentration of VOCs in the upper few feet or even inches of the water table. Sample data should be collected from this zone, preferably by direct push, grab sample methods or monitoring wells with short (e.g., five foot) well screens. This helps to avoid mixing deeper, less contaminated groundwater with shallow groundwater. It is important to ensure that monitoring well screens span the top of the water table.

Screening levels for vapor emissions from groundwater into overlying buildings are incorporated into the F-series tables in Appendix 1 and the summary tables presented at the end of this volume as well as the ESL Surfer (electronic version of the ESL lookup tables). Imported fill material or disturbed native soils should be considered to be highly permeable in site-specific assessments unless vapor flow data into existing buildings indicate otherwise. This is incorporated into the updated USEPA spreadsheets by use of a default vapor flow rate into buildings of approximately five liters per minute per 100m^2 of floor space ("Qsoil").

The groundwater screening levels for vapor intrusion concerns are based on an assumed three-meter depth to groundwater (see Appendix 1). These screening levels may not be adequately conservative for use at sites with shallower water tables. Proceeding directly to the collection of soil vapor data directly below building floors or adjacent, paved areas is instead preferable.

4.5.2.4 Collection and Evaluation of Soil vapor Data

Soil vapor samples should be collected at sites where soil or groundwater data suggest potentially significant vapor intrusion concerns, as described in the Hawai‘i DOH *Technical Guidance Manual* or as otherwise approved by the overseeing regulatory agency (HDOH 2016 and updates). Soil vapor samples should be collected over the core of the groundwater plume and in nearby areas of concern (e.g., near residential homes, commercial buildings, utility corridors, etc.). Ideally, samples should be collected immediately beneath the foundations of existing buildings (“subslab”). If this is impractical, then samples should be collected from paved areas immediately adjacent to buildings.

In unpaved areas, soil vapor samples should be collected from a depth of 1.5m (five feet) below ground surface (bgs). Samples collected from depths less than 1.5m in open (i.e., unpaved) areas are considered unreliable due to the increased potential to draw in ambient surface air (see CalEPA 2016c). The collection of deeper soil vapor samples and soil-type data may also be useful in evaluating the lateral and vertical extent of VOCs in the subsurface, as well as in evaluation of deeper utility corridors to serve as preferential pathways for vapors into enter a building.

The collection of additional soil geotechnical data should be considered if site-specific modeling of vapor flow rates or indoor-air impacts is to be carried out, (e.g., soil grain-size analysis, moisture content, fraction organic carbon, etc.). For existing buildings with slab-on-grade construction, data must be collected from the fill material immediately beneath the slab. This is the layer of soil that controls the advective (pressure-induced) flow of vapors into the building. In most cases, the soil consists of a relatively dry, silty sand or sandy silt that exhibits a relatively high vapor permeability. This assumption is incorporated into the vapor intrusion models used to develop the screening levels presented in this guidance (refer to Appendix 1). It is inappropriate to use deeper soil data to model this layer, since increased clay and moisture contents could significantly under predict the ability of the soil to convect vapors into the building.

For undeveloped sites where there are no existing buildings, the presence of a layer of dry, permeable fill material under future buildings should be assumed. Data can, however, be collected from deeper layers of soil and used to model these layers in the vapor intrusion model. Care should be taken to ensure that modeled groundwater and in particular shallow, soil vapor concentrations are reflective of actual field conditions, even if the required, input stratigraphy in the model does not fully match field conditions.

The use of lab-based, soil vapor permeability tests to replace the default vapor flux rate (Qsoil) of 5 liters/minute (per 100m^2 of ground floor area) in the USEPA models is discouraged. These tests often do not adequately take into account enhanced permeability due to soil heterogeneities, soil fractures, relict root structures, shallow fill material, disturbance during redevelopment, and other types of secondary permeability.

4.5.2.5 Use of Soil vapor Data to Determine Need for an Indoor Air Study

The collection and evaluation of indoor air sample data is discussed in Section 4.5.3. Both subslab sample data and shallow soil vapor data (i.e., $\leq$1.5m bgs) should be compared to the soil vapor screening levels presented in Table G. Where screening levels are approached or exceeded, the need to carry out an indoor air study should be more closely evaluated.

The California EPA vapor intrusion guidance recommends that an indoor air study be considered if site-specific, soil-gas-to-indoor vapor intrusion models suggest that impacts to indoor air may exceed a cumulative excess cancer risk of 10^{-6} or a noncancer hazard index >1.0 (CalEPA 2016c). While this approach may seem reasonable in concept, it is often impractical due to likely impacts to indoor air from other sources that will mask potential impacts from subsurface, vapor intrusion (e.g., cleaners, glues, auto exhaust, etc.). Impacts due to subsurface versus vapor intrusion versus indoor or outdoor sources are not distinguishable.

For example, the concentration of TPH, benzene and other auto exhaust-related contaminants in outdoor air near roadways can exceed risk-based screening levels by up to two orders of magnitude (Figure 4-8; see also CalARB 2001, Kurtz and Folkes 2002, MADEP 2002d, NYDOH 2003, USEPA 2011b). Trace levels of chlorinated solvents are also commonly reported for indoor air (e.g, tetrachloroethylene or “PCE,” used for dry cleaning). In such cases, sampling of indoor air would not be useful unless concentrations of targeted chemical in subslab soil vapor exceed 1,000 (residential) to 2,000 (commercial/industrial) times typical indoor ambient concentrations of the chemical (Figure 4-9; default soil vapor:indoor air attenuation factors assumed in vapor intrusion models). Refer also to Appendix 1 Chapter 2 and MADEP (2002a).

Decisions for cleanup of VOC-contaminated soil and groundwater for vapor intrusion concerns should instead be based on an evaluation of soil vapor data in conjunction with ideal target indoor air goals, even if these goals cannot be currently met due to other sources of contamination, such as vehicle exhaust in ambient air. If soil vapor screening levels are exceeded, then cleanup of the source areas to reduce vapor intrusion concerns should be considered.

An alternative approach for determining when indoor air studies are needed at commercial/industrial (C/I) settings if soil vapor screening levels for commercial/industrial sites are exceeded is described below:

Step 1. Confirm and Evaluate Soil vapor Data.

- Confirm soil vapor data with a second round of sampling in targeted areas of potential concern (e.g., co-located with hot spots identified in first round of soil vapor data collection and previously identified hot spots in soil and/or groundwater). If significant differences in reported concentrations of VOCs are reported at individual sample points and ESLs were exceeded in one or both sampling events, consider the installation of permanent vapor monitoring wells in a denser grid (e.g., 10m to 20m grid) and additional sampling until the range of potential site conditions is adequately defined. Statistical approaches may be required at sites where wide temporal variations in concentrations of VOCs in soil vapor are identified.

- If soil vapor ESLs for noncarcinogens are not exceeded (based on a target, noncancer risk of 0.2, or 1.0 for TPH) and ESLs for carcinogens are not exceeded by more than one order of magnitude (equivalent to a target risk of 10^{-5}), then no further action is warranted (refer to Table E-2 in Appendix 1).

- If soil vapor ESLs are exceeded by more than amounts noted above, calculate a site-specific, cumulative noncancer Hazard Index and cumulative excess cancer risk (see Hawai'i DOH *Technical Guidance Manual*, HDOH 2016; see also guidance referenced in USEPA 2017).

Step 2. Evaluate site-specific vapor intrusion risks.

- **Site-specific, cumulative excess cancer risk <10^{-5} and/or cumulative noncancer hazard index <1.0 (and potential impacts to indoor air less than typical, ambient, outdoor air).** Testing of indoor air not required. Install permanent vapor monitoring probes in areas of primary concern and test quarterly for a period of one year to confirm soil vapor data. If concentrations of VOCs do not increase significantly (i.e., to exceed cumulative 10^{-5} excess cancer risk or HI>1.0), no further action is warranted under current site conditions. Additional evaluation may be warranted if building conditions change or if new buildings are constructed over impacted areas.

- **Site-specific, cumulative excess cancer risk >10^{-5} and/or cumulative noncancer hazard index >1.0.** Install permanent vapor monitoring probes and resample soil vapor. If resampling of soil vapor indicates a potential indoor air risk <10^{-5} and/or cumulative noncancer hazard index <1.0, carry out quarterly monitoring for one year to confirm (see above). Carry out indoor air testing if soil vapor data suggest a potential excess cancer risk of >10^{-5} and/or a cumulative noncancer hazard index >1.0 is confirmed and the concentrations of targeted VOCs in soil vapor are high enough that intruding vapors could cause impacts to indoor air in excess of typical ambient levels (see Figure 4-9; refer also to Section 2.6).

The above approach is intended to be general guidance only and should not be used as a strict requirement. The appropriateness of the approach should be evaluated on a case-by-case basis and discussed with the overseeing regulatory agency.

4.5.2.6 Soil vapor and Tight Soils

At sites where soil vapor samples cannot be collected using traditional methods due to tight soil conditions (e.g., wet, clayey soils), other approaches should be attempted. In many cases, simply moving the collection probe over a few feet from the initial location will address the problem. If problems still persist, the installation of temporary soil vapor probes encased in permeable sand packs and capped with a bentonite clay mixture can be considered (refer to CalEPA 2002). The diameter and depth of the vapor probe borehole should be adjusted to allow sufficient pore space for the collection of soil vapor samples. Adequate time (generally several weeks) should be allowed for VOCs in the surrounding clays to equilibrate with soil vapor in the vapor probe sand pack.

Passive soil vapor sampling techniques may also prove useful in tight soils, provided that the actual concentrations of VOCs present can be quantified (e.g., recent advances in “Gore^{TM} Sorbers). This approach has not been widely used at this time and is still being evaluated. Where possible, both “active” and passive soil vapor data should be collected in amenable areas of a site and used to verify the interpretation of passive soil vapor data from areas where active data could not be collected.

At sites where groundwater is impacted with VOCs and the collection of soil vapor data is simply not possible, groundwater data should be compared to conservative screening levels and the need to go directly to crawl space and/or indoor air sampling evaluated. At “soil only” sites, soil data should be similarly collected and compared to conservative screening levels (see below).

4.5.2.7 Use of Soil Data

Soil screening levels for potential vapor intrusion concerns are incorporated in the ESL lookup tables (see Appendix 1, Table A-D series and Table E-1b). At sites where minor releases of volatile chemicals have occurred (e.g., small spills around underground storage tank fill ports), direct comparison of soil screening levels to site data is generally acceptable. If soil screening levels are exceeded, the need to collect soil vapor samples and further evaluate vapor intrusion concerns should be evaluated. **At sites where significant releases of volatile chemicals have occurred, the direct use of soil vapor data in conjunction with soil data is strongly recommended.**

An advantage of the soil vapor intrusion model is the inclusion of “mass-balance” considerations in the evaluation of potential long-term impacts to indoor air. As discussed in the following section, this issue is not included in the soil vapor vapor intrusion models or corresponding screening levels. (Mass balance issues are also not considered in the groundwater models. The continued migration of contaminated groundwater from upgradient areas is assumed to provide an ongoing source of VOCs to areas of concern, however, and mass-balance issues are less relevant.)

4.5.2.8 Soil vapor and Mass-Balance Issues

At sites with high levels of VOCs in soil vapor but a limited total mass of VOCs in soil, a mass balanced approach to the evaluation of vapor intrusion concerns may be appropriate. For example, it is not uncommon to find relatively high levels of PCE in soil vapor immediately beneath the floors of dry cleaners but relatively little PCE in soil samples collected in the same area. Most of the PCE is in vapor phase, with very little total mass present. This is most likely related to the presence of dry soil with very little organic carbon directly under the floor of the building.

Based on soil vapor data alone, the vapor intrusion models may predict unacceptable, long-term impacts to indoor air. The actual mass of VOCs present may be insufficient to maintain initial impacts over the full span of the exposure duration assumed in development of the screening levels, however. In such cases, the screening levels presented in could be overly conservative for evaluation of long-term, chronic health risk concerns and a more site-specific evaluation of vapor intrusion concerns may be warranted. The mass of VOCs present can be further assessed through the collection of MI soil samples within the same area (refer to Section 4 of the Hawaii *Technical Guidance Manual*; HDOH 2016). Access to soil beneath a slab will in many cases, however, be too limited for collection of reliable soil sample data.

4.5.3 Collection of Indoor Air Data

As discussed in the previous section, the collection of indoor data will in some cases be necessary to further evaluate vapor intrusion concerns (see Section 4.5.2.5; see also Figure 4-9). Proposals and workplans for indoor air studies should be discussed with the overseeing regulatory agency. The collection of indoor air data without soil vapor data and, if applicable, crawl space data is not recommended. Such data are critical in determining the source of any VOCs identified in indoor air. Guidance on the collection and evaluation of indoor air data is discussed in Section 4.5.3 and Section 7 of the Hawai‘i DOH *Technical Guidance Manual* (HDOH 2016) and will not be repeated in detail here.

The California EPA guidance document provides a table of recommended actions at sites where impacts to indoor air are identified (CalEPA 2016c). A slightly modified version of that table is provided below:

***Indoor Air Sampling Results**	**Response**	**Activities**
Risk: $<10^{-6}$ HI: <0.5	No Further Action	Confirm that vapor intrusion impacts are not likely to increase in the future.
Risk: 10^{-4} to 10^{-6} HI: 0.5 to 1.0	Monitoring +/- Mitigation	Collect soil vapor, indoor air and/or crawl space samples semi-annually as appropriate. Mitigation may be recommended in some cases to reduce exposure even though health risk goals may not be exceeded.
Risk: $>10^{-4}$ HI: >1.0	Mitigation Required	Institute engineering controls to mitigate exposure and collect soil vapor samples and indoor air samples semiannually to verify mitigation of exposure.

*Contaminants identified in indoor air that are directly linked to the intrusion of subsurface vapors.
Risk = Cumulative excess cancer risk
HI = Hazard Index – Cumulative risk posed by sum of noncancer hazard quotients of specific chemicals of concern.

Earlier editions of the CalEPA guidance calls for monitoring +/- mitigation of indoor air impacts if the cumulative Hazard Index (HI) is between 1.0 and 3.0, with mitigation required if the HI exceeds 3.0. Acute inhalation screening levels for some contaminants can be approached at HI of 3.0, however (e.g., benzene). For the purpose of this guidance, an HI of 1.0 was therefore selected as a default target for mitigation of indoor air impacts. This can be reviewed on a site-specific basis as needed.

If structures in the subject area are underlain by crawl spaces then the concurrent collection air samples from these areas should also be considered. Crawl space data should be compared directly to indoor air data. As discussed above, the dilution of VOCs in crawl spaces as air is pulled into a building is difficult to predict.

The above are initial recommendations only. Ultimate actions required at a given site should be determined on a case-by-case basis in coordination with the overseeing regulatory agency. As noted in the California EPA guidance document, indoor air data should be used to better ascertain human health concerns when potentially significant impacts are implied by soil vapor and other subsurface data. The California EPA document recommends that at least two rounds of indoor air data be collected prior to determining appropriate response activities. The scope of specific responses should be determined on a case-by-case basis in coordination with the overseeing regulatory agency. Active mitigation of indoor air impacts may be recommended (or even required) at sites where a reduction of individual exposure is desired even though health risk objectives noted above are not exceeded. A contingency plan based on the data to be collected should be included as part of the indoor air sampling plan.

If vapor intrusion concerns are primarily for future buildings, then remediation of VOC impacts prior to construction should be considered. If this is not feasible (e.g., due to impacts from a continuing offsite source) then institutional and engineering controls to mitigate vapor intrusion concerns should be incorporated into future building designs. The scope and oversight of these controls should be determined on a site-specific basis in coordination with the overseeing regulator agency. Long-term oversight requirements are typically much more stringent for residential properties. In some cases, formal incorporation of engineered controls into building permits may be warranted with long-term oversight of the controls being undertaken by the planning agency.

4.5.4 Special Considerations for Petroleum-Contaminated Sites

A discussion of contaminants of potential concern for petroleum is provided in Section 2.5 (see also Figure 2.3). Based on data compiled by the Hawai‘i DOH, aliphatic compounds associated with Total Petroleum Hydrocarbons (TPH) and not benzene or other individual volatile chemicals generally drives vapor intrusion risks for releases of middle distillates and in some cases even gasolines (see Appendices 1 and 6; see also Brewer et al. 2013). As noted in Figure 2.3, soil vapor (and indoor air) samples should be tested for TPH (sometimes reported as *Total Volatile Hydrocarbons* or similar terms) and the noted, individual chemicals. The laboratory standard used for the TPH analyses should match the petroleum product released at the site. Vapor intrusion screening levels for TPH in soil and groundwater cannot easily be calculated using the models referenced in Appendix 1 and are not included in the ESL lookup tables. The direct collection of soil vapor samples at sites where significant soil contamination (e.g., >10m3 of soil) or free product ton groundwater are identified. Carbon range PH data may be desirable for site-specific environmental hazard evaluations.

Testing of indoor air for petroleum-related contaminants associated with the intrusion of vapors from subsurface sources is rarely useful. Common household cleaners, glues and other products can contain petroleum and serve as indoor sources of contamination (look for “Flammable” on labels; see Figure 4-8). Auto exhaust is also a major contribution to petroleum-related contaminants in outdoor air. Unless the building is located directly over heavily contaminated soil or free product on shallow groundwater, petroleum vapors related to other indoor and outdoor sources will overwhelm additional contamination related to vapors emitted from underlying soil and groundwater.

For example, ambient concentrations of benzene in urban, outdoor air related to auto-exhaust typically ranges from 1 to >5 ug/m^3 (see Figure 4-8), well above the risk-based, screening level for residential exposure of 0.31 ug/m^3 (refer to Table G). Ambient concentrations of TPH in indoor and outdoor air typically ranges between 100 and 1,000 ug/m^3 or even higher based on data collected at sites in Hawai‘i, well above the residential indoor air screening level of 120 ug/m^3. As a general rule, and as discussed in Section 4.5.3, indoor air should only be tested if concentrations of target contaminants in soil vapor exceed at least 2,000 times anticipated levels in ambient air. This reflects the default soil vapor:indoor air subslab attenuation factor (SSAF) for residences (see Appendix 1, Section 2.2.4; SSAF of. 4,000 applied to commercial/industrial buildings). This correlates to concentrations of TPH in soil vapor of 2,000,000 ug/m^3 and 2,000 ug/m^3 for benzene before it impacts to indoor air above ambient conditions might be discernible.

This does not mean that the additional contamination of indoor air related to vapor intrusion is not a concern. If reported levels of TPH, BTEX or other contaminants in soil vapor exceed screening levels (or approved alternatives) then lower floor of the building should be inspected and cracks and gaps (e.g., around utilities) should be sealed. The building heating, air conditioning and ventilation (HVAC) system should also be inspected to ensure that it is operating properly (e.g., maintaining a positive indoor air pressure) and that adequate fresh air is being brought into the building.

It is also important to screen for methane in soil vapor samples. Additional evaluation of methane explosion hazards is required if methane levels in soil exceed 5,000 ppmv (10% of the lower explosive level; refer to Section 4.5.4 and the Hawai‘i DOH *Technical Guidance Manual*). TPHgasoline vapors could also pose explosion hazards at some sites. An evaluation of potential vapor intrusion and explosion hazards will in particular be needed at sites where full cleanup of heavily contaminated soil and groundwater is not practicable and long-term monitoring of residual contamination is required.

4.6 Environmental Hazard Evaluations for Parklands

It is strongly recommended that sites that are to be used as parks or wildlife refuges be remediated to meet unrestricted land use when practicable. Potential hazards posed to eco-habitats should also be evaluated. Recreational-use exposure scenarios used in human health risk assessments often incorporate much lower exposure frequencies (e.g., days per year visited) and durations (total number of years) than traditional, residential exposure scenarios. This implies that substantially higher concentrations of contaminants can be left in place in a park area and not pose a threat to users of the park. Risk-based cleanup levels based on recreational land-use scenarios can even be higher (less stringent) than levels typically allowed for commercial/industrial properties.

This intuitively goes against the concept of park lands as a "refuge" for humans and wildlife. Assumption of a limited exposure frequency and duration (e.g., 100 days per year for ten years) also puts an implicit restriction on the number of days and years that an individual can visit the park incurring an unacceptably high contaminant dose. Long-term, future uses of such properties are also difficult to predict. Additionally, public parks are typically frequented by children, young mothers, elderly people, and other more-sensitive subpopulations. This issue is usually omitted from standard, human health risk assessments.

Remediation of proposed parklands to unrestricted land-use standards may in some cases not technically or economically practicable. If cleanup is not feasible, and the property is intended for recreational use, then the appropriateness of allowing unrestricted access to the area should be carefully evaluated. Institutional controls may be needed, such as the imposition of access restrictions on the property or posting of signs at the property entrance that warn of potential environmental hazards.

4.7 Ecological Risk Assessment

Preparation of a more detailed Ecological Risk Assessment may be required in some cases to better evaluate and document impacts to terrestrial and aquatic habitats. An Ecological Risk Assessment is a detailed appraisal of the actual or potential effects of a hazardous waste site on plants and animals other than people or domesticated species (USEPA 1989b). Published guidance documents for preparation of Ecological Risk Assessments include the following:

- Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (USEPA 1997b); and
- Risk Assessment Guidance for Superfund: Volume II Environmental Evaluation Manual (USEPA 1989b).

Detailed guidance regarding the preparation of Ecological Risk Assessments is beyond the scope of this Manual, and the above list of references is not intended to be comprehensive. Additional Ecological Risk Assessment guidance should be referred to as needed. Updates to guidance included in the Hawai‘i TGM are currently in preparation (HDOH 2016).

Table 4-1. Progressive development of a residential, direct-exposure soil screening level for dieldrin (see Section 4.1.2).

Toxicity Factor Type	**[1]Value**	**Target Risk**	**Equivalent Soil Screening level**
Range of Noncancer-Based Screening levels			
LOAEL	0.05 mg/kg-day	HQ=1.0	3,100 mg/kg
NOAEL	0.005 mg/kg-day	HQ=1.0	310 mg/kg
RfD	0.0005 mg/kg-day	HQ=1.0	3.1 mg/kg
		HQ=0.5	1.5 mg/kg
		HQ=0.2	0.60 mg/kg
Range of Cancer-Based Screening levels			
Slope Factor	16 $(mg/kg\text{-}day)^{-1}$	10^{-4}	3.0 mg/kg
		10^{-6}	0.03 mg/kg
Final Direct Exposure Soil Screening level Selected: 1.5 mg/kg			

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Long-Term Management of Contaminated Sites

An expanded discussion of the long-term management of contaminated sites is included in revisions to the Hawai'i DOH *Technical Guidance Manual* (HDOH 2016). Refer also to the Hawai'i DOH guidance published for the long-term management of petroleum-contaminated sites (HDOH 2007b, provided in Appendix 8). Although focused on petroleum contamination, the latter guidance can also be expanded to other types of releases that require long-term management.

An *Environmental Hazard Management Plan* (EHMP) should be prepared for all sites where residual contamination in soil and groundwater exceeds action levels for unrestricted land use. Ideally the EHMP should be prepared as a stand-alone document which can be easily referenced by the property owner and others who may disturb soil or groundwater at the site. However, the EHMP can be prepared as a separate document, an appendix to a site investigation, or within the main body of a site investigation report, depending on the needs of the project. A basic EHMP should include the following information or be included in a document that contains the same information (refer also to Sections 18 and 19 of the HEER Office Technical Guidance Manual):

- Brief summary of the site background and history of contaminant releases;
- Identification of specific contaminants of concern, including TPH, "Target Indicator Compounds" and any other contaminants associated with the release (refer to Step 1);
- Clear depiction of the extent and magnitude of remaining contamination in soil, groundwater and/or soil vapor, presented on easily readable, to-scale maps with a north arrow (refer to Step 2);
- Identification and discussion of all potential environmental concerns (refer to Step 3);
- Requirements for long-term monitoring of contaminants in soil, groundwater, and/or soil vapor;
- Discussion of engineering and/or institutional controls needed to address identified environmental concerns, including caps, barriers, etc.,

needed to eliminate exposure pathways;

- Guidance on the proper management and disposal of contaminated soil and/or groundwater encountered during future site activities;
- Measures for repair or replacement of engineered controls that are disturbed or breached during future site activities; and
- Any other information required to adequately mitigate and manage remaining environmental concerns at the site.

The scope of EHMPs for individual sites will vary based on the nature and extent of the remaining contamination, as well as the potential environmental hazards posed by the contamination. An EHMP prepared for sites where only a small amount of petroleum-contaminated soil or groundwater has been left in place and only gross contamination hazards remain will likely be relatively short and simple. A more detailed EHMP that includes formal restrictions on site use and engineered controls to prevent exposure to residual contaminants may be required at sites where contamination is to be left in place that poses significant environmental hazards if not managed properly. A brief *Fact Sheet* that summarizes key elements of the EHMP in simple, non-technical terms may also be required for large, complex sites where significant public review is anticipated.

The use of engineered controls to prevent exposure to contaminated soil or groundwater is generally discouraged for properties that are to be developed for single-family homes or town homes where residents could dig in their yards. This is because long-term management of the controls by residents cannot be assured (e.g., maintenance of clean soil caps over contaminated soil). Permanent soil caps in commercial/industrial sites or high-density residential sites should be at least 30cm (twelve inches) thick (USEPA 2003b). For garden areas, at least 60cms (24 inches) of clean fill is recommended. If offsite disposal alternatives do not exist, contaminated soil could also be placed under building pads or other paved areas, provided that the location of the soil is properly surveyed and documented in the EHMP. Soil re-used off-site must be assessed in accordance with the Fill Guidance and meet most stringent EALs in accordance with the HDOH “Clean Fill” guidance (HDOH 2017). Utility trenches should also be backfilled with clean soil in order to reduce exposure of future workers and avoid accidental reuse of excavated soil in areas where workers and residents may be exposed to residual contaminants. Contaminated soil that is to be isolated at depth should in general be kept at least one meter above the highest groundwater level.

The above is not necessarily a comprehensive list of issues that must be taken into consideration at sites where contaminated soil and groundwater are to be left in place. Plans for long-term management of contaminated soil on properties should be discussed with the overseeing regulatory agency.

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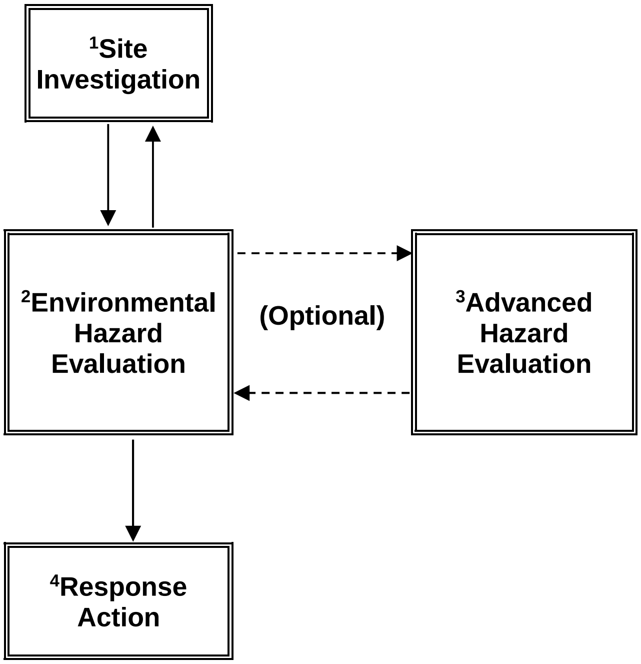
FIGURES

Figure 1-1. Overview of the Environmental Site Assessment Process.



1. The extent and magnitude of contamination above levels of potential concern is determined during the site investigation stage of the process.

2. Potential environmental concerns at contaminated sites are identified in a preliminary Environmental Hazard Evaluation (EHE). Specific, potential hazards are evaluated in more detail as needed (see below). The final EHE is used determine the need for response actions.

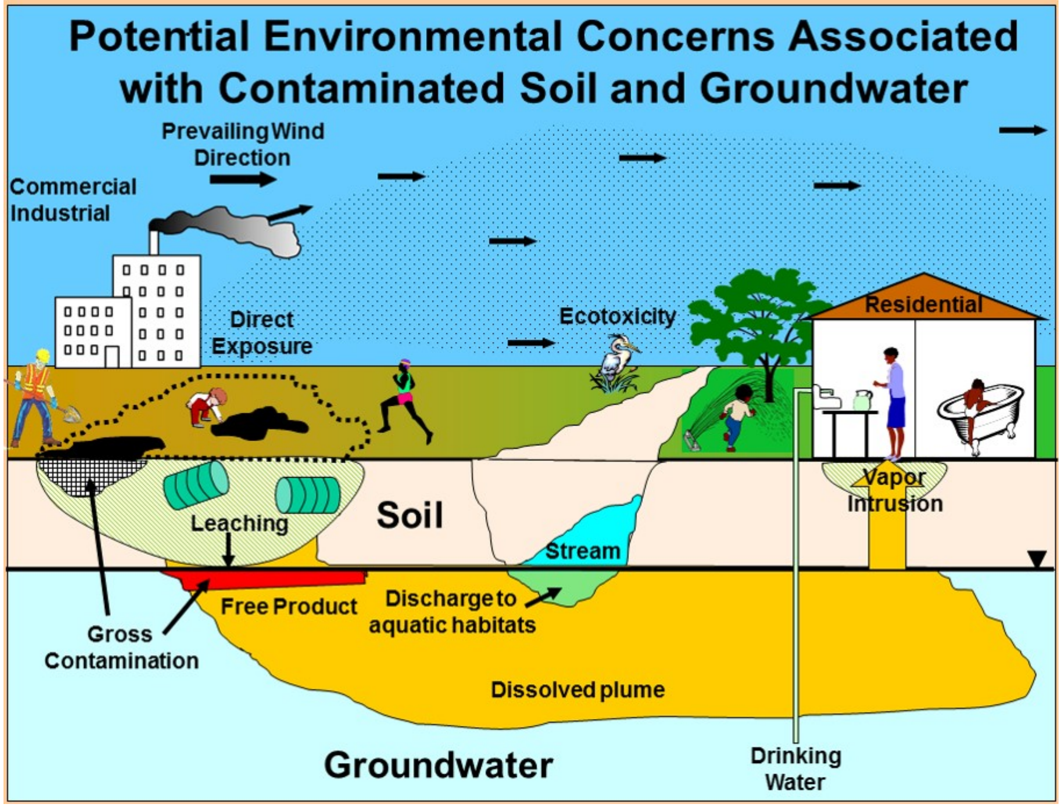
3. An advanced evaluation of specific environmental hazards can be carried out as needed. For example, soil vapor data can be collected to better evaluate vapor intrusion hazards; soil batch tests can be carried out to better evaluate leaching hazards; a site-specific human-health risk assessment and/or ecological risk assessment can be prepared to better define risks to human and ecological receptors; etc. The conclusions are used to help support the need for response actions.

4. The most appropriate response action to address the identified environmental hazards is identified and implemented. This could include no further action, active remediation, long-term management, etc.

Figure 1-2a. Summary of common environmental hazards associated with contaminated soil and groundwater.

Contaminated Soil	
Environmental Hazard	**Description**
Human Health Risk	
• Direct Exposure	Exposure to contaminants in soil via incidental ingestion, dermal absorption and inhalation of vapors or dust in outdoor air.
• Vapor Intrusion	Emission of volatile contaminants from soil and intrusion into overlying buildings.
Leaching	Leaching of contamination from soil by infiltrating surface water (rainfall, irrigation, etc.) and subsequent contamination of groundwater resources.
Impacts to Terrestrial Habitats	Toxicity to terrestrial flora and fauna
Gross contamination	Includes potentially mobile free product, odors, aesthetics, generation of explosive vapors, general resource degradation, etc.
Contaminated Groundwater	
Environmental Hazard	**Description**
Human Health Risk	
• Contamination of drinking water supplies	Toxicity concerns related to contamination of groundwater that is a current or potential source of drinking water.
• Vapor Intrusion	Emission of volatile contaminants from groundwater and intrusion into overlying buildings.
Impact to Aquatic Habitats	Discharges of contaminated groundwater and toxicity to aquatic organisms
Gross contamination	Includes taste and odor concerns for contaminated drinking water supplies, free product, potential, sheens and odors on surface water, general resource degradation, etc.

Figure 1-2b. Summary of common environmental hazards associated with contaminated soil and groundwater (schematic).



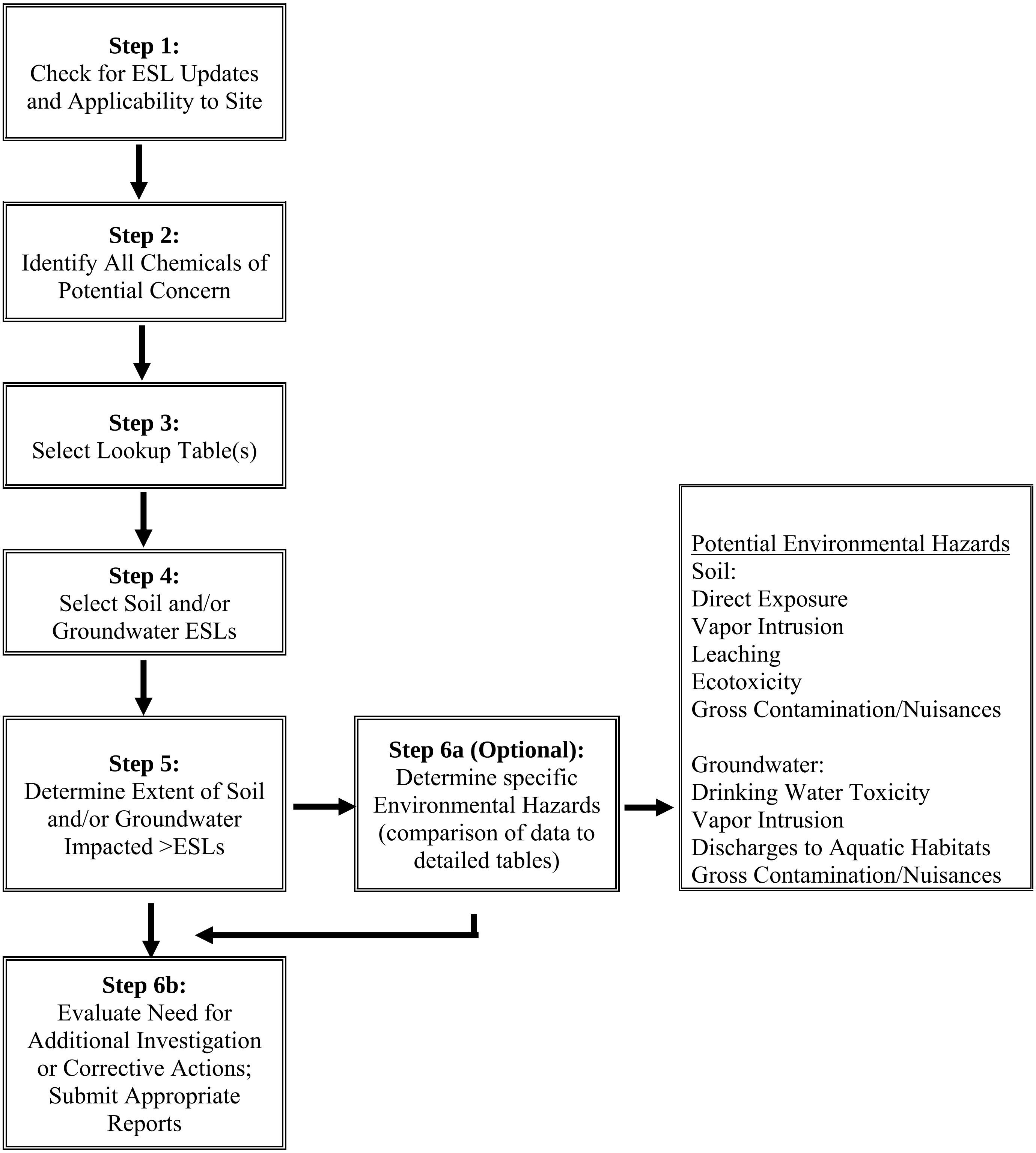


Figure 1-3. Steps for use of the Tier 1 ESL lookup tables during the site assessment process. Although not necessary for sites where cleanup to Tier 1 ESLs can easily be attained, identification of specific environmental hazards is recommended and in particular required for sites where long-term, on-site management of contaminated soil and groundwater is proposed.

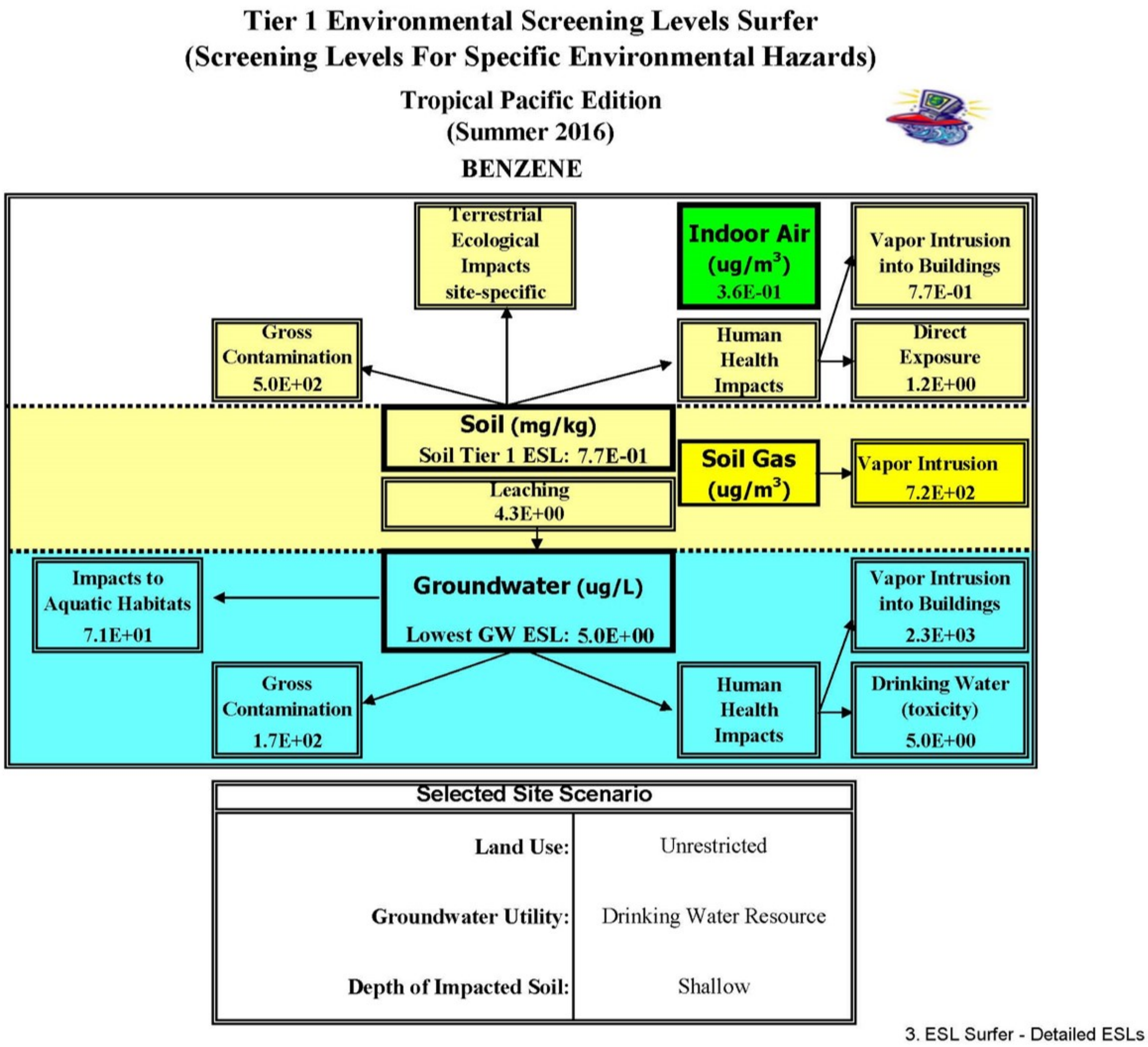
Figure 2-1. Primary references for compilation of Tier 1 Environmental Screening Levels.

Soil

Environmental Hazard	Primary Reference	Comments
Direct Exposure	USEPA Regional Screening Levels (RSLs)	RSLs for noncancer concerns adjusted to a Hazard Quotient of 0.2 (i.e., divided by five) for most chemicals; alternative target cancer risk used for some chemicals
Vapor Intrusion	USEPA Vapor Intrusion Guidance and Model	Model formatted for use in tropical to temperate climates with shallow groundwater
Leaching	Massachusetts Department of Environment Soil Leaching Model	Model modified to reflect target groundwater screening levels
Terrestrial Ecotoxicity	Ontario Ministry of Environment Compilation	Discontinued in 2012 update of EHE guidance (see text)
Gross Contamination	Massachusetts Department of Environment Gross Contamination Guidance	Generic approach for gross contamination concerns

Groundwater

Environmental Hazard		Primary Reference	Comments
Drinking Water Toxicity		Local Agency Primary Maximum Contaminant Levels	USEPA Tapwater RSLs used for chemicals that lack Primary MCLs
Vapor Intrusion		USEPA Vapor Intrusion Guidance and Model	Model modified for use in tropical to temperate climates with shallow groundwater
Discharges to Aquatic Habitats		USEPA Surface Water Standards	Incorporated by reference in CNMI and Guam regulations; other sources referred to for chemicals that lack surface water standards
Gross Contamination	Drinking Water Resource	Local Agency Secondary Maximum Contaminant Levels	Alternative references used for chemicals that lack Secondary MCLs
	Non-Drinking Water Resource	Massachusetts Department of Environment Gross Contamination Guidance	Generic approach for gross contamination concerns



Tier 1 Environmental Screening Levels Surfer
(Screening Levels For Specific Environmental Hazards)

Tropical Pacific Edition
(Summer 2016)
BENZENE

Selected Site Scenario	
Land Use:	Unrestricted
Groundwater Utility:	Drinking Water Resource
Depth of Impacted Soil:	Shallow

3. ESL Surfer - Detailed ESLs

Figure 2-2. Detailed screening levels used to select final, Tier 1 soil and groundwater ESLs for benzene.

Figure 2-3. Target analytes for releases of petroleum products (see also Section 9 of Hawai‘i Technical Guidance Manual; HDOH 2016).

Petroleum Product	**Media**	**Recommended Target Analytes**
Gasolines	Soil	TPH, benzene, toluene, ethylbenzene, xylenes (BTEX), naphthalene, MTBE and appropriate additives and breakdown products (e.g., DBA, TBA, lead, ethanol, etc.)
	Soil vapor	Same as soil plus methane
	Groundwater	Same as soil
Middle Distillates (diesel, kerosene, stoddard solvent, heating fuels, jet fuel, etc.)	Soil	TPH, BTEX, naphthalene, methylnaphthalenes (total 1- and 2-)
	Soil vapor	Same excluding methylnaphthalenes, plus methane
	Groundwater	Same as soil
Residual Fuels (lube oils, hydraulic oils, mineral oils, transformer oils, Fuel Oil #6/Bunker C, waste oil, etc.)	Soil	TPH, *VOCs, naphthalene, methylnaphthalenes plus remaining 15 priority pollutant PAHs, plus PCBs and heavy metals unless otherwise justified
	Soil vapor	TPH, VOCs, naphthalene, methane
	Groundwater	same as soil

*VOC: Volatile Organic Compounds, including BTEX and chlorinated solvent compounds.

Figure 2-4. Summary of models and approaches used to develop screening levels incorporated into the Tier 1 ESLs (refer also to Appendix 1).

Groundwater Screening Levels	
Contamination of drinking water supplies	USEPA promulgated drinking water standards (referenced in CNMI and Guam regulations) or USEPA Regional Screening Levels model for tapwater. Refer to Appendix 1 (Section 5.2 & Table F-3 series) and Appendix 2.
Vapor Intrusion	USEPA vapor intrusion spreadsheets. Refer to Appendix 1 (Section 5.4 & Table E-1a) and Appendix 4.
Impact to Aquatic Habitats	USEPA promulgated drinking water standards (referenced in CNMI and Guam regulations) or USEPA and other references if not available. Refer to Appendix 1 (Section 5.3 and Table F-4 series).
Gross contamination	Massachusetts DEP approach, modified as indicated. Refer to Appendix 1 (Section 5.5 & Table I series).
Soil Screening Levels	
Environmental Hazard	**Reference**
Direct Exposure	USEPA Regional Screening Levels models for direct exposure concerns (with modifications for some chemicals as described in text). Refer to Appendix 1 (Section 4.2 & Table K series) and Appendix 2.
Vapor Intrusion	USEPA vapor intrusion spreadsheets. Refer to Appendix 1 (Section 4.3 & Table E-1b) and Appendix 4.
Leaching	Massachusetts DEP soil leaching model. Refer to Appendix 1 (Section 4.4 & Table G-1a&b) and Appendix 5. Alternative assumptions used for sites with thin soils and heightened leaching risks for unconfined aquifers.
Gross contamination	Massachusetts DEP approach, modified as indicated. Refer to Appendix 1 (Section 4.6 & Table H series).
Soil vapor and Indoor Air Screening Levels	
Vadose-Zone Leachate	Comparison of groundwater screening level to Henry's Constant (soil vapor). Refer to Appendix 1 (Section 4.4.3 and Table G-2).
Vapor Intrusion	USEPA vapor intrusion spreadsheets modified for use in tropical and subtropical areas (soil vapor and indoor air). Refer to Appendix 1 (Section 3 & Tables E-2 and E-3) and Appendix 4.

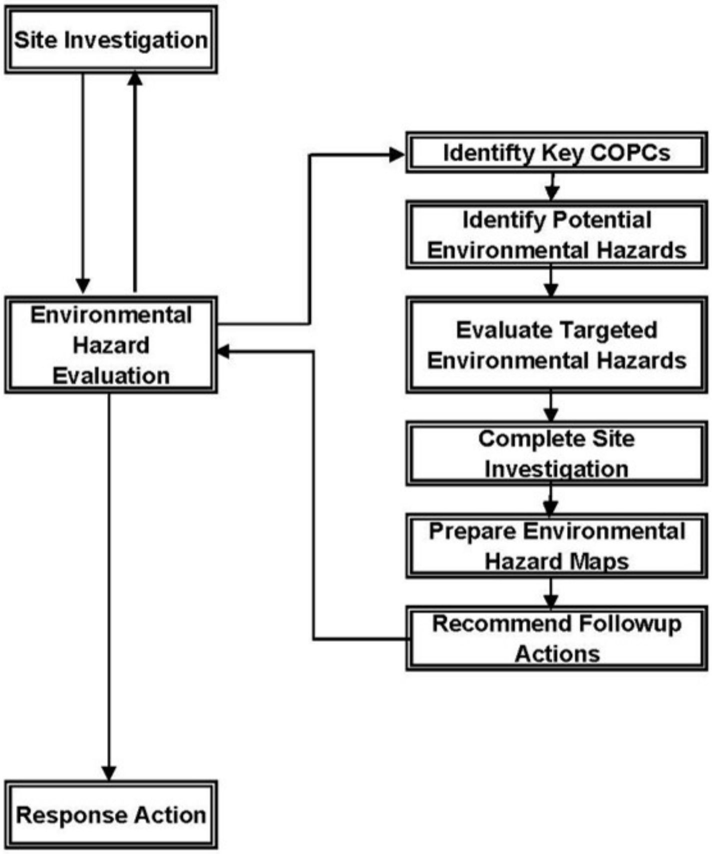
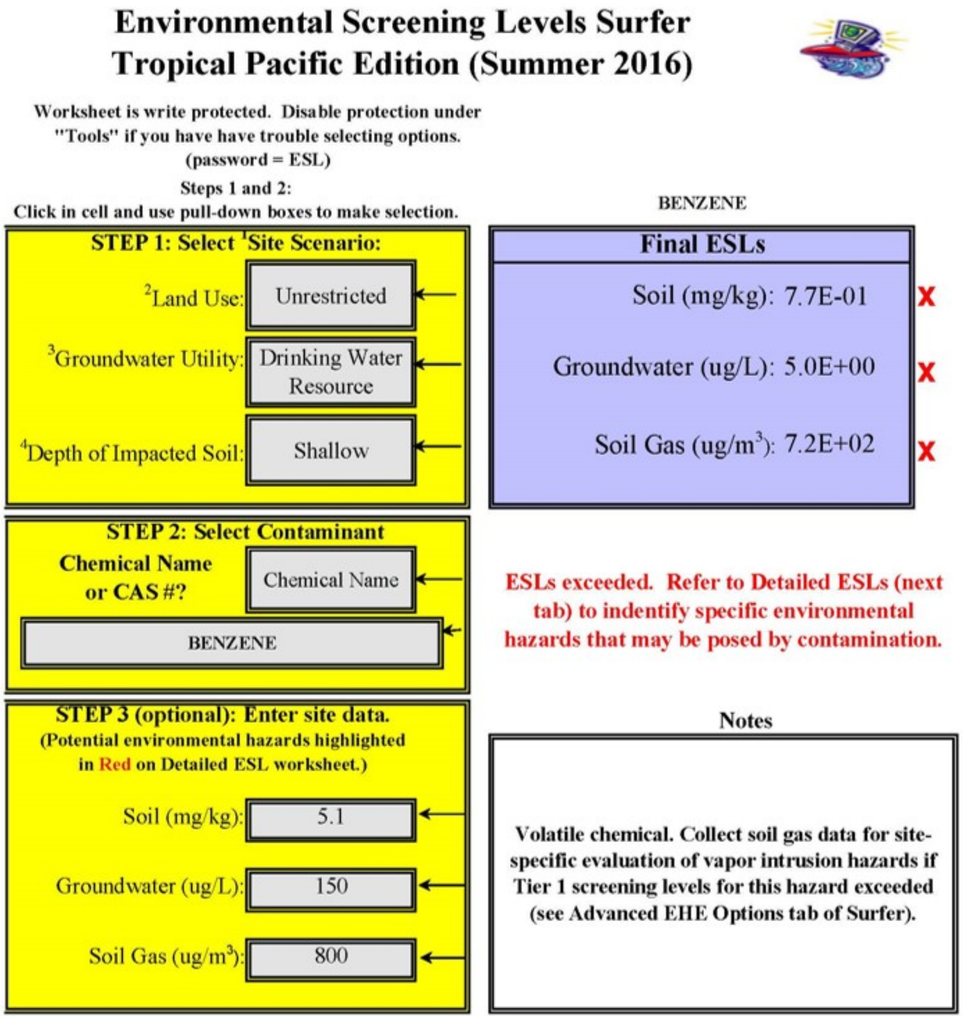


Figure 3-1. Overview of the Environmental Hazard Evaluation process (preparation of Environmental Hazard maps optional)..



Environmental Screening Levels Surfer
Tropical Pacific Edition (Summer 2016)

Worksheet is write protected. Disable protection under "Tools" if you have have trouble selecting options. (password = ESL)

Steps 1 and 2:
Click in cell and use pull-down boxes to make selection.

STEP 1: Select [1]Site Scenario:

[2]Land Use: Unrestricted

[3]Groundwater Utility: Drinking Water Resource

[4]Depth of Impacted Soil: Shallow

STEP 2: Select Contaminant

Chemical Name or CAS #? Chemical Name

BENZENE

STEP 3 (optional): Enter site data.
(Potential environmental hazards highlighted in Red on Detailed ESL worksheet.)

Soil (mg/kg): 5.1

Groundwater (ug/L): 150

Soil Gas (ug/m^3): 800

BENZENE

Final ESLs

Soil (mg/kg): 7.7E-01 X

Groundwater (ug/L): 5.0E+00 X

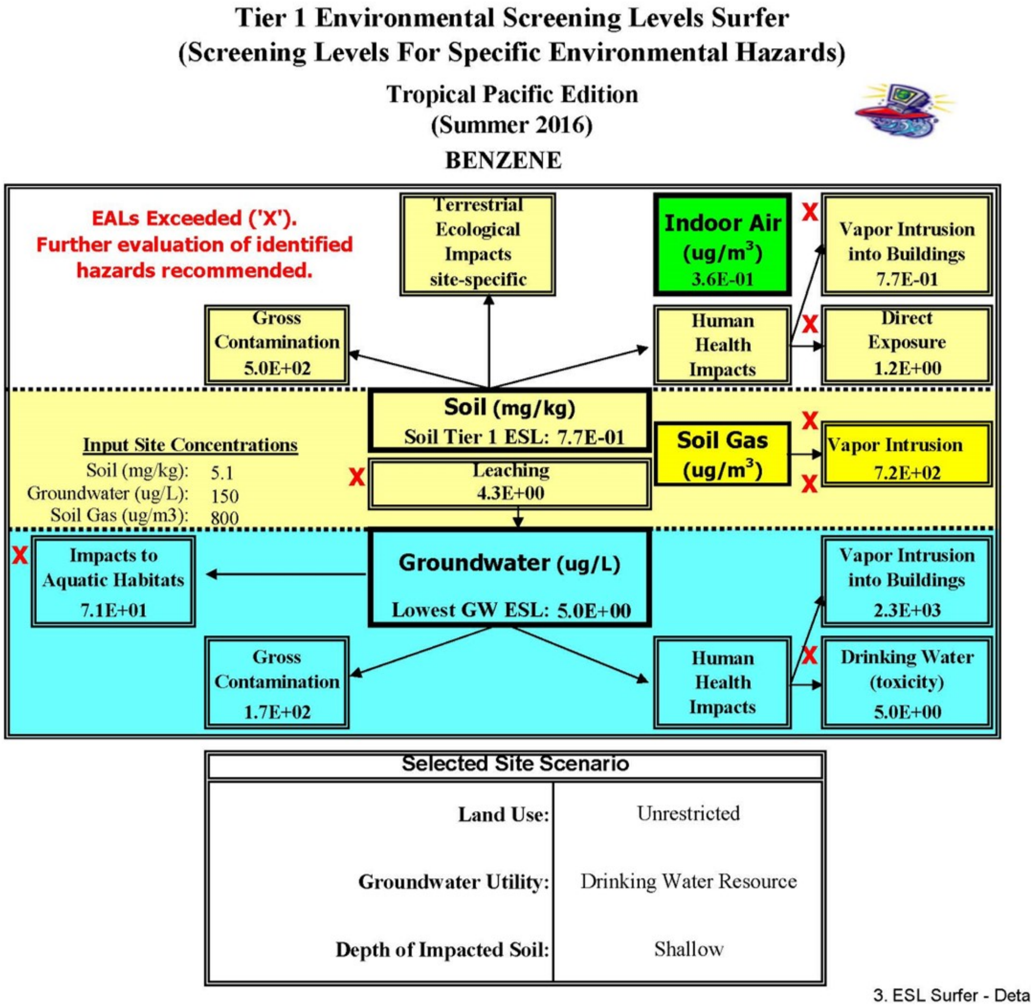
Soil Gas (ug/m^3): 7.2E+02 X

ESLs exceeded. Refer to Detailed ESLs (next tab) to indentify specific environmental hazards that may be posed by contamination.

Notes

Volatile chemical. Collect soil gas data for site-specific evaluation of vapor intrusion hazards if Tier 1 screening levels for this hazard exceeded (see Advanced EHE Options tab of Surfer).

Figure 3-2a. Printout of ESL Surfer input page, using benzene at noted concentrations in soil and groundwater as an example.



Tier 1 Environmental Screening Levels Surfer
(Screening Levels For Specific Environmental Hazards)

Tropical Pacific Edition
(Summer 2016)

BENZENE

Selected Site Scenario	
Land Use:	Unrestricted
Groundwater Utility:	Drinking Water Resource
Depth of Impacted Soil:	Shallow

3. ESL Surfer - Deta

Figure 3-2b. Printout of ESL Surfer detailed environmental hazard identification page, using benzene at noted concentrations in soil and groundwater as an example.

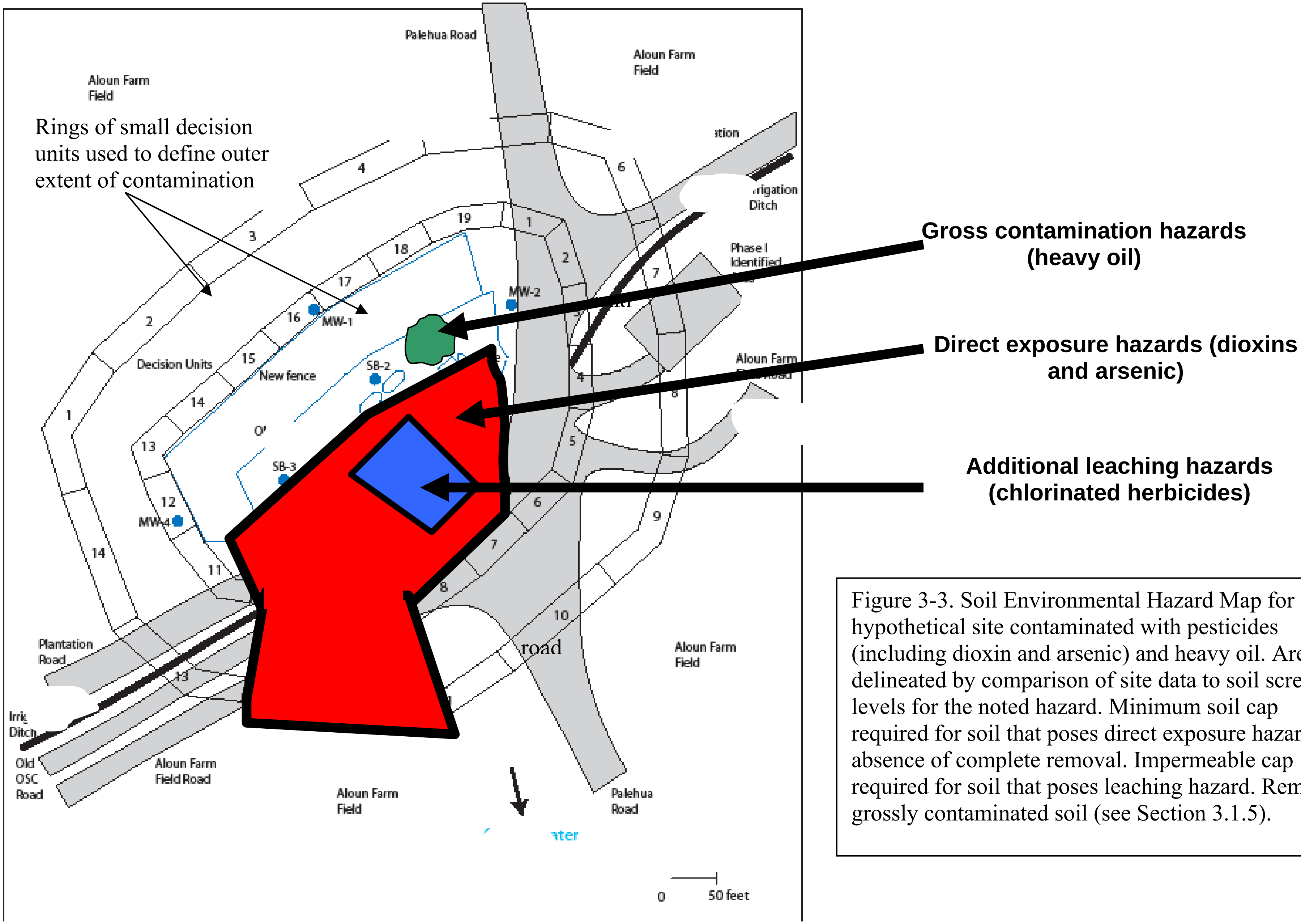
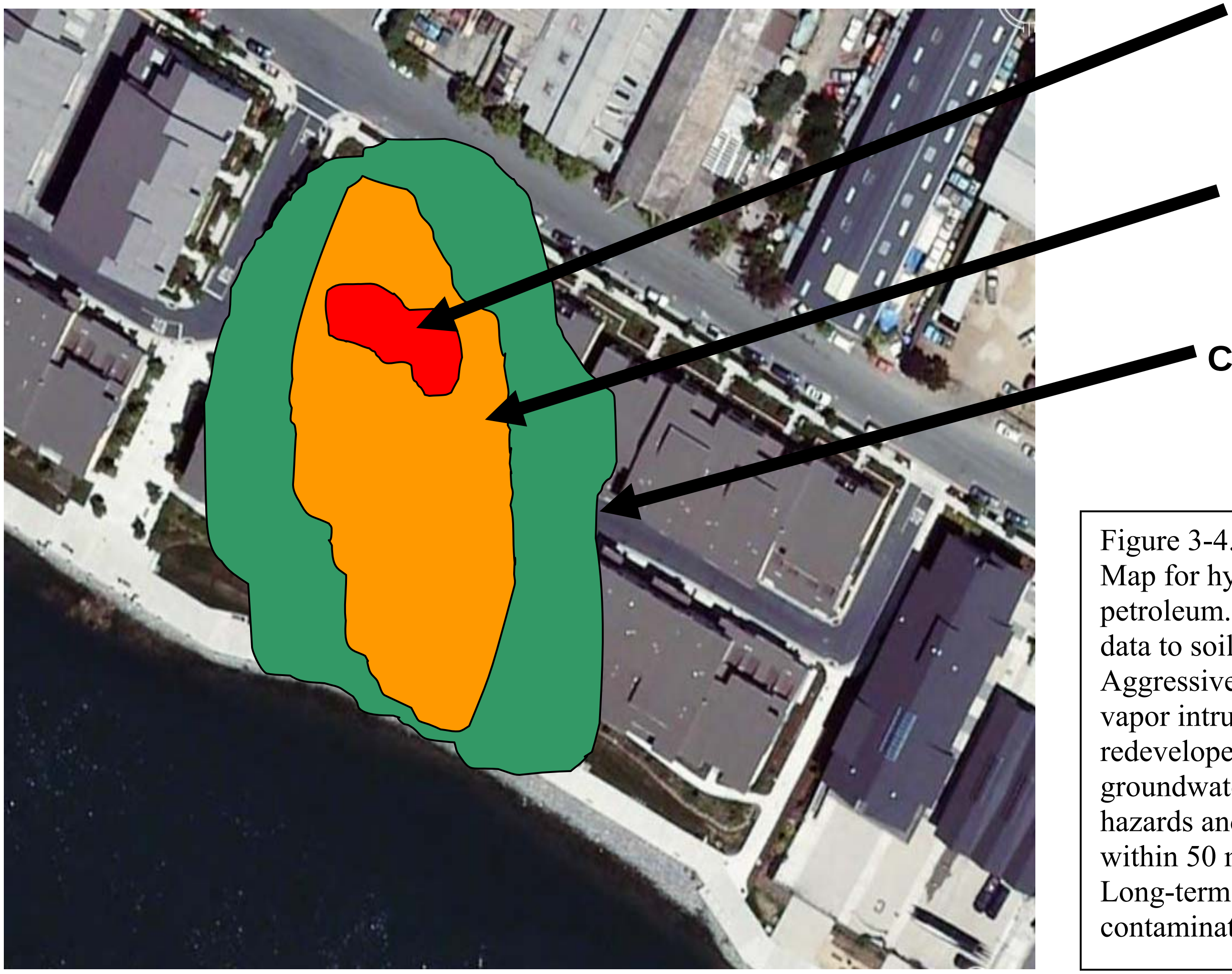


Figure 3-3. Soil Environmental Hazard Map for hypothetical site contaminated with pesticides (including dioxin and arsenic) and heavy oil. Areas delineated by comparison of site data to soil screening levels for the noted hazard. Minimum soil cap required for soil that poses direct exposure hazard in absence of complete removal. Impermeable cap required for soil that poses leaching hazard. Remove grossly contaminated soil (see Section 3.1.5).



Vapor intrusion hazards (TPHgasoline and benzene)

Acute aquatic toxicity and gross contamination hazards (TPHgasoline, benzene, ethylbenzene and xylenes)

Chronic aquatic toxicity hazards (same contaminants)

Figure 3-4. Groundwater Environmental Hazard Map for hypothetical site contaminated with petroleum. Areas delineated by comparison of site data to soil screening levels for the noted hazard. Aggressive remediation should focus on removal of vapor intrusion hazard so property can be redeveloped. Aggressive remediation of groundwater that poses acute aquatic toxicity hazards and gross contamination (odors, sheens) within 50 meters of the shoreline also recommended. Long-term monitoring of remaining groundwater contamination required (see Section 3.1.5).

Figure 3.5a. Example format for summary of environmental hazards posed by contaminated soil under current and unrestricted site conditions before and after response actions.

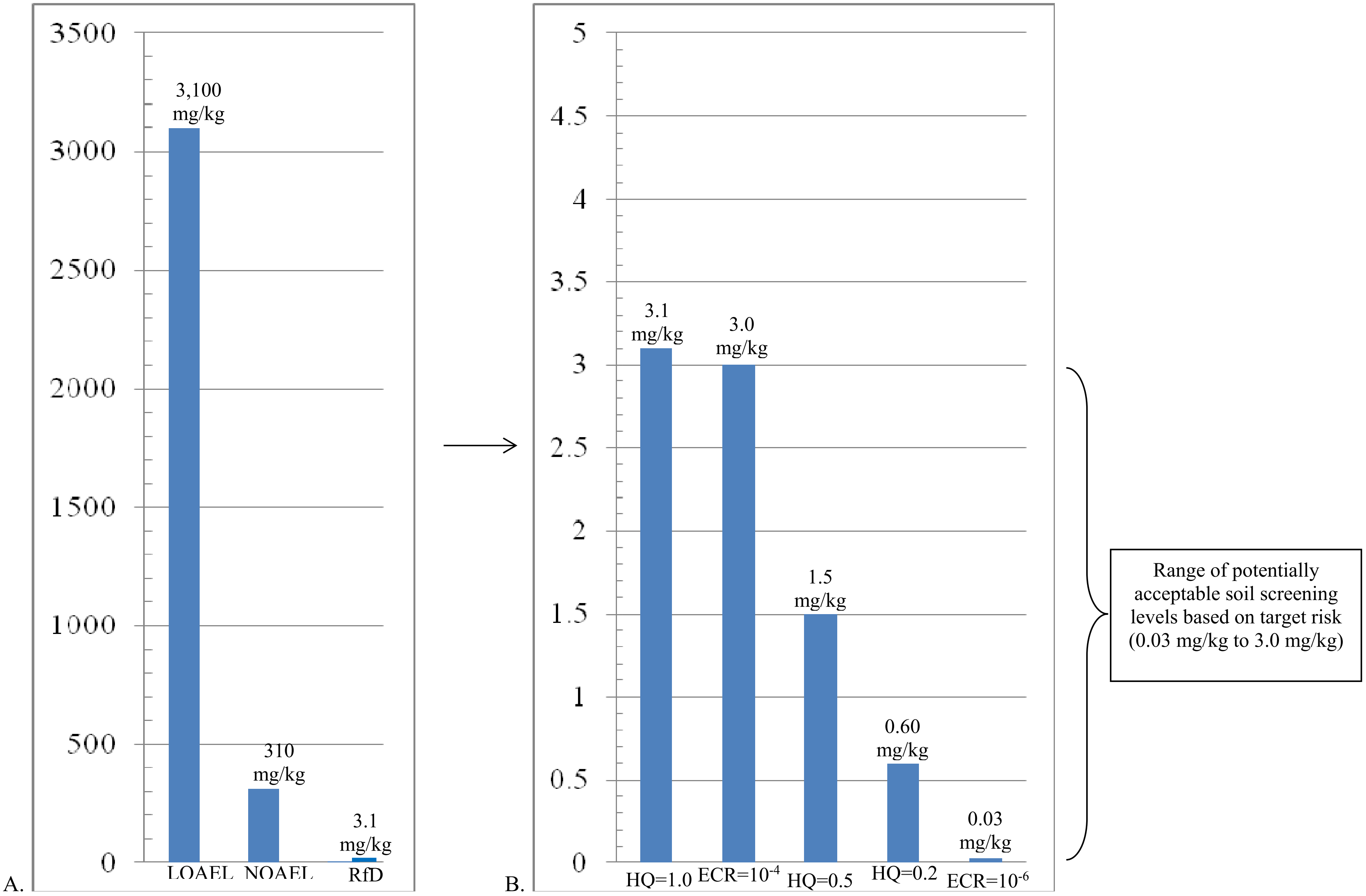
		[1,2]**Common Environmental Hazards Posed by Contaminated Soil**				
	Key Questions	**Direct Exposure**	**Vapor Emissions to Indoor Air**	**Terrestrial Ecological Impacts**	**Gross Contamination**	**Leaching to Groundwater**
PRE-RESPONSE	Before this response action, [3]**under unrestricted use** of the property, could the release have posed this environmental hazard?					
	Before this response action, [4]**under current conditions,** did the release pose this environmental hazard?					
	If the answer to the first question is YES and the second question is NO, then describe the **existing conditions prior to this response action** that provide controls for this hazard.					
RESPONSE ACTIONS	Describe the cleanup methods used in this response action that addressed this hazard:					
POST-RESPONSE	After this response action, [3]**under unrestricted use,** could the release pose this environmental hazard?					
	If the answer to the above is YES, then describe the **engineering controls and institutional controls** used to provide controls for this hazard:					

Figure 3.5b. Example format for summary of environmental hazards posed by contaminated groundwater under current and unrestricted site conditions before and after response actions.

		[1,2]Common Environmental Hazards Posed by Contaminated Groundwater			
	Key Questions	**Drinking Water Toxicity**	**Vapor Emissions to Indoor Air**	**Discharge to Surface Water**	**Gross Contamination**
PRE-RESPONSE	Before this response action, [3]**under unrestricted use** of the property, could the release have posed this environmental hazard?				
	Before this response action, [4]**under current conditions,** did the release pose this environmental hazard?				
	If the answer to the first question is YES and the second question is NO, then describe the **existing conditions prior to this response action** that provide controls for this hazard.				
RESPONSE ACTIONS	Describe the cleanup methods used in this response action that addressed this hazard:				
POST-RESPONSE	After this response action, [3]**under unrestricted use,** could the release pose this environmental hazard?				
	If the answer to the above is YES, then describe the **engineering controls and institutional controls** used to provide controls for this hazard:				

Figure 3-5 notes

1. Refer to Section 1.2 and Figures 1-2a,b for summary of common environmental hazards posed by contaminated soil and groundwater
2. Compare representative site data for targeted contaminants to Tropical Pacific screening levels (or equivalent) for the noted environmental hazard.
3. Unrestricted site conditions: Assumes an absence of current and/or future controls to prevent disturbance of contaminated soil or groundwater or the migration of contaminants into indoor air or nearby bodies of surface water (e.g., caps, vapor mitigation systems, land use restrictions, etc.).
4. Takes into account the presence of existing caps, lack of buildings threatened by vapor emissions, restrictions on land use, absence of water supply wells, monitoring data that indicate groundwater plumes are not migrating or expanding and threatening offsite wells or surface water bodies, etc.



Range of potentially acceptable soil screening levels based on target risk (0.03 mg/kg to 3.0 mg/kg)

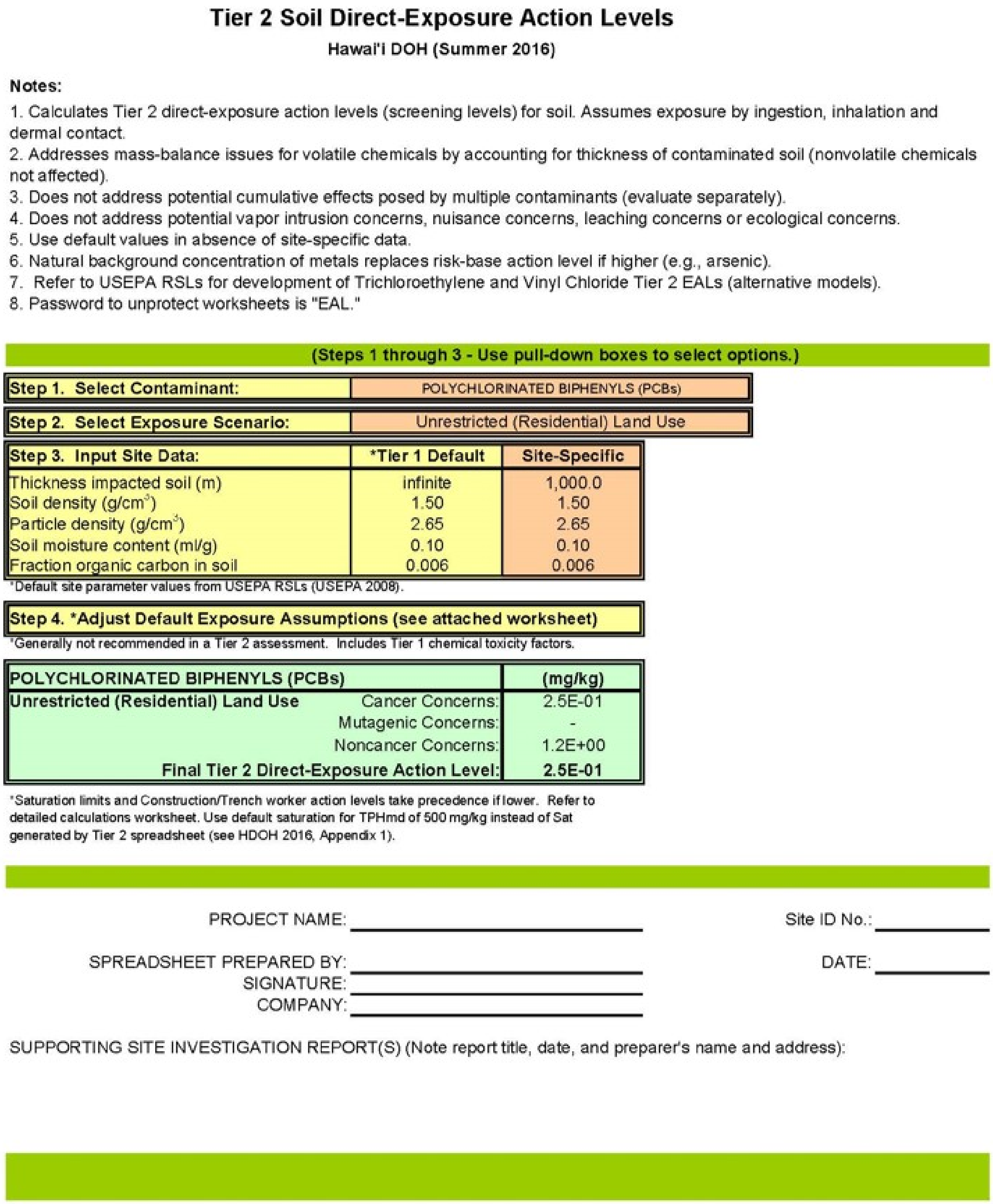
Figure 4-1. Progressive selection of a Tier 1 soil screening level for dieldrin (see Section 4.2 for discussion). Y axis represents dieldrin concentrations in soil equivalent to noted toxicity factor and target risk and default exposure assumptions. A: Downward adjustment of initial LOAEL determined from toxicological studies to incorporate safety and uncertainty factors (LOAEL to NOAEL to RfD, noted soil concentrations based on an noncancer HQ of 1.0). B: Further adjustment of soil screening level downward to consider the range of acceptable, noncancer (HQ) and cancer (ECR) risks. A Residential direct-exposure soil screening of 1.5 mg/kg was ultimately selected for use in the EHE guidance (see Table K-1 in Appendix 1).

Figure 4-2a. Example approaches to advanced evaluation of environmental hazards associated with contaminated soil.

Environmental Hazard	Example Site-Specific Evaluation Approaches
Direct Exposure	• Use of Multi Increment sample data to evaluate direct exposure concerns in targeted decision units. • Use of Tier 2 Direct Exposure Spreadsheet to calculate alternative screening levels. • Use of laboratory bioaccessibility tests to better evaluate arsenic toxicity. • Preparation of a site-specific human health risk assessment that considers engineered and institutional controls to eliminate or minimize exposure pathways, alternative exposure assumptions, alternative target risks, etc.
Vapor Intrusion	• Collection of soil vapor data to better evaluate vapor intrusion or explosive hazards. • Preparation of site-specific vapor intrusion model.
Leaching	• Collection of soil vapor data to estimate VOCs in leachate, leachate fate and transport evaluation • Collection of groundwater data. • Use of laboratory batch test model to evaluate contaminant mobility and estimate concentrations in source area leachate.
Impacts to Terrestrial Habitats	• Field inspection to determine the presence or absence of potentially significant, terrestrial ecological habits. • Preparation of a detailed, ecological risk assessment.
Gross Contamination	• Field inspection of petroleum-contaminated soil to evaluate potential gross contamination concerns (especially in existing or planned residential areas).

Figure 4-2b. Example approaches to advanced evaluation of environmental hazards associated with contaminated groundwater.

Environmental Hazard	Example Site-Specific Evaluation Approaches
Contamination of Drinking Water Resources (toxicity and/or taste & odor hazards)	• Identification and monitoring of nearby, groundwater supply wells and guard wells. • Long-term monitoring of groundwater to evaluate plume migration potential. • Use of groundwater plume fate & transport models in combination with long-term monitoring to evaluate plume migration potential.
Vapor Intrusion	• Collection of soil vapor data to better evaluate vapor intrusion or explosion hazards. • Preparation of site-specific vapor intrusion model.
Impacts to Aquatic Habitats	• Use of groundwater data to evaluate plume expansion and migration over time. • Use of fate and transport models to predict long-term migration potential of groundwater contaminant plumes.
Gross Contamination	• Check groundwater for free product. • Check discharge areas for sheen and other gross contamination concerns.



Tier 2 Soil Direct-Exposure Action Levels

Hawai'i DOH (Summer 2016)

Notes:

1. Calculates Tier 2 direct-exposure action levels (screening levels) for soil. Assumes exposure by ingestion, inhalation and dermal contact.
2. Addresses mass-balance issues for volatile chemicals by accounting for thickness of contaminated soil (nonvolatile chemicals not affected).
3. Does not address potential cumulative effects posed by multiple contaminants (evaluate separately).
4. Does not address potential vapor intrusion concerns, nuisance concerns, leaching concerns or ecological concerns.
5. Use default values in absence of site-specific data.
6. Natural background concentration of metals replaces risk-base action level if higher (e.g., arsenic).
7. Refer to USEPA RSLs for development of Trichloroethylene and Vinyl Chloride Tier 2 EALs (alternative models).
8. Password to unprotect worksheets is "EAL."

(Steps 1 through 3 - Use pull-down boxes to select options.)

Step 1. Select Contaminant:	POLYCHLORINATED BIPHENYLS (PCBs)
Step 2. Select Exposure Scenario:	Unrestricted (Residential) Land Use

Step 3. Input Site Data:	***Tier 1 Default**	**Site-Specific**
Thickness impacted soil (m)	infinite	1,000.0
Soil density (g/cm^3)	1.50	1.50
Particle density (g/cm^3)	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
Fraction organic carbon in soil	0.006	0.006

*Default site parameter values from USEPA RSLs (USEPA 2008).

Step 4. *Adjust Default Exposure Assumptions (see attached worksheet)

*Generally not recommended in a Tier 2 assessment. Includes Tier 1 chemical toxicity factors.

POLYCHLORINATED BIPHENYLS (PCBs)		**(mg/kg)**
Unrestricted (Residential) Land Use	Cancer Concerns:	2.5E-01
	Mutagenic Concerns:	-
	Noncancer Concerns:	1.2E+00
	Final Tier 2 Direct-Exposure Action Level:	**2.5E-01**

*Saturation limits and Construction/Trench worker action levels take precedence if lower. Refer to detailed calculations worksheet. Use default saturation for TPHmd of 500 mg/kg instead of Sat generated by Tier 2 spreadsheet (see HDOH 2016, Appendix 1).

PROJECT NAME: ______________ Site ID No.: ________

SPREADSHEET PREPARED BY: ______________ DATE: ________

SIGNATURE: ______________

COMPANY: ______________

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

Figure 4-3. Primary input page of Hawai'i Department of Health Tier2 Direct Exposure Model for site-specific calculation of soil screening levels for direct exposure to contaminants in soil. Noted action levels reflect an input cancer risk of 10^{-6} and noncancer Hazard Quotient of 1.0.

Figure 4-4. Summary of Arsenic Soil Screening Levels and associated soil management categories.

Soil Management Category	**Action**
Total Arsenic (< 2 mm size fraction)	
Category A Total Arsenic ≤20 mg/kg	**Background.** Within range of expected background conditions in non-agricultural and non-industrial areas. No further action required and no restrictions on land use.
Bioaccessible Arsenic (<250 µm size fraction)	
Category B Total Arsenic >20 mg/kg and Bioaccessible Arsenic ≤23 mg/kg	**Minimally Impacted-Unrestricted Land Use.** Exceeds expected background conditions but at levels anticipated for many agricultural fields where arsenic-based chemicals were used historically. Potential health risks considered to be within the range of acceptable health risks for long-term exposure. Include Category B soil in remedial actions for more heavily contaminated spill areas as practicable in order to reduce exposure (e.g., outer margins of pesticide mixing areas). Offsite reuse of soil as fill material that exceeds 24 mg/kg total arsenic but meets bioaccessible action levels should documented and kept with property records to avoid the need for retesting in the future. Use of soil for intermediate (e.g., temporarily inactive portions) or interim (e.g., daily or weekly) cover at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Although not strictly necessary from a health-risk standpoint, owners of existing homes where pesticide-related, Category B soils are identified may want to consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc) as described in the HDOH fact sheet *Arsenic in Hawaiian Soils: Questions and Answers on Health Concerns* (HDOH 2010c). For new developments on large, former field areas, notify future homeowners of elevated levels of arsenic on the property and recommend similar, precautionary measures (e.g., include in information provided to home buyers during property transactions, see also HDOH 2016).

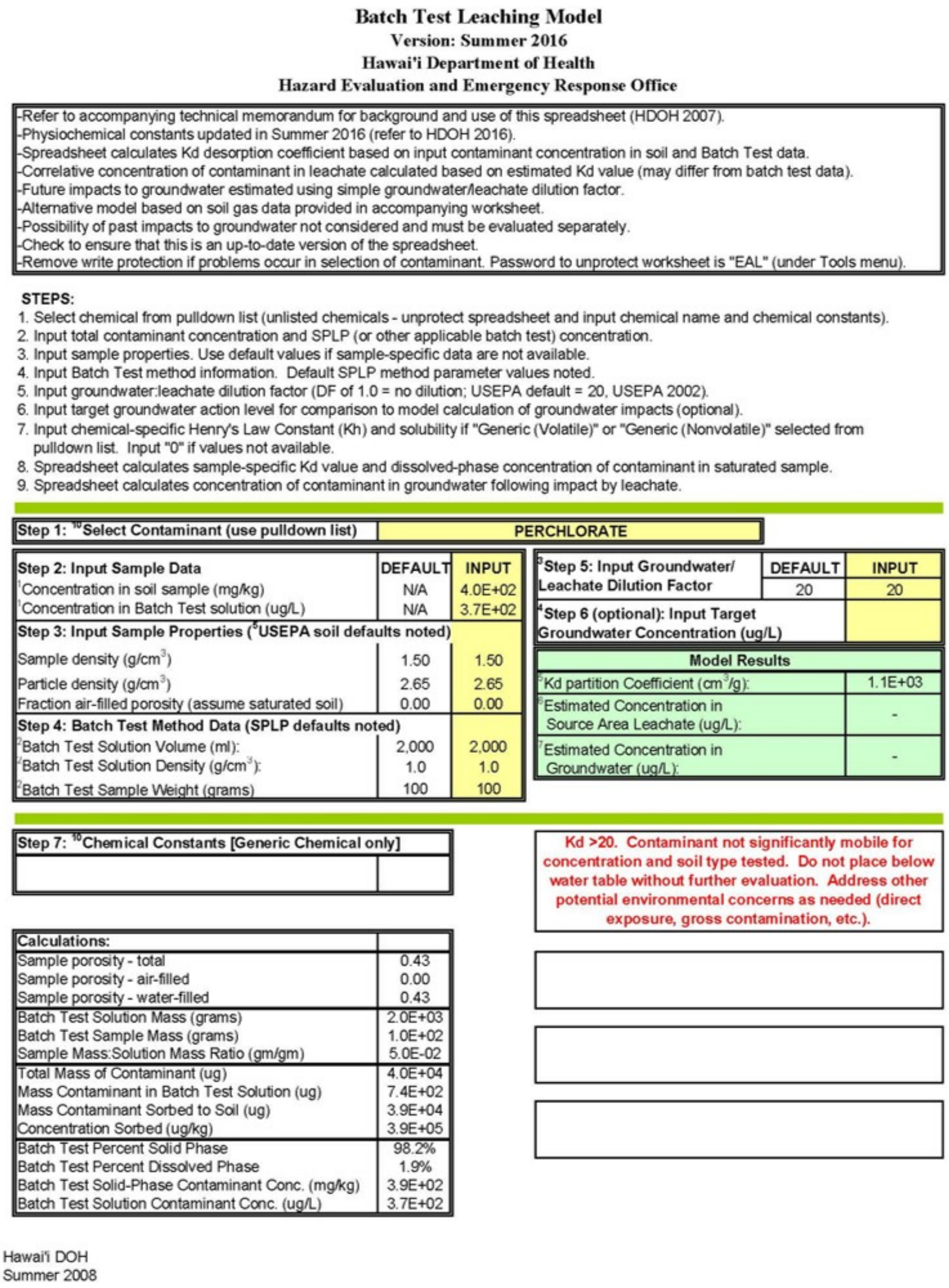
Figure 4-4 (cont.). Summary of Arsenic Soil Screening Levels and associated soil management categories.

Category C (Bioaccessible Arsenic >23 but ≤95 mg/kg)	**Moderately Impacted-Commercial/Industrial Land Use Only.** Identified at several, former pesticide mixing areas and wood treatment facilities. May be co-located with pentachlorophenol, dioxin and triazine pesticide contamination at agricultural sites. Restriction to commercial/industrial land use is typically required in the absence of remediation or significant institutional and engineered controls and approval of the overseeing regulatory agency. Use of soil as soil as intermediate (e.g., temporarily inactive portions) or interim (e.g., daily or weekly) cover at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Preparation of a site-specific, *Environmental Hazard Management Plan* (EHMP) required if soil is left on site for long-term management (e.g., see also HDOH 2016). Treatment to reduce bioavailability and/or removal of isolated spill areas is recommended when practicable in order to minimize future management and liability concerns. This includes controls to ensure no off-site dispersion (e.g., dust or surface runoff) or inadvertent excavation and reuse at properties with sensitive land uses.
Category D (Bioaccessible Arsenic >95 mg/kg)	**Heavily Impacted-Remedial Actions Required.** Identified at a small number of former pesticide storage and mixing areas (e.g., sugarcane operations), former plantation housing areas and wood treatment facilities. May be co-located with dioxin and triazine pesticide contamination. Remedial actions required under any land use scenario in order to reduce potential exposure. Potentially adverse health risks under both sensitive and commercial/industrial land use scenarios in the absence of significant institutional and/or engineered controls. Disposal of soil at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Preparation of site-specific EHMP required if left on site.

Figure 4-5. Summary of TEQ Dioxin Soil Action Levels and associated soil management categories.

Soil Management Category	*Action
Category A (≤20 ng/kg)	**Background.** Within range of expected background conditions in non-agricultural and non-industrial areas. No further action required and no restrictions on land use.
Category B (>20 but ≤240 ng/kg)	**Minimally Impacted.** Exceeds expected background conditions but within range anticipated for agricultural fields. Potential health risks considered to be insignificant. Include Category B soil in remedial actions for more heavily contaminated spill areas as practicable in order to reduce exposure (e.g., outer margins of pesticide mixing areas). Offsite reuse of soil for fill material or as final cover on a decommissioned landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. For existing homes, consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc.).
Category C (>240 but ≤1,500 ng/kg)	**Moderately Impacted.** Typical of incinerator ash, burn pits, wood treatment operations that used pentachlorophenol (PCP), and the margins of heavily impacted, pesticide mixing areas associated with former sugarcane operations that used PCP. Restriction to commercial/industrial land use required with a formal restriction to the deed against sensitive land uses (e.g., residential, schools, day care, medical facilities, etc.) in the absence of institutional and engineered controls and HDOH approval. Use of soil as intermediate (e.g., temporarily inactive portions) or interim (e.g., daily or weekly) cover at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Preparation of a site-specific, *Environmental Hazard Management Plan* (EHMP) required if soil left on site for long-term management. Removal of isolated spill areas recommended when practicable in order to minimize future management and liability concerns. This includes controls to ensure no off-site dispersion (e.g., dust or surface runoff) or inadvertent excavation and reuse at properties with sensitive land uses.
Category D (>1,500 ng/kg)	**Heavily Impacted.** Typical of former pesticide mixing areas that used PCP (e.g., sugarcane operations). Remedial actions required under any land use scenario in order to reduce potential exposure. Potentially adverse health risks under both sensitive and commercial/industrial land use scenarios in the absence of significant institutional and/or engineered controls. Disposal of soil at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions.

*Consider remediation of sites with Category C or D soils to the HDOH default soil background level of 20 ng/kg if to be used for residential or other sensitive purposes (refer to HDOH 2010b).



Batch Test Leaching Model
Version: Summer 2016
Hawai'i Department of Health
Hazard Evaluation and Emergency Response Office

-Refer to accompanying technical memorandum for background and use of this spreadsheet (HDOH 2007).
-Physiochemical constants updated in Summer 2016 (refer to HDOH 2016).
-Spreadsheet calculates Kd desorption coefficient based on input contaminant concentration in soil and Batch Test data.
-Correlative concentration of contaminant in leachate calculated based on estimated Kd value (may differ from batch test data).
-Future impacts to groundwater estimated using simple groundwater/leachate dilution factor.
-Alternative model based on soil gas data provided in accompanying worksheet.
-Possibility of past impacts to groundwater not considered and must be evaluated separately.
-Check to ensure that this is an up-to-date version of the spreadsheet.
-Remove write protection if problems occur in selection of contaminant. Password to unprotect worksheet is "EAL" (under Tools menu).

STEPS:

1. Select chemical from pulldown list (unlisted chemicals - unprotect spreadsheet and input chemical name and chemical constants).
2. Input total contaminant concentration and SPLP (or other applicable batch test) concentration.
3. Input sample properties. Use default values if sample-specific data are not available.
4. Input Batch Test method information. Default SPLP method parameter values noted.
5. Input groundwater:leachate dilution factor (DF of 1.0 = no dilution; USEPA default = 20, USEPA 2002).
6. Input target groundwater action level for comparison to model calculation of groundwater impacts (optional).
7. Input chemical-specific Henry's Law Constant (Kh) and solubility if "Generic (Volatile)" or "Generic (Nonvolatile)" selected from pulldown list. Input "0" if values not available.
8. Spreadsheet calculates sample-specific Kd value and dissolved-phase concentration of contaminant in saturated sample.
9. Spreadsheet calculates concentration of contaminant in groundwater following impact by leachate.

Step 1: [10]Select Contaminant (use pulldown list)	**PERCHLORATE**

Step 2: Input Sample Data	**DEFAULT**	**INPUT**
[1]Concentration in soil sample (mg/kg)	N/A	4.0E+02
[1]Concentration in Batch Test solution (ug/L)	N/A	3.7E+02
Step 3: Input Sample Properties ([5]USEPA soil defaults noted)		
Sample density (g/cm^3)	1.50	1.50
Particle density (g/cm^3)	2.65	2.65
Fraction air-filled porosity (assume saturated soil)	0.00	0.00
Step 4: Batch Test Method Data (SPLP defaults noted)		
[2]Batch Test Solution Volume (ml):	2,000	2,000
[2]Batch Test Solution Density (g/cm^3):	1.0	1.0
[2]Batch Test Sample Weight (grams)	100	100

[3]Step 5: Input Groundwater/ Leachate Dilution Factor	**DEFAULT**	**INPUT**
	20	20
[4]Step 6 (optional): Input Target Groundwater Concentration (ug/L)		

Model Results	
[6]Kd partition Coefficient (cm^3/g):	1.1E+03
[6]Estimated Concentration in Source Area Leachate (ug/L):	-
[7]Estimated Concentration in Groundwater (ug/L):	-

Step 7: [10]Chemical Constants [Generic Chemical only]	

Kd >20. Contaminant not significantly mobile for concentration and soil type tested. Do not place below water table without further evaluation. Address other potential environmental concerns as needed (direct exposure, gross contamination, etc.).

Calculations:	
Sample porosity - total	0.43
Sample porosity - air-filled	0.00
Sample porosity - water-filled	0.43
Batch Test Solution Mass (grams)	2.0E+03
Batch Test Sample Mass (grams)	1.0E+02
Sample Mass:Solution Mass Ratio (gm/gm)	5.0E-02
Total Mass of Contaminant (ug)	4.0E+04
Mass Contaminant in Batch Test Solution (ug)	7.4E+02
Mass Contaminant Sorbed to Soil (ug)	3.9E+04
Concentration Sorbed (ug/kg)	3.9E+05
Batch Test Percent Solid Phase	98.2%
Batch Test Percent Dissolved Phase	1.9%
Batch Test Solid-Phase Contaminant Conc. (mg/kg)	3.9E+02
Batch Test Solution Contaminant Conc. (ug/L)	3.7E+02

Hawai'i DOH
Summer 2008

Figure 4-6. Input page of Hawai'i Department of Health Soil Batch Leaching Test model.

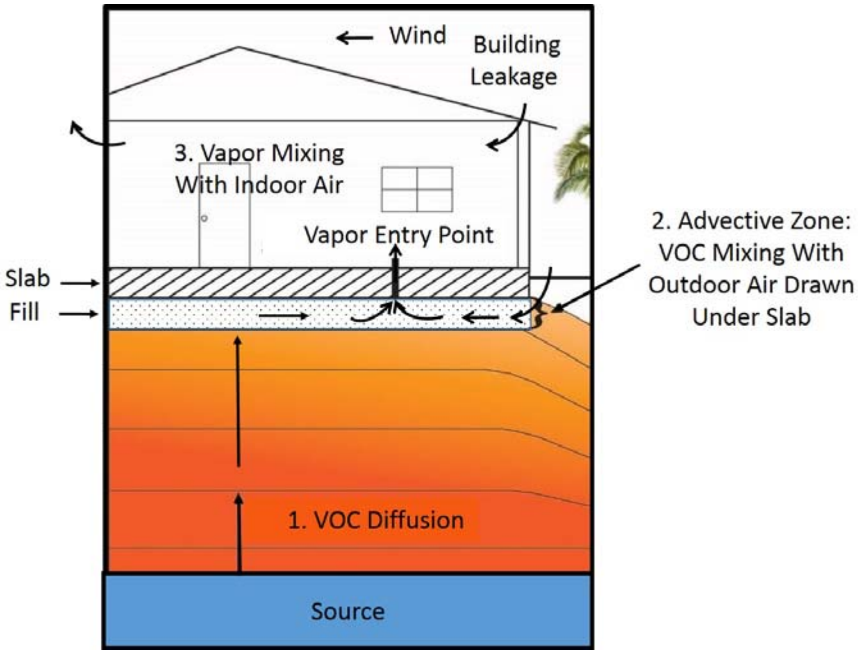


Figure 4-7. The three stages of vapor intrusion: 1) Outward diffusion of VOCs from source area, 2) Advective zone mixing of VOCs with outdoor air drawn under the building slab due to depressurization of the overlying structure and 3) Intrusion and mixing of VOC-contaminated air/vapors with indoor air, including outdoor air drawn into the building due to leakage in the above-ground portion of the structure.

Figure 4-8. Comparison of indoor air screening levels to typical concentrations of volatile chemicals in indoor, residential air. Concentrations of the chemicals in the indoor air of commercial/industrial buildings could be much higher, depending on chemicals used and stored in the building. Ambient levels of highlighted chemicals may exceed action levels some or much of the time at a conservative target risk level.

	[1]Indoor Air Screening Level (ug/m^3)		[2]Typical Indoor Air Background Range (ug/m^3)		
Compound	**Residential**	**Commercial/Industrial**	**50th Percentile**	**75th Percentile**	**90th Percentile**
Petroleum Related					
Benzene	0.31	0.52	<RL to 4.7	1.9 to 7.0	9.9 to 29
Ethylbenzene	0.97	1.6	1 to 3.7	2.0 to 5.6	12 to 17
Toluene	1,000	1,500	4.8 to 24	12 to 41	79 to 144
Xylenes (total)	21	29	2.6 to 5.0	7.0 to 27	34 to 84
Naphthalene	0.07	0.12	<RL	<RL	2.7
[3]Total Petroleum Hydrocarbons	230	330	126	240	594+
[2]C5-C8 Aliphatics	630	880	58	130	330+
[2]C9-C12+ Aliphatics	100	150	69	110	220+
[2]C9-C10+ Aromatics	100	150	<RL	<RL	44+
Chlorinated Solvents					
Carbon Tetrachloride	0.41	0.68	<RL to 0.68	<RL to 0.72	<RL to 1.1
1,1 Dichloroethylene	42	58	<RL	<RL to 0.37	0.7
1,2 cis-Dichloroethylene	1.5	2.0	<RL	<RL	<RL to 1.2
[2]1,2 trans-Dichloroethylene	13	18	<RL	<RL	<RL
Methylene Chloride	5.2	8.7	0.68 to 6.1	1.0 to 8.2	2.9-45
Tetrachloroethylene	0.41	0.69	<RL to 2.2	<RL to 4.1	4.1 to 9.5
1,1,1 Trichloroethane	1,000	1,500	<RL to 5.9	<RL to 7.0	3.4 to 28
Trichloroethylene	1.2	2.0	<RL to 1.1	<RL to 1.2	0.56 to 3.3
Vinyl Chloride	0.55	0.93	<RL	<RL	<RL to 0.09

Figure 4-8 (cont.). Notes

1. See Table G and Appendix 1, Table E-3. Refer to Appendix 1, Chapter 6 of Appendix 1 for discussion of indoor air screening levels for TPH and individual carbon ranges.
2. Primary reference: USEPA 2011b.
3. TPH as sum of individual hydrocarbon ranges (excludes BTEX). Levels of TPH in indoor air could exceed 1,000 ug/m^3 if petroleum-based fuels, cleaners or other products stored or recently used in the building.
4. Reporting Limit (RL) for individual VOCs varied between studies.

Compound	**[1]Chance that Indoor Air Impacts will not be Discernible from Background Indoor Air at Noted Subslab Soil vapor Concentration (ug/m^3).** Up to 50%	**Up to 25%**	**Up to 10%**
Petroleum Related			
Benzene	9,400	14,000	58,000
Ethylbenzene	7,400	11,200	34,000
Toluene	48,000	82,000	288,000
Xylenes (total)	10,000	54,000	168,000
Naphthalene	-	-	5,400
Total Petroleum Hydrocarbons	252,000	480,000	1,188,000
C5-C8 Aliphatics	116,000	260,000	660,000
C9-C12+ Aliphatics	138,000	220,000	440,000
C9-C10+ Aromatics	-	-	88,000
Chlorinated Solvents			
Carbon Tetrachloride	1,360	1,440	2,200
1,1 Dichloroethylene	-	740	1,400
1,2 cis-Dichloroethylene	-	-	2,400
[2]1,2 trans-Dichloroethylene	-	-	-
Methylene Chloride	12,200	16,400	90,000
Tetrachloroethylene	4,400	8,200	19,000
1,1,1 Trichloroethane	11,800	14,000	56,000
Trichloroethylene	2,200	2,400	6,600
Vinyl Chloride	-	-	180

Notes

1. Uppermost concentration for range noted in Figure 4-8 divided by the default, Indoor Air:Subslab Soil vapor Attenuation Factor for residential homes of 0.0005 (1/2000).

Figure 4-9. Chance that impacts to indoor air from the intrusion of subsurface vapors into a building will not be discernible from typical background concentrations at the noted concentration of the chemical in subslab soil vapor (see Table 4-7a). Based on a residential home scenario levels. Equivalent subslab soil vapor levels for commercial/industrial buildings necessary to impact indoor air above typical background could be much higher. For general guidance only.

TABLES

TABLE A: SHALLOW SOIL ($\leq$3M BGS) - WATER IS A CURRENT OR POTENTIAL SOURCE OF DRINKING WATER

Notes:

- Always compare final soil data for commercial/industrial sites to unrestricted land use ESLs and evaluate need for formal land-use restrictions (see Section 2.8).

TABLE A. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS Current or Potential Source of Drinking Water

CHEMICAL PARAMETER	[1]Shallow Soil		[3]Groundwater (ug/L)
	[2]Unrestricted Land Use (mg/kg)	Commercial/ Industrial Land Use Only (mg/kg)	
ACENAPHTHENE	4.0E+01	4.0E+01	1.5E+01
ACENAPHTHYLENE	5.5E+00	5.5E+00	1.3E+01
ACETONE	1.0E+00	1.0E+00	1.5E+03
ALDRIN	2.8E+00	2.8E+00	1.4E-04
AMETRYN	1.3E+01	1.3E+01	1.8E+02
AMINO,2- DINITROTOLUENE,3,6-	8.5E-01	8.5E-01	1.8E+01
AMINO,4- DINITROTOLUENE,2,6-	5.2E-01	5.2E-01	1.1E+01
ANTHRACENE	1.4E+00	1.4E+00	2.0E-02
ANTIMONY	6.3E+00	9.3E+01	6.0E+00
ARSENIC	2.4E+01	9.5E+01	1.0E+01
ATRAZINE	1.3E-02	1.3E-02	3.4E-01
BARIUM	1.0E+03	2.5E+03	2.2E+02
BENOMYL	7.8E-03	7.8E-03	1.4E-01
BENZENE	3.0E-01	3.0E-01	5.0E+00
BENZO(a)ANTHRACENE	3.3E+00	3.3E+00	2.7E-02
BENZO(a)PYRENE	3.6E+00	5.9E+00	6.0E-02
BENZO(b)FLUORANTHENE	1.1E+01	2.1E+01	2.2E-01
BENZO(g,h,i)PERYLENE	3.5E+01	3.5E+01	1.3E-01
BENZO(k)FLUORANTHENE	3.9E+01	3.9E+01	4.0E-01
BERYLLIUM	3.1E+01	1.5E+02	6.6E-01
BIPHENYL, 1,1-	1.0E+01	4.3E+01	5.0E-01
BIS(2-CHLOROETHYL)ETHER	7.5E-05	7.5E-05	1.4E-02
BIS(2-CHLORO-1-METHYLETHYL)ETHER	4.0E-03	4.0E-03	3.7E-01
BIS(2-ETHYLHEXYL)PHTHALATE	3.9E+01	6.5E+01	3.0E+00
BORON	1.0E+03	2.5E+03	1.0E+03
BROMODICHLOROMETHANE	2.5E-03	2.5E-03	1.4E-01
BROMOFORM	8.6E-01	8.6E-01	1.0E+02
BROMOMETHANE	2.2E-01	3.6E-01	7.6E+00
CADMIUM	1.4E+01	7.4E+01	2.5E-01
CARBON TETRACHLORIDE	1.0E-01	7.3E-01	5.0E+00
CHLORDANE (TECHNICAL)	7.6E+00	7.6E+00	4.0E-03
CHLOROANILINE, p-	7.3E-03	7.3E-03	3.9E-01
CHLOROBENZENE	1.5E+00	1.5E+00	2.5E+01
CHLOROETHANE	1.2E+00	1.2E+00	1.6E+01
CHLOROFORM	2.6E-02	1.9E-01	2.8E+01
CHLOROMETHANE	4.0E+00	1.1E+01	1.9E+02
CHLOROPHENOL, 2-	1.2E-02	1.2E-02	1.8E-01
CHROMIUM (Total)	1.1E+03	1.1E+03	1.1E+01
CHROMIUM III	1.0E+03	2.5E+03	2.0E+01
CHROMIUM VI	3.0E+01	4.8E+02	4.3E-02
CHRYSENE	3.0E+01	3.0E+01	1.0E+00
COBALT	8.0E+01	8.0E+01	6.0E+00
COPPER	6.3E+02	2.5E+03	3.1E+00
CYANIDE (Free)	4.8E+00	3.1E+01	1.0E+00
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	1.0E-02	1.0E-02	7.1E-01
DALAPON	1.6E-01	1.6E-01	3.0E+02
DIBENZO(a,h)ANTHTRACENE	1.1E+00	9.6E+00	2.2E-02

TABLE A. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS Current or Potential Source of Drinking Water

	[1]Shallow Soil		
CHEMICAL PARAMETER	[2]Unrestricted Land Use (mg/kg)	Commercial/ Industrial Land Use Only (mg/kg)	[3]Groundwater (ug/L)
DIBROMO,1,2- CHLOROPROPANE,3-	4.0E-03	4.0E-03	2.0E-01
DIBROMOCHLOROMETHANE	9.4E-03	9.4E-03	9.3E-01
DIBROMOETHANE, 1,2-	5.3E-04	5.3E-04	5.0E-02
DICHLOROBENZENE, 1,2-	7.5E-01	7.5E-01	1.0E+01
DICHLOROBENZENE, 1,3-	2.5E+00	2.5E+00	2.2E+01
DICHLOROBENZENE, 1,4-	5.5E-02	3.9E-01	5.0E+00
DICHLOROBENZIDINE, 3,3-	9.2E-02	9.2E-02	1.7E-01
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.3E+00	9.6E+00	1.1E-02
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.0E+00	9.3E+00	4.6E-02
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.9E+00	1.9E+00	1.0E-03
DICHLOROETHANE, 1,1-	1.1E-01	1.1E-01	2.8E+00
DICHLOROETHANE, 1,2-	2.3E-02	7.0E-02	5.0E+00
DICHLOROETHYLENE, 1,1-	1.2E+00	1.2E+00	7.0E+00
DICHLOROETHYLENE, Cis 1,2-	3.6E-01	2.2E+00	7.0E+01
DICHLOROETHYLENE, Trans 1,2-	3.6E+00	6.5E+00	1.0E+02
DICHLOROPHENOL, 2,4-	7.3E-03	7.3E-03	3.0E-01
DICHLOROPHENOXYACETIC ACID (2,4-D)	3.4E-01	3.4E-01	7.0E+01
DICHLOROPROPANE, 1,2-	1.4E-01	1.4E-01	5.0E+00
DICHLOROPROPENE, 1,3-	2.1E-03	2.1E-03	6.0E-02
DIELDRIN	2.5E+00	7.9E+00	1.9E-03
DIETHYLPHTHALATE	3.7E+00	3.7E+00	2.1E+02
DIMETHYLPHENOL, 2,4-	9.0E+00	9.0E+00	1.1E+02
DIMETHYLPHTHALATE	2.6E+01	2.6E+01	1.1E+03
DINITROBENZENE, 1,3-	1.2E-01	1.2E-01	2.0E+00
DINITROPHENOL, 2,4-	1.1E+00	1.1E+00	1.4E+01
DINITROTOLUENE, 2,4- (2,4-DNT)	2.4E-02	2.4E-02	2.5E-01
DINITROTOLUENE, 2,6- (2,6-DNT)	5.1E-03	5.1E-03	5.2E-02
DIOXANE, 1,4-	2.1E-04	2.1E-04	4.6E-01
DIOXIN (TEQ)	4.8E-04	4.3E-03	3.1E-09
DIURON	7.3E-01	7.3E-01	4.0E+01
ENDOSULFAN	4.4E+00	4.4E+00	8.7E-03
ENDRIN	3.8E+00	1.0E+01	2.3E-03
ETHANOL	4.5E+00	4.5E+00	5.0E+04
ETHYLBENZENE	9.0E-01	9.0E-01	7.3E+00
FLUORANTHENE	2.9E+01	2.9E+01	8.0E-01
FLUORENE	3.1E+01	3.1E+01	3.9E+00
GLYPHOSATE	5.0E+02	6.3E+02	1.8E+03
HEPTACHLOR	1.4E+00	6.3E+00	3.6E-03
HEPTACHLOR EPOXIDE	2.0E-01	3.0E+00	3.6E-03
HEXACHLOROBENZENE	7.8E-02	7.8E-02	3.0E-04
HEXACHLOROBUTADIENE	4.1E-02	4.1E-02	2.0E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.9E-02	2.9E-02	6.3E-02
HEXACHLOROETHANE	2.3E-02	2.3E-02	4.0E-01
HEXAZINONE	1.4E+01	1.4E+01	6.6E+02
INDENO(1,2,3-cd)PYRENE	1.1E+01	3.1E+01	9.5E-02
ISOPHORONE	8.9E-01	8.9E-01	8.2E+01
LEAD	2.0E+02	8.0E+02	2.5E+00

TABLE A. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS Current or Potential Source of Drinking Water

CHEMICAL PARAMETER	[1]Shallow Soil [2]Unrestricted Land Use (mg/kg)	 Commercial/ Industrial Land Use Only (mg/kg)	[3]Groundwater (ug/L)
MERCURY	4.7E+00	7.0E+01	7.7E-01
METHOXYCHLOR	5.4E+00	5.4E+00	1.9E-02
METHYL ETHYL KETONE	6.2E+00	6.2E+00	5.6E+03
METHYL ISOBUTYL KETONE	5.0E-01	5.0E-01	1.7E+02
METHYL MERCURY	1.6E+00	2.3E+01	2.8E-03
METHYL TERT BUTYL ETHER	2.8E-02	2.8E-02	5.0E+00
METHYLENE CHLORIDE	1.2E-01	1.2E-01	5.0E+00
METHYLNAPHTHALENE, 1-	8.9E-01	8.9E-01	2.1E+00
METHYLNAPHTHALENE, 2-	1.9E+00	1.9E+00	4.7E+00
MOLYBDENUM	7.8E+01	1.2E+03	1.0E+02
NAPHTHALENE	3.1E+00	3.1E+00	1.2E+01
NICKEL	4.1E+02	7.5E+02	8.2E+00
NITROBENZENE	5.3E-03	5.3E-03	1.4E-01
NITROGLYCERIN	3.9E-02	3.9E-02	2.0E+00
NITROTOLUENE, 2-	2.2E-02	2.2E-02	3.5E-01
NITROTOLUENE, 3-	1.2E-01	1.2E-01	2.0E+00
NITROTOLUENE, 4-	2.9E-01	2.9E-01	4.9E+00
PENTACHLOROPHENOL	9.8E-02	9.8E-02	1.0E+00
PENTAERYTHRITOLTETRANITRATE (PETN)	2.1E+00	2.1E+00	1.9E+01
PERCHLORATE	7.0E-03	7.0E-03	1.5E+01
PHENANTHRENE	2.3E+01	2.3E+01	4.6E+00
PHENOL	1.6E-01	1.6E-01	5.0E+00
POLYCHLORINATED BIPHENYLS (PCBs)	1.2E+00	9.7E+00	1.4E-02
PROPICONAZOLE	2.5E+01	2.5E+01	9.5E+01
PYRENE	4.1E+01	4.1E+01	4.6E+00
SELENIUM	7.8E+01	1.2E+03	5.0E+00
SILVER	7.8E+01	1.2E+03	6.0E-02
SIMAZINE	1.6E-02	1.6E-02	6.5E-01
STYRENE	9.1E-01	9.1E-01	1.0E+01
TERBACIL	2.2E+00	2.2E+00	2.6E+02
tert-BUTYL ALCOHOL	3.2E-02	3.2E-02	5.2E+00
TETRACHLOROETHANE, 1,1,1,2-	1.8E-02	1.8E-02	6.1E-01
TETRACHLOROETHANE, 1,1,2,2-	1.4E-03	1.4E-03	7.8E-02
TETRACHLOROETHYLENE	9.8E-02	6.4E-01	5.0E+00
TETRACHLOROPHENOL, 2,3,4,6-	5.6E-02	5.6E-02	1.2E+00
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	1.9E+01	1.9E+01	2.2E+02
THALLIUM	7.8E-01	1.2E+01	2.0E+00
TOLUENE	7.8E-01	7.8E-01	9.8E+00
TOXAPHENE	4.9E-01	2.1E+00	2.0E-04
TPH (gasolines)	1.0E+02	5.0E+02	3.0E+02
TPH (middle distillates)	2.2E+02	5.0E+02	4.0E+02
TPH (residual fuels)	5.0E+02	2.5E+03	5.0E+02
TRICHLOROBENZENE, 1,2,4-	1.8E-01	1.4E+00	7.0E+01
TRICHLOROETHANE, 1,1,1-	1.2E+00	1.2E+00	1.1E+01
TRICHLOROETHANE, 1,1,2-	8.9E-03	6.2E-02	5.0E+00
TRICHLOROETHYLENE	8.9E-02	3.6E-01	5.0E+00
TRICHLOROPHENOL, 2,4,5-	2.9E+00	2.9E+00	1.1E+01

TABLE A. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS Current or Potential Source of Drinking Water

CHEMICAL PARAMETER	[1]Shallow Soil: [2]Unrestricted Land Use (mg/kg)	[1]Shallow Soil: Commercial/ Industrial Land Use Only (mg/kg)	[3]Groundwater (ug/L)
TRICHLOROPHENOL, 2,4,6-	3.1E-01	3.1E-01	4.9E+00
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	3.6E+00	3.6E+00	2.0E+02
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	8.7E-01	8.7E-01	3.0E+01
TRICHLOROPROPANE, 1,2,3-	1.5E-05	1.5E-05	7.2E-04
TRICHLOROPROPENE, 1,2,3-	8.1E-02	8.1E-02	6.2E-01
TRIFLURALIN	5.9E+00	5.9E+00	1.1E+00
TRINITROBENZENE, 1,3,5-	2.8E+00	2.8E+00	1.0E+01
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	3.1E+01	3.1E+01	4.0E+01
TRINITROTOLUENE, 2,4,6- (TNT)	1.2E+00	1.2E+00	2.6E+00
VANADIUM	7.7E+02	7.7E+02	2.7E+01
VINYL CHLORIDE	3.6E-02	3.5E-01	2.0E+00
XYLENES	1.4E+00	1.4E+00	1.3E+01
ZINC	1.0E+03	2.5E+03	8.1E+01
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0	4.0	-
Sodium Adsorption Ratio	5.0	12	-

Notes:

1. Shallow soils defined as soils less than or equal to 3 meters (approximately 10 feet) below ground surface for residential/unrestricted land use and less than one meter (approximately three feet) for commercial/industrial sites.

2. Category "Unrestricted Land Use" generally considered adequate for residential and other sensitive uses (e.g., schools, day-care centers, hospitals, etc.)

3. Assumes potential discharge of groundwater into a freshwater, marine or estuary surface water system.

Source of soil ESLs: Refer to Appendix 1, Tables A-1 and A-2.

Source of groundwater ESLs: Refer to Appendix 1, Table F-1a. Compare to *dissolved-phase* concentration.

Soil data should be reported on dry-weight basis (see Appendix 1, Section 7.2).

Soil ESLs intended to address direct-exposure, groundwater protection and nuisance concerns under noted land-use scenarios. **Soil gas data should be collected for additional evaluation of potential indoor-air impacts at sites with significant areas of VOC-impacted soil (refer to Section 4.5 and Table G).**

Groundwater ESLs intended to be address drinking water, surface water, indoor-air and nuisance concerns. **Use in conjunction with soil gas screening levels to more closely evaluate potential vapor intrusion hazards if groundwater screening levels for this concern approached or exceeded (refer to Section 4.5 and Table G).**

Aquatic habitat goals for bioaccumulation concerns not considered in selection of groundwater goals (refer to Section 2.2).

Refer to appendices for summary of ESL components.

Soil and water ESLs for ethanol based on gross contamination concerns (see Appendix 1, Chapter 6 and related tables).

TPH -Total Petroleum Hydrocarbons. TPH ESLs must be used in conjunction with ESLs for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Volume 1, Section 2.2 and Appendix 1, Chapter 6.

TABLE B: SHALLOW SOIL (≤3M BGS) - WATER IS NOT A CURRENT OR POTENTIAL SOURCE OF DRINKING WATER

Notes:

- Always compare final soil data for commercial/industrial sites to unrestricted land use ESLs and evaluate need for formal land-use restrictions (see Section 2.8).
- Assumption that groundwater is not a current or potential source of drinking water should be approved by overseeing regulatory agency prior to use of this table (see Section 2.2).

TABLE B. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

CHEMICAL PARAMETER	[1]Shallow Soil		[3]Groundwater (ug/L)
	[2]Unrestricted Land Use (mg/kg)	Commercial/ Industrial Land Use Only (mg/kg)	
ACENAPHTHENE	4.0E+01	4.0E+01	1.5E+01
ACENAPHTHYLENE	5.5E+00	5.5E+00	1.3E+01
ACETONE	1.0E+00	1.0E+00	1.5E+03
ALDRIN	2.8E+00	2.8E+00	1.4E-04
AMETRYN	5.0E+01	5.0E+01	7.0E+02
AMINO,2- DINITROTOLUENE,3,6-	8.5E-01	8.5E-01	1.8E+01
AMINO,4- DINITROTOLUENE,2,6-	5.2E-01	5.2E-01	1.1E+01
ANTHRACENE	1.4E+00	1.4E+00	2.0E-02
ANTIMONY	6.3E+00	9.3E+01	3.0E+01
ARSENIC	2.4E+01	9.5E+01	3.6E+01
ATRAZINE	4.5E-01	4.5E-01	1.2E+01
BARIUM	1.0E+03	2.5E+03	2.2E+02
BENOMYL	7.8E-03	7.8E-03	1.4E-01
BENZENE	7.7E-01	4.3E+00	7.1E+01
BENZO(a)ANTHRACENE	3.3E+00	3.3E+00	2.7E-02
BENZO(a)PYRENE	3.6E+00	5.9E+00	6.0E-02
BENZO(b)FLUORANTHENE	1.1E+01	6.8E+01	6.8E-01
BENZO(g,h,i)PERYLENE	3.5E+01	3.5E+01	1.3E-01
BENZO(k)FLUORANTHENE	3.9E+01	3.9E+01	4.0E-01
BERYLLIUM	3.1E+01	1.5E+02	6.6E-01
BIPHENYL, 1,1-	1.0E+01	4.3E+01	5.0E+00
BIS(2-CHLOROETHYL)ETHER	7.9E-03	6.7E-02	1.8E+02
BIS(2-CHLORO-1-METHYLETHYL)ETHER	4.0E-03	4.0E-03	3.7E-01
BIS(2-ETHYLHEXYL)PHTHALATE	3.9E+01	6.5E+01	3.0E+00
BORON	1.0E+03	2.5E+03	1.0E+03
BROMODICHLOROMETHANE	1.6E-02	1.2E-01	1.1E+02
BROMOFORM	2.0E+00	2.0E+00	2.3E+02
BROMOMETHANE	2.2E-01	7.6E-01	1.6E+01
CADMIUM	1.4E+01	7.4E+01	2.5E-01
CARBON TETRACHLORIDE	1.0E-01	7.3E-01	9.8E+00
CHLORDANE (TECHNICAL)	7.6E+00	7.6E+00	4.0E-03
CHLOROANILINE, p-	3.6E-01	3.6E-01	1.9E+01
CHLOROBENZENE	1.5E+00	1.5E+00	2.5E+01
CHLOROETHANE	1.2E+01	1.2E+01	1.6E+02
CHLOROFORM	2.6E-02	1.9E-01	2.8E+01
CHLOROMETHANE	4.0E+00	1.1E+01	1.9E+02
CHLOROPHENOL, 2-	1.2E-01	1.2E-01	1.8E+00
CHROMIUM (Total)	1.1E+03	1.1E+03	1.1E+01
CHROMIUM III	1.0E+03	2.5E+03	2.0E+01
CHROMIUM VI	3.0E+01	4.8E+02	1.1E+01
CHRYSENE	3.0E+01	3.0E+01	1.0E+00
COBALT	8.0E+01	8.0E+01	1.9E+01
COPPER	6.3E+02	2.5E+03	3.1E+00
CYANIDE (Free)	4.8E+00	3.1E+01	1.0E+00
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	1.2E+00	1.2E+00	7.9E+01
DALAPON	1.6E-01	1.6E-01	3.0E+02
DIBENZO(a,h)ANTHTRACENE	1.1E+00	2.1E+01	8.0E-01

TABLE B. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

	[1]Shallow Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
DIBROMO,1,2- CHLOROPROPANE,3-	4.0E-03	4.0E-03	2.0E-01
DIBROMOCHLOROMETHANE	3.4E-01	3.4E-01	3.4E+01
DIBROMOETHANE, 1,2-	1.0E-03	7.3E-03	1.9E+01
DICHLOROBENZENE, 1,2-	1.1E+00	1.1E+00	1.4E+01
DICHLOROBENZENE, 1,3-	2.5E+00	2.5E+00	2.2E+01
DICHLOROBENZENE, 1,4-	5.5E-02	4.0E-01	9.4E+00
DICHLOROBENZIDINE, 3,3-	1.2E+00	2.4E+00	4.5E+00
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.3E+00	9.6E+00	1.1E-02
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.0E+00	9.3E+00	4.1E-01
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.9E+00	1.9E+00	1.0E-03
DICHLOROETHANE, 1,1-	3.8E-01	1.9E+00	4.7E+01
DICHLOROETHANE, 1,2-	2.3E-02	1.7E-01	1.8E+02
DICHLOROETHYLENE, 1,1-	4.2E+00	4.2E+00	2.5E+01
DICHLOROETHYLENE, Cis 1,2-	3.6E-01	2.5E+00	6.2E+02
DICHLOROETHYLENE, Trans 1,2-	3.6E+00	2.5E+01	5.6E+02
DICHLOROPHENOL, 2,4-	7.3E-02	7.3E-02	3.0E+00
DICHLOROPHENOXYACETIC ACID (2,4-D)	3.4E-01	3.4E-01	7.0E+01
DICHLOROPROPANE, 1,2-	1.6E-01	1.2E+00	1.0E+02
DICHLOROPROPENE, 1,3-	2.1E-03	2.1E-03	6.0E-02
DIELDRIN	2.5E+00	7.9E+00	1.9E-03
DIETHYLPHTHALATE	3.7E+00	3.7E+00	2.1E+02
DIMETHYLPHENOL, 2,4-	9.0E+00	9.0E+00	1.1E+02
DIMETHYLPHTHALATE	2.6E+01	2.6E+01	1.1E+03
DINITROBENZENE, 1,3-	5.8E-01	5.8E-01	1.0E+01
DINITROPHENOL, 2,4-	1.1E+00	1.1E+00	1.4E+01
DINITROTOLUENE, 2,4- (2,4-DNT)	8.7E-01	8.7E-01	9.1E+00
DINITROTOLUENE, 2,6- (2,6-DNT)	3.6E-01	1.5E+00	8.1E+01
DIOXANE, 1,4-	5.4E+00	2.3E+01	5.0E+04
DIOXIN (TEQ)	4.8E-04	4.3E-03	3.1E-09
DIURON	1.1E+00	1.1E+00	6.0E+01
ENDOSULFAN	4.4E+00	4.4E+00	8.7E-03
ENDRIN	3.8E+00	1.0E+01	2.3E-03
ETHANOL	4.5E+00	4.5E+00	5.0E+04
ETHYLBENZENE	9.0E-01	9.0E-01	7.3E+00
FLUORANTHENE	2.9E+01	2.9E+01	8.0E-01
FLUORENE	3.1E+01	3.1E+01	3.9E+00
GLYPHOSATE	5.0E+02	6.3E+02	1.8E+03
HEPTACHLOR	1.4E+00	6.3E+00	3.6E-03
HEPTACHLOR EPOXIDE	2.0E-01	3.0E+00	3.6E-03
HEXACHLOROBENZENE	7.8E-02	7.8E-02	3.0E-04
HEXACHLOROBUTADIENE	6.1E-02	6.1E-02	3.0E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.9E-02	2.9E-02	6.3E-02
HEXACHLOROETHANE	6.8E-01	6.8E-01	1.2E+01
HEXAZINONE	3.7E+02	3.7E+02	1.7E+04
INDENO(1,2,3-cd)PYRENE	1.1E+01	3.1E+01	9.5E-02
ISOPHORONE	1.0E+01	1.0E+01	9.2E+02
LEAD	2.0E+02	8.0E+02	2.5E+00

TABLE B. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

	[1]Shallow Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
MERCURY	4.7E+00	7.0E+01	7.7E-01
METHOXYCHLOR	5.4E+00	5.4E+00	1.9E-02
METHYL ETHYL KETONE	1.5E+01	1.5E+01	1.4E+04
METHYL ISOBUTYL KETONE	5.0E-01	5.0E-01	1.7E+02
METHYL MERCURY	1.6E+00	2.3E+01	2.8E-03
METHYL TERT BUTYL ETHER	2.3E+00	1.0E+01	1.8E+03
METHYLENE CHLORIDE	2.2E+01	3.6E+01	1.5E+03
METHYLNAPHTHALENE, 1-	8.9E-01	8.9E-01	2.1E+00
METHYLNAPHTHALENE, 2-	1.9E+00	1.9E+00	4.7E+00
MOLYBDENUM	7.8E+01	1.2E+03	3.7E+02
NAPHTHALENE	3.1E+00	3.1E+00	1.2E+01
NICKEL	4.1E+02	7.5E+02	8.2E+00
NITROBENZENE	5.6E+00	1.4E+01	3.8E+02
NITROGLYCERIN	3.5E-01	3.5E-01	1.8E+01
NITROTOLUENE, 2-	3.2E+00	4.4E+00	7.1E+01
NITROTOLUENE, 3-	1.3E+00	2.5E+00	4.2E+01
NITROTOLUENE, 4-	2.8E+00	2.8E+00	4.6E+01
PENTACHLOROPHENOL	7.8E-01	7.8E-01	7.9E+00
PENTAERYTHRITOLTETRANITRATE (PETN)	2.5E+01	3.3E+02	2.2E+04
PERCHLORATE	1.2E+00	1.2E+00	6.0E+02
PHENANTHRENE	2.3E+01	2.3E+01	4.6E+00
PHENOL	1.8E+00	1.8E+00	5.8E+01
POLYCHLORINATED BIPHENYLS (PCBs)	1.2E+00	9.7E+00	1.4E-02
PROPICONAZOLE	2.5E+01	2.5E+01	9.5E+01
PYRENE	4.1E+01	4.1E+01	4.6E+00
SELENIUM	7.8E+01	1.2E+03	5.0E+00
SILVER	7.8E+01	1.2E+03	6.0E-02
SIMAZINE	2.2E-01	2.2E-01	9.0E+00
STYRENE	2.9E+00	2.9E+00	3.2E+01
TERBACIL	2.2E+00	2.2E+00	2.6E+02
tert-BUTYL ALCOHOL	9.1E+01	1.1E+02	1.8E+04
TETRACHLOROETHANE, 1,1,1,2-	3.2E-01	3.2E-01	1.1E+01
TETRACHLOROETHANE, 1,1,2,2-	1.0E-02	7.5E-02	2.0E+02
TETRACHLOROETHYLENE	9.8E-02	7.2E-01	5.3E+01
TETRACHLOROPHENOL, 2,3,4,6-	5.6E-02	5.6E-02	1.2E+00
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	1.9E+01	1.9E+01	2.2E+02
THALLIUM	7.8E-01	1.2E+01	6.0E+00
TOLUENE	7.8E-01	7.8E-01	9.8E+00
TOXAPHENE	4.9E-01	2.1E+00	2.0E-04
TPH (gasolines)	1.0E+02	5.0E+02	5.0E+02
TPH (middle distillates)	2.2E+02	5.0E+02	6.4E+02
TPH (residual fuels)	5.0E+02	2.5E+03	6.4E+02
TRICHLOROBENZENE, 1,2,4-	1.8E-01	1.4E+00	1.1E+02
TRICHLOROETHANE, 1,1,1-	1.2E+00	1.2E+00	1.1E+01
TRICHLOROETHANE, 1,1,2-	8.9E-03	6.2E-02	1.1E+02
TRICHLOROETHYLENE	8.9E-02	6.2E-01	4.7E+01
TRICHLOROPHENOL, 2,4,5-	2.9E+00	2.9E+00	1.1E+01

TABLE B. SOIL AND GROUNDWATER SCREENING LEVELS
Shallow Soils (≤3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

	[1]Shallow Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
TRICHLOROPHENOL, 2,4,6-	3.1E-01	3.1E-01	4.9E+00
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	1.2E+01	1.2E+01	6.9E+02
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	8.7E-01	8.7E-01	3.0E+01
TRICHLOROPROPANE, 1,2,3-	5.1E-03	1.1E-01	1.4E+01
TRICHLOROPROPENE, 1,2,3-	8.1E-02	8.1E-02	6.2E-01
TRIFLURALIN	5.9E+00	5.9E+00	1.1E+00
TRINITROBENZENE, 1,3,5-	2.8E+00	2.8E+00	1.0E+01
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	3.1E+01	3.1E+01	4.0E+01
TRINITROTOLUENE, 2,4,6- (TNT)	6.1E+00	6.1E+00	1.3E+01
VANADIUM	7.7E+02	7.7E+02	2.7E+01
VINYL CHLORIDE	3.6E-02	9.9E-01	1.8E+01
XYLENES	1.4E+00	1.4E+00	1.3E+01
ZINC	1.0E+03	2.5E+03	8.1E+01
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	2.0	4.0	-
Sodium Adsorption Ratio	5.0	12	-

Notes:

1. Shallow soils defined as soils less than or equal to 3 meters (approximately 10 feet) below ground surface for residential/unrestricted land use and less than one meter (approximately three feet) for commercial/industrial sites.

2. Category "Unrestricted Land Use" generally considered adequate for residential and other sensitive uses (e.g., schools, day-care centers, hospitals, etc.)

3. Assumes potential discharge of groundwater into marine or estuary surface water system.

Source of soil ESLs: Refer to Appendix 1, Tables B-1 and B-2.

Source of groundwater ESLs: Refer to Appendix 1, Table F-1b. Compare to *dissolved-phase* concentration.

Soil data should be reported on dry-weight basis (see Appendix 1, Section 7.2).

Soil ESLs intended to address direct-exposure, groundwater protection and nuisance concerns under noted land-use scenarios. **Soil gas data should be collected for additional evaluation of potential indoor-air impacts at sites with significant areas of VOC-impacted soil (refer to Section 4.5 and Table G).**

Groundwater ESLs intended to address surface water, indoor-air and nuisance concerns. **Use in conjunction with soil gas screening levels to more closely evaluate potential impacts to indoor-air if groundwater screening levels for this concern approached or exceeded (refer to Section 4.5 and Table G).**

Aquatic habitat goals for bioaccumulation concerns not considered in selection of groundwater goals (refer to Section 2.2).

Refer to appendices for summary of ESL components.

Soil and water ESLs for ethanol based on gross contamination concerns (see Appendix 1, Chapter 6 and related tables).

TPH -Total Petroleum Hydrocarbons. TPH ESLs must be used in conjunction with ESLs for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Volume 1, Section 2.2 and Appendix 1, Chapter 6.

TABLE C: DEEP SOIL (>3M BGS) - WATER IS A CURRENT OR POTENTIAL SOURCE OF DRINKING WATER

Notes:

- Always compare final soil data for commercial/industrial sites to unrestricted land use ESLs and evaluate need for formal land-use restrictions (see Section 2.8).
- ESLs for deep soils may be applicable to soils <3m below ground surface at commercial/industrial sites provided institutional controls are put in place to maintain an adequate cap and provide proper management of soil if exposed in future (see Section 2.2 and Section 2.8).

TABLE C. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS a Current or Potential Source of Drinking Water

	[1]Deep Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
ACENAPHTHENE	4.0E+01	4.0E+01	1.5E+01
ACENAPHTHYLENE	5.5E+00	5.5E+00	1.3E+01
ACETONE	1.0E+00	1.0E+00	1.5E+03
ALDRIN	2.8E+00	2.8E+00	1.4E-04
AMETRYN	1.3E+01	1.3E+01	1.8E+02
AMINO,2- DINITROTOLUENE,3,6-	8.5E-01	8.5E-01	1.8E+01
AMINO,4- DINITROTOLUENE,2,6-	5.2E-01	5.2E-01	1.1E+01
ANTHRACENE	1.4E+00	1.4E+00	2.0E-02
ANTIMONY	2.0E+02	2.0E+02	6.0E+00
ARSENIC	1.3E+02	1.3E+02	1.0E+01
ATRAZINE	1.3E-02	1.3E-02	3.4E-01
BARIUM	2.5E+03	4.3E+03	2.2E+02
BENOMYL	7.8E-03	7.8E-03	1.4E-01
BENZENE	3.0E-01	3.0E-01	5.0E+00
BENZO(a)ANTHRACENE	3.3E+00	3.3E+00	2.7E-02
BENZO(a)PYRENE	5.9E+00	5.9E+00	6.0E-02
BENZO(b)FLUORANTHENE	2.1E+01	2.1E+01	2.2E-01
BENZO(g,h,i)PERYLENE	3.5E+01	3.5E+01	1.3E-01
BENZO(k)FLUORANTHENE	3.9E+01	3.9E+01	4.0E-01
BERYLLIUM	1.5E+02	1.5E+02	6.6E-01
BIPHENYL, 1,1-	6.2E+01	6.2E+01	5.0E-01
BIS(2-CHLOROETHYL)ETHER	7.5E-05	7.5E-05	1.4E-02
BIS(2-CHLORO-1-METHYLETHYL)ETHER	4.0E-03	4.0E-03	3.7E-01
BIS(2-ETHYLHEXYL)PHTHALATE	6.5E+01	6.5E+01	3.0E+00
BORON	2.5E+03	5.0E+03	1.0E+03
BROMODICHLOROMETHANE	2.5E-03	2.5E-03	1.4E-01
BROMOFORM	8.6E-01	8.6E-01	1.0E+02
BROMOMETHANE	2.2E-01	3.6E-01	7.6E+00
CADMIUM	7.4E+01	7.4E+01	2.5E-01
CARBON TETRACHLORIDE	1.0E-01	7.3E-01	5.0E+00
CHLORDANE (TECHNICAL)	7.6E+00	7.6E+00	4.0E-03
CHLOROANILINE, p-	7.3E-03	7.3E-03	3.9E-01
CHLOROBENZENE	1.5E+00	1.5E+00	2.5E+01
CHLOROETHANE	1.2E+00	1.2E+00	1.6E+01
CHLOROFORM	2.6E-02	1.9E-01	2.8E+01
CHLOROMETHANE	4.0E+00	1.1E+01	1.9E+02
CHLOROPHENOL, 2-	1.2E-02	1.2E-02	1.8E-01
CHROMIUM (Total)	1.1E+03	1.1E+03	1.1E+01
CHROMIUM III	2.5E+03	5.0E+03	2.0E+01
CHROMIUM VI	4.8E+02	4.8E+02	4.3E-02
CHRYSENE	3.0E+01	3.0E+01	1.0E+00
COBALT	8.0E+01	8.0E+01	6.0E+00
COPPER	2.5E+03	5.0E+03	3.1E+00
CYANIDE (Free)	5.0E+01	5.0E+01	1.0E+00
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	1.0E-02	1.0E-02	7.1E-01
DALAPON	1.6E-01	1.6E-01	3.0E+02
DIBENZO(a,h)ANTHTRACENE	9.6E+00	9.6E+00	2.2E-02

TABLE C. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS a Current or Potential Source of Drinking Water

CHEMICAL PARAMETER	[1]Deep Soil: [2]Unrestricted Land Use (mg/kg)	[1]Deep Soil: Commercial/ Industrial Land Use Only (mg/kg)	[3]Groundwater (ug/L)
DIBROMO,1,2- CHLOROPROPANE,3-	4.0E-03	4.0E-03	2.0E-01
DIBROMOCHLOROMETHANE	9.4E-03	9.4E-03	9.3E-01
DIBROMOETHANE, 1,2-	5.3E-04	5.3E-04	5.0E-02
DICHLOROBENZENE, 1,2-	7.5E-01	7.5E-01	1.0E+01
DICHLOROBENZENE, 1,3-	2.5E+00	2.5E+00	2.2E+01
DICHLOROBENZENE, 1,4-	5.5E-02	3.9E-01	5.0E+00
DICHLOROBENZIDINE, 3,3-	9.2E-02	9.2E-02	1.7E-01
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.1E+01	2.1E+01	1.1E-02
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	9.4E+00	9.4E+00	4.6E-02
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.9E+00	1.9E+00	1.0E-03
DICHLOROETHANE, 1,1-	1.1E-01	1.1E-01	2.8E+00
DICHLOROETHANE, 1,2-	2.3E-02	7.0E-02	5.0E+00
DICHLOROETHYLENE, 1,1-	1.2E+00	1.2E+00	7.0E+00
DICHLOROETHYLENE, Cis 1,2-	3.6E-01	2.2E+00	7.0E+01
DICHLOROETHYLENE, Trans 1,2-	3.6E+00	6.5E+00	1.0E+02
DICHLOROPHENOL, 2,4-	7.3E-03	7.3E-03	3.0E-01
DICHLOROPHENOXYACETIC ACID (2,4-D)	3.4E-01	3.4E-01	7.0E+01
DICHLOROPROPANE, 1,2-	1.4E-01	1.4E-01	5.0E+00
DICHLOROPROPENE, 1,3-	2.1E-03	2.1E-03	6.0E-02
DIELDRIN	7.9E+00	7.9E+00	1.9E-03
DIETHYLPHTHALATE	3.7E+00	3.7E+00	2.1E+02
DIMETHYLPHENOL, 2,4-	9.0E+00	9.0E+00	1.1E+02
DIMETHYLPHTHALATE	2.6E+01	2.6E+01	1.1E+03
DINITROBENZENE, 1,3-	1.2E-01	1.2E-01	2.0E+00
DINITROPHENOL, 2,4-	1.1E+00	1.1E+00	1.4E+01
DINITROTOLUENE, 2,4- (2,4-DNT)	2.4E-02	2.4E-02	2.5E-01
DINITROTOLUENE, 2,6- (2,6-DNT)	5.1E-03	5.1E-03	5.2E-02
DIOXANE, 1,4-	2.1E-04	2.1E-04	4.6E-01
DIOXIN (TEQ)	4.3E-03	4.3E-03	3.1E-09
DIURON	7.3E-01	7.3E-01	4.0E+01
ENDOSULFAN	4.4E+00	4.4E+00	8.7E-03
ENDRIN	1.0E+01	1.0E+01	2.3E-03
ETHANOL	4.5E+00	4.5E+00	5.0E+04
ETHYLBENZENE	9.0E-01	9.0E-01	7.3E+00
FLUORANTHENE	2.9E+01	2.9E+01	8.0E-01
FLUORENE	3.1E+01	3.1E+01	3.9E+00
GLYPHOSATE	6.3E+02	6.3E+02	1.8E+03
HEPTACHLOR	1.5E+01	1.5E+01	3.6E-03
HEPTACHLOR EPOXIDE	4.1E+00	4.1E+00	3.6E-03
HEXACHLOROBENZENE	7.8E-02	7.8E-02	3.0E-04
HEXACHLOROBUTADIENE	4.1E-02	4.1E-02	2.0E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.9E-02	2.9E-02	6.3E-02
HEXACHLOROETHANE	2.3E-02	2.3E-02	4.0E-01
HEXAZINONE	1.4E+01	1.4E+01	6.6E+02
INDENO(1,2,3-cd)PYRENE	3.1E+01	3.1E+01	9.5E-02
ISOPHORONE	8.9E-01	8.9E-01	8.2E+01
LEAD	8.0E+02	8.0E+02	2.5E+00

TABLE C. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS a Current or Potential Source of Drinking Water

CHEMICAL PARAMETER	[1]Deep Soil [2]Unrestricted Land Use (mg/kg)	Commercial/ Industrial Land Use Only (mg/kg)	[3]Groundwater (ug/L)
MERCURY	1.4E+02	1.4E+02	7.7E-01
METHOXYCHLOR	5.4E+00	5.4E+00	1.9E-02
METHYL ETHYL KETONE	6.2E+00	6.2E+00	5.6E+03
METHYL ISOBUTYL KETONE	5.0E-01	5.0E-01	1.7E+02
METHYL MERCURY	5.1E+01	5.1E+01	2.8E-03
METHYL TERT BUTYL ETHER	2.8E-02	2.8E-02	5.0E+00
METHYLENE CHLORIDE	1.2E-01	1.2E-01	5.0E+00
METHYLNAPHTHALENE, 1-	8.9E-01	8.9E-01	2.1E+00
METHYLNAPHTHALENE, 2-	1.9E+00	1.9E+00	4.7E+00
MOLYBDENUM	2.5E+03	2.5E+03	1.0E+02
NAPHTHALENE	3.1E+00	3.1E+00	1.2E+01
NICKEL	7.5E+02	7.5E+02	8.2E+00
NITROBENZENE	5.3E-03	5.3E-03	1.4E-01
NITROGLYCERIN	3.9E-02	3.9E-02	2.0E+00
NITROTOLUENE, 2-	2.2E-02	2.2E-02	3.5E-01
NITROTOLUENE, 3-	1.2E-01	1.2E-01	2.0E+00
NITROTOLUENE, 4-	2.9E-01	2.9E-01	4.9E+00
PENTACHLOROPHENOL	9.8E-02	9.8E-02	1.0E+00
PENTAERYTHRITOLTETRANITRATE (PETN)	2.1E+00	2.1E+00	1.9E+01
PERCHLORATE	7.0E-03	7.0E-03	1.5E+01
PHENANTHRENE	2.3E+01	2.3E+01	4.6E+00
PHENOL	1.6E-01	1.6E-01	5.0E+00
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+01	1.1E+01	1.4E-02
PROPICONAZOLE	2.5E+01	2.5E+01	9.5E+01
PYRENE	4.1E+01	4.1E+01	4.6E+00
SELENIUM	2.5E+03	2.5E+03	5.0E+00
SILVER	2.5E+03	2.5E+03	6.0E-02
SIMAZINE	1.6E-02	1.6E-02	6.5E-01
STYRENE	9.1E-01	9.1E-01	1.0E+01
TERBACIL	2.2E+00	2.2E+00	2.6E+02
tert-BUTYL ALCOHOL	3.2E-02	3.2E-02	5.2E+00
TETRACHLOROETHANE, 1,1,1,2-	1.8E-02	1.8E-02	6.1E-01
TETRACHLOROETHANE, 1,1,2,2-	1.4E-03	1.4E-03	7.8E-02
TETRACHLOROETHYLENE	9.8E-02	6.4E-01	5.0E+00
TETRACHLOROPHENOL, 2,3,4,6-	5.6E-02	5.6E-02	1.2E+00
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	1.9E+01	1.9E+01	2.2E+02
THALLIUM	2.5E+01	2.5E+01	2.0E+00
TOLUENE	7.8E-01	7.8E-01	9.8E+00
TOXAPHENE	8.5E+01	8.5E+01	2.0E-04
TPH (gasolines)	7.0E+02	7.0E+02	3.0E+02
TPH (middle distillates)	5.0E+02	5.0E+02	4.0E+02
TPH (residual fuels)	5.0E+03	5.0E+03	5.0E+02
TRICHLOROBENZENE, 1,2,4-	1.8E-01	1.4E+00	7.0E+01
TRICHLOROETHANE, 1,1,1-	1.2E+00	1.2E+00	1.1E+01
TRICHLOROETHANE, 1,1,2-	8.9E-03	6.2E-02	5.0E+00
TRICHLOROETHYLENE	8.9E-02	3.6E-01	5.0E+00
TRICHLOROPHENOL, 2,4,5-	2.9E+00	2.9E+00	1.1E+01

TABLE C. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS a Current or Potential Source of Drinking Water

	[1]Deep Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
TRICHLOROPHENOL, 2,4,6-	3.1E-01	3.1E-01	4.9E+00
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	3.6E+00	3.6E+00	2.0E+02
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	8.7E-01	8.7E-01	3.0E+01
TRICHLOROPROPANE, 1,2,3-	1.5E-05	1.5E-05	7.2E-04
TRICHLOROPROPENE, 1,2,3-	8.1E-02	8.1E-02	6.2E-01
TRIFLURALIN	5.9E+00	5.9E+00	1.1E+00
TRINITROBENZENE, 1,3,5-	2.8E+00	2.8E+00	1.0E+01
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	3.1E+01	3.1E+01	4.0E+01
TRINITROTOLUENE, 2,4,6- (TNT)	1.2E+00	1.2E+00	2.6E+00
VANADIUM	7.7E+02	7.7E+02	2.7E+01
VINYL CHLORIDE	3.6E-02	3.5E-01	2.0E+00
XYLENES	1.4E+00	1.4E+00	1.3E+01
ZINC	2.5E+03	5.0E+03	8.1E+01
(mS/cm, USEPA Method 120.1 MOD)	not applicable	not applicable	-
Sodium Adsorption Ratio	not applcable	not applcable	-

Notes:

1. Deep soils defined as soils greater than to 3 meters (approximately 10 feet) below ground surface for residential/unrestricted land use and more than one meter (approximately three feet) for commercial/industrial sites.

2. Category "Unrestricted Land Use" generally considered adequate for residential and other sensitive uses (e.g., schools, day-care centers, hospitals, etc.)

3. Assumes potential discharge of groundwater into a freshwater, marine or estuary surface water system.

Source of soil ESLs: Refer to Appendix 1, Tables C-1 and C-2.

Source of groundwater ESLs: Refer to Appendix 1, Table F-1a. Compare to *dissolved-phase* concentration.

Soil data should be reported on dry-weight basis (see Appendix 1, Section 7.2).

Soil ESLs intended to address human health, groundwater protection and nuisance concerns under a construction/trench worker exposure scenario and noted land-use scenarios. **Soil gas data should be collected for additional evaluation of potential indoor-air impacts at sites with significant areas of VOC-impacted soil (refer to Section 4.5 and Table G).**

Groundwater ESLs intended to be address drinking water, surface water, indoor-air and nuisance concerns. **Use in conjunction with soil gas screening levels to more closely evaluate potential impacts to indoor-air if groundwater screening levels for this concern approached or exceeded (refer to Section 4.5 and Table G).**

Aquatic habitat goals for bioaccumulation concerns not considered in selection of groundwater goals (refer to Section 2.2).

Refer to appendices for summary of ESL components.

Soil and water ESLs for ethanol based on gross contamination concerns (see Appendix 1, Chapter 6 and related tables).

TPH -Total Petroleum Hydrocarbons. TPH ESLs must be used in conjunction with ESLs for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Volume 1, Section 2.2 and Appendix 1, Chapter 6.

TABLE D: DEEP SOIL (>3M BGS) - WATER IS NOT A CURRENT OR POTENTIAL SOURCE OF DRINKING WATER

Notes:

- Always compare final soil data for commercial/industrial sites to unrestricted land use ESLs and evaluate need for formal land-use restrictions (see Section 2.8).
- Assumption that groundwater is not a current or potential source of drinking water should be approved by overseeing regulatory agency prior to use of this table (see Section 2.2).
- ESLs for deep soils may be applicable to soils <3m below ground surface at commercial/industrial sites provided institutional controls are put in place to maintain an adequate cap and provide proper management of soil if exposed in future (see Section 2.2 and Section 2.8).

TABLE D. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

	[1]Deep Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
ACENAPHTHENE	4.0E+01	4.0E+01	1.5E+01
ACENAPHTHYLENE	5.5E+00	5.5E+00	1.3E+01
ACETONE	1.0E+00	1.0E+00	1.5E+03
ALDRIN	2.8E+00	2.8E+00	1.4E-04
AMETRYN	5.0E+01	5.0E+01	7.0E+02
AMINO,2- DINITROTOLUENE,3,6-	8.5E-01	8.5E-01	1.8E+01
AMINO,4- DINITROTOLUENE,2,6-	5.2E-01	5.2E-01	1.1E+01
ANTHRACENE	1.4E+00	1.4E+00	2.0E-02
ANTIMONY	2.0E+02	2.0E+02	3.0E+01
ARSENIC	1.3E+02	1.3E+02	3.6E+01
ATRAZINE	4.5E-01	4.5E-01	1.2E+01
BARIUM	2.5E+03	4.3E+03	2.2E+02
BENOMYL	7.8E-03	7.8E-03	1.4E-01
BENZENE	7.7E-01	4.3E+00	7.1E+01
BENZO(a)ANTHRACENE	3.3E+00	3.3E+00	2.7E-02
BENZO(a)PYRENE	5.9E+00	5.9E+00	6.0E-02
BENZO(b)FLUORANTHENE	6.8E+01	6.8E+01	6.8E-01
BENZO(g,h,i)PERYLENE	3.5E+01	3.5E+01	1.3E-01
BENZO(k)FLUORANTHENE	3.9E+01	3.9E+01	4.0E-01
BERYLLIUM	1.5E+02	1.5E+02	6.6E-01
BIPHENYL, 1,1-	6.2E+01	6.2E+01	5.0E+00
BIS(2-CHLOROETHYL)ETHER	7.9E-03	6.7E-02	1.8E+02
BIS(2-CHLORO-1-METHYLETHYL)ETHER	4.0E-03	4.0E-03	3.7E-01
BIS(2-ETHYLHEXYL)PHTHALATE	6.5E+01	6.5E+01	3.0E+00
BORON	2.5E+03	5.0E+03	1.0E+03
BROMODICHLOROMETHANE	1.6E-02	1.2E-01	1.1E+02
BROMOFORM	2.0E+00	2.0E+00	2.3E+02
BROMOMETHANE	2.2E-01	7.6E-01	1.6E+01
CADMIUM	7.4E+01	7.4E+01	2.5E-01
CARBON TETRACHLORIDE	1.0E-01	7.3E-01	9.8E+00
CHLORDANE (TECHNICAL)	7.6E+00	7.6E+00	4.0E-03
CHLOROANILINE, p-	3.6E-01	3.6E-01	1.9E+01
CHLOROBENZENE	1.5E+00	1.5E+00	2.5E+01
CHLOROETHANE	1.2E+01	1.2E+01	1.6E+02
CHLOROFORM	2.6E-02	1.9E-01	2.8E+01
CHLOROMETHANE	4.0E+00	1.1E+01	1.9E+02
CHLOROPHENOL, 2-	1.2E-01	1.2E-01	1.8E+00
CHROMIUM (Total)	1.1E+03	1.1E+03	1.1E+01
CHROMIUM III	2.5E+03	5.0E+03	2.0E+01
CHROMIUM VI	4.8E+02	4.8E+02	1.1E+01
CHRYSENE	3.0E+01	3.0E+01	1.0E+00
COBALT	8.0E+01	8.0E+01	1.9E+01
COPPER	2.5E+03	5.0E+03	3.1E+00
CYANIDE (Free)	5.0E+01	5.0E+01	1.0E+00
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	1.2E+00	1.2E+00	7.9E+01
DALAPON	1.6E-01	1.6E-01	3.0E+02
DIBENZO(a,h)ANTHTRACENE	1.5E+02	1.5E+02	8.0E-01

TABLE D. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

	[1]Deep Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
DIBROMO,1,2- CHLOROPROPANE,3-	4.0E-03	4.0E-03	2.0E-01
DIBROMOCHLOROMETHANE	3.4E-01	3.4E-01	3.4E+01
DIBROMOETHANE, 1,2-	1.0E-03	7.3E-03	1.9E+01
DICHLOROBENZENE, 1,2-	1.1E+00	1.1E+00	1.4E+01
DICHLOROBENZENE, 1,3-	2.5E+00	2.5E+00	2.2E+01
DICHLOROBENZENE, 1,4-	5.5E-02	4.0E-01	9.4E+00
DICHLOROBENZIDINE, 3,3-	2.4E+00	2.4E+00	4.5E+00
DICHLORODIPHENYLDICHLOROETHANE (DDD)	2.1E+01	2.1E+01	1.1E-02
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	9.4E+00	9.4E+00	4.1E-01
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	1.9E+00	1.9E+00	1.0E-03
DICHLOROETHANE, 1,1-	3.8E-01	1.9E+00	4.7E+01
DICHLOROETHANE, 1,2-	2.3E-02	1.7E-01	1.8E+02
DICHLOROETHYLENE, 1,1-	4.2E+00	4.2E+00	2.5E+01
DICHLOROETHYLENE, Cis 1,2-	3.6E-01	2.5E+00	6.2E+02
DICHLOROETHYLENE, Trans 1,2-	3.6E+00	2.5E+01	5.6E+02
DICHLOROPHENOL, 2,4-	7.3E-02	7.3E-02	3.0E+00
DICHLOROPHENOXYACETIC ACID (2,4-D)	3.4E-01	3.4E-01	7.0E+01
DICHLOROPROPANE, 1,2-	1.6E-01	1.2E+00	1.0E+02
DICHLOROPROPENE, 1,3-	2.1E-03	2.1E-03	6.0E-02
DIELDRIN	7.9E+00	7.9E+00	1.9E-03
DIETHYLPHTHALATE	3.7E+00	3.7E+00	2.1E+02
DIMETHYLPHENOL, 2,4-	9.0E+00	9.0E+00	1.1E+02
DIMETHYLPHTHALATE	2.6E+01	2.6E+01	1.1E+03
DINITROBENZENE, 1,3-	5.8E-01	5.8E-01	1.0E+01
DINITROPHENOL, 2,4-	1.1E+00	1.1E+00	1.4E+01
DINITROTOLUENE, 2,4- (2,4-DNT)	8.7E-01	8.7E-01	9.1E+00
DINITROTOLUENE, 2,6- (2,6-DNT)	7.9E+00	7.9E+00	8.1E+01
DIOXANE, 1,4-	2.3E+01	2.3E+01	5.0E+04
DIOXIN (TEQ)	4.3E-03	4.3E-03	3.1E-09
DIURON	1.1E+00	1.1E+00	6.0E+01
ENDOSULFAN	4.4E+00	4.4E+00	8.7E-03
ENDRIN	1.0E+01	1.0E+01	2.3E-03
ETHANOL	4.5E+00	4.5E+00	5.0E+04
ETHYLBENZENE	9.0E-01	9.0E-01	7.3E+00
FLUORANTHENE	2.9E+01	2.9E+01	8.0E-01
FLUORENE	3.1E+01	3.1E+01	3.9E+00
GLYPHOSATE	6.3E+02	6.3E+02	1.8E+03
HEPTACHLOR	1.5E+01	1.5E+01	3.6E-03
HEPTACHLOR EPOXIDE	4.1E+00	4.1E+00	3.6E-03
HEXACHLOROBENZENE	7.8E-02	7.8E-02	3.0E-04
HEXACHLOROBUTADIENE	6.1E-02	6.1E-02	3.0E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	2.9E-02	2.9E-02	6.3E-02
HEXACHLOROETHANE	6.8E-01	6.8E-01	1.2E+01
HEXAZINONE	3.7E+02	3.7E+02	1.7E+04
INDENO(1,2,3-cd)PYRENE	3.1E+01	3.1E+01	9.5E-02
ISOPHORONE	1.0E+01	1.0E+01	9.2E+02
LEAD	8.0E+02	8.0E+02	2.5E+00

TABLE D. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

CHEMICAL PARAMETER	[1]Deep Soil: [2]Unrestricted Land Use (mg/kg)	[1]Deep Soil: Commercial/ Industrial Land Use Only (mg/kg)	[3]Groundwater (ug/L)
MERCURY	1.4E+02	1.4E+02	7.7E-01
METHOXYCHLOR	5.4E+00	5.4E+00	1.9E-02
METHYL ETHYL KETONE	1.5E+01	1.5E+01	1.4E+04
METHYL ISOBUTYL KETONE	5.0E-01	5.0E-01	1.7E+02
METHYL MERCURY	5.1E+01	5.1E+01	2.8E-03
METHYL TERT BUTYL ETHER	2.3E+00	1.0E+01	1.8E+03
METHYLENE CHLORIDE	2.2E+01	3.6E+01	1.5E+03
METHYLNAPHTHALENE, 1-	8.9E-01	8.9E-01	2.1E+00
METHYLNAPHTHALENE, 2-	1.9E+00	1.9E+00	4.7E+00
MOLYBDENUM	2.5E+03	2.5E+03	3.7E+02
NAPHTHALENE	3.1E+00	3.1E+00	1.2E+01
NICKEL	7.5E+02	7.5E+02	8.2E+00
NITROBENZENE	1.4E+01	1.4E+01	3.8E+02
NITROGLYCERIN	3.5E-01	3.5E-01	1.8E+01
NITROTOLUENE, 2-	4.4E+00	4.4E+00	7.1E+01
NITROTOLUENE, 3-	2.5E+00	2.5E+00	4.2E+01
NITROTOLUENE, 4-	2.8E+00	2.8E+00	4.6E+01
PENTACHLOROPHENOL	7.8E-01	7.8E-01	7.9E+00
PENTAERYTHRITOLTETRANITRATE (PETN)	6.6E+02	6.6E+02	2.2E+04
PERCHLORATE	1.2E+00	1.2E+00	6.0E+02
PHENANTHRENE	2.3E+01	2.3E+01	4.6E+00
PHENOL	1.8E+00	1.8E+00	5.8E+01
POLYCHLORINATED BIPHENYLS (PCBs)	1.1E+01	1.1E+01	1.4E-02
PROPICONAZOLE	2.5E+01	2.5E+01	9.5E+01
PYRENE	4.1E+01	4.1E+01	4.6E+00
SELENIUM	2.5E+03	2.5E+03	5.0E+00
SILVER	2.5E+03	2.5E+03	6.0E-02
SIMAZINE	2.2E-01	2.2E-01	9.0E+00
STYRENE	2.9E+00	2.9E+00	3.2E+01
TERBACIL	2.2E+00	2.2E+00	2.6E+02
tert-BUTYL ALCOHOL	1.1E+02	1.1E+02	1.8E+04
TETRACHLOROETHANE, 1,1,1,2-	3.2E-01	3.2E-01	1.1E+01
TETRACHLOROETHANE, 1,1,2,2-	1.0E-02	7.5E-02	2.0E+02
TETRACHLOROETHYLENE	9.8E-02	7.2E-01	5.3E+01
TETRACHLOROPHENOL, 2,3,4,6-	5.6E-02	5.6E-02	1.2E+00
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	1.9E+01	1.9E+01	2.2E+02
THALLIUM	2.5E+01	2.5E+01	6.0E+00
TOLUENE	7.8E-01	7.8E-01	9.8E+00
TOXAPHENE	8.5E+01	8.5E+01	2.0E-04
TPH (gasolines)	1.2E+03	1.2E+03	5.0E+02
TPH (middle distillates)	5.0E+02	5.0E+02	6.4E+02
TPH (residual fuels)	5.0E+03	5.0E+03	6.4E+02
TRICHLOROBENZENE, 1,2,4-	1.8E-01	1.4E+00	1.1E+02
TRICHLOROETHANE, 1,1,1-	1.2E+00	1.2E+00	1.1E+01
TRICHLOROETHANE, 1,1,2-	8.9E-03	6.2E-02	1.1E+02
TRICHLOROETHYLENE	8.9E-02	6.2E-01	4.7E+01
TRICHLOROPHENOL, 2,4,5-	2.9E+00	2.9E+00	1.1E+01

TABLE D. SOIL AND GROUNDWATER SCREENING LEVELS
Deep Soils (>3m bgs)
Groundwater IS NOT a Current or Potential Source of Drinking Water

	[1]Deep Soil		
CHEMICAL PARAMETER	**[2]Unrestricted Land Use (mg/kg)**	**Commercial/ Industrial Land Use Only (mg/kg)**	**[3]Groundwater (ug/L)**
TRICHLOROPHENOL, 2,4,6-	3.1E-01	3.1E-01	4.9E+00
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	1.2E+01	1.2E+01	6.9E+02
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	8.7E-01	8.7E-01	3.0E+01
TRICHLOROPROPANE, 1,2,3-	3.0E-01	3.0E-01	1.4E+01
TRICHLOROPROPENE, 1,2,3-	8.1E-02	8.1E-02	6.2E-01
TRIFLURALIN	5.9E+00	5.9E+00	1.1E+00
TRINITROBENZENE, 1,3,5-	2.8E+00	2.8E+00	1.0E+01
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	3.1E+01	3.1E+01	4.0E+01
TRINITROTOLUENE, 2,4,6- (TNT)	6.1E+00	6.1E+00	1.3E+01
VANADIUM	7.7E+02	7.7E+02	2.7E+01
VINYL CHLORIDE	3.6E-02	9.9E-01	1.8E+01
XYLENES	1.4E+00	1.4E+00	1.3E+01
ZINC	2.5E+03	5.0E+03	8.1E+01
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	not applicable	not applicable	-
Sodium Adsorption Ratio	not applcable	not applcable	-

Notes:

1. Deep soils defined as soils greater than to 3 meters (approximately 10 feet) below ground surface for residential/unrestricted land use and more than one meter (approximately three feet) for commercial/industrial sites.

2. Category "Unrestricted Land Use" generally considered adequate for residential and other sensitive uses (e.g., schools, day-care centers, hospitals, etc.)

3. Assumes potential discharge of groundwater into marine or estuary surface water system.

Source of soil ESLs: Refer to Appendix 1, Tables D-1 and D-2.

Source of groundwater ESLs: Refer to Appendix 1, Table F-1b. Compare to *dissolved-phase* concentration.

Soil data should be reported on dry-weight basis (see Appendix 1, Section 7.2).

Soil ESLs intended to address human health, groundwater protection and nuisance concerns under a construction/trench worker exposure scenario and noted land-use scenarios. **Soil gas data should be collected for additional evaluation of potential indoor-air impacts at sites with significant areas of VOC-impacted soil (refer to Section 4.5 and Table G).**

Groundwater ESLs intended to address surface water, indoor-air and nuisance concerns. **Use in conjunction with soil gas screening levels to more closely evaluate potential impacts to indoor-air if groundwater screening levels for this concern approached or exceeded (refer to Section 4.5 and Table G).**

Aquatic habitat goals for bioaccumulation concerns not considered in selection of groundwater goals (refer to Section 2.2).

Refer to appendices for summary of ESL components.

Soil and water ESLs for ethanol based on gross contamination concerns (see Appendix 1, Chapter 6 and related tables).

TPH -Total Petroleum Hydrocarbons. TPH ESLs must be used in conjunction with ESLs for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Volume 1, Section 2.2 and Appendix 1, Chapter 6.

TABLE E: ADDITIONAL SOIL SCREENING LEVELS FOR PROTECTION OF GROUNDWATER IN AREAS OF THIN SOIL COVER

Notes:

- <1m thickness of soil over bedrock and unconfined, drinking water aquifer; elevated leaching threat from normally low-mobility chemicals;
- SPLP batch test recommended to evaluate contaminant mobility if screening level exceeded (not applicable to TPH; see Section 4.3.3)

TABLE E. [1,2]ADDITIONAL SOIL SCREENING LEVELS FOR LEACHING CONCERNS AT SITES WITH THIN (<1m) SOIL COVER OVER BEDROCK

(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	Soil Screening Level (mg/kg)
ACENAPHTHENE	1.7E+01
ACENAPHTHYLENE	-
ACETONE	-
ALDRIN	1.5E-02
AMETRYN	-
AMINO,2- DINITROTOLUENE,3,6-	-
AMINO,4- DINITROTOLUENE,2,6-	-
ANTHRACENE	-
ANTIMONY	-
ARSENIC	-
ATRAZINE	-
BARIUM	-
BENOMYL	-
BENZENE	-
BENZO(a)ANTHRACENE	-
BENZO(a)PYRENE	-
BENZO(b)FLUORANTHENE	-
BENZO(g,h,i)PERYLENE	-
BENZO(k)FLUORANTHENE	-
BERYLLIUM	-
BIPHENYL, 1,1-	4.3E-01
BIS(2-CHLOROETHYL)ETHER	-
BIS(2-CHLORO-1-METHYLETHYL)ETHER	-
BIS(2-ETHYLHEXYL)PHTHALATE	-
BORON	-
BROMODICHLOROMETHANE	-
BROMOFORM	-
BROMOMETHANE	-
CADMIUM	-
CARBON TETRACHLORIDE	-
CHLORDANE (TECHNICAL)	-
CHLOROANILINE, p-	-
CHLOROBENZENE	-
CHLOROETHANE	-
CHLOROFORM	-
CHLOROMETHANE	-
CHLOROPHENOL, 2-	-
CHROMIUM (Total)	-
CHROMIUM III	-
CHROMIUM VI	-
CHRYSENE	-
COBALT	-
COPPER	-
CYANIDE (Free)	-
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	-

TABLE E. [1,2]ADDITIONAL SOIL SCREENING LEVELS FOR LEACHING CONCERNS AT SITES WITH THIN (<1m) SOIL COVER OVER BEDROCK

(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	Soil Screening Level (mg/kg)
DALAPON	-
DIBENZO(a,h)ANTHTRACENE	-
DIBROMO,1,2- CHLOROPROPANE,3-	-
DIBROMOCHLOROMETHANE	-
DIBROMOETHANE, 1,2-	-
DICHLOROBENZENE, 1,2-	-
DICHLOROBENZENE, 1,3-	-
DICHLOROBENZENE, 1,4-	-
DICHLOROBENZIDINE, 3,3-	-
DICHLORODIPHENYLDICHLOROETHANE (DDD)	-
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	-
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	-
DICHLOROETHANE, 1,1-	-
DICHLOROETHANE, 1,2-	-
DICHLOROETHYLENE, 1,1-	-
DICHLOROETHYLENE, Cis 1,2-	-
DICHLOROETHYLENE, Trans 1,2-	-
DICHLOROPHENOL, 2,4-	-
DICHLOROPHENOXYACETIC ACID (2,4-D)	-
DICHLOROPROPANE, 1,2-	-
DICHLOROPROPENE, 1,3-	-
DIELDRIN	3.7E-02
DIETHYLPHTHALATE	-
DIMETHYLPHENOL, 2,4-	-
DIMETHYLPHTHALATE	-
DINITROBENZENE, 1,3-	-
DINITROPHENOL, 2,4-	-
DINITROTOLUENE, 2,4- (2,4-DNT)	-
DINITROTOLUENE, 2,6- (2,6-DNT)	-
DIOXANE, 1,4-	-
DIOXIN (TEQ)	-
DIURON	-
ENDOSULFAN	-
ENDRIN	6.7E+00
ETHANOL	-
ETHYLBENZENE	-
FLUORANTHENE	-
FLUORENE	-
GLYPHOSATE	-
HEPTACHLOR	2.7E+00
HEPTACHLOR EPOXIDE	3.4E-01
HEXACHLOROBENZENE	-
HEXACHLOROBUTADIENE	-
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	-
HEXACHLOROETHANE	-

TABLE E. [1,2]ADDITIONAL SOIL SCREENING LEVELS FOR LEACHING CONCERNS AT SITES WITH THIN (<1m) SOIL COVER OVER BEDROCK

(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	**Soil Screening Level (mg/kg)**
HEXAZINONE	-
INDENO(1,2,3-cd)PYRENE	-
ISOPHORONE	-
LEAD	-
MERCURY	-
METHOXYCHLOR	-
METHYL ETHYL KETONE	-
METHYL ISOBUTYL KETONE	-
METHYL MERCURY	-
METHYL TERT BUTYL ETHER	-
METHYLENE CHLORIDE	-
METHYLNAPHTHALENE, 1-	-
METHYLNAPHTHALENE, 2-	-
MOLYBDENUM	-
NAPHTHALENE	-
NICKEL	-
NITROBENZENE	-
NITROGLYCERIN	-
NITROTOLUENE, 2-	-
NITROTOLUENE, 3-	-
NITROTOLUENE, 4-	-
PENTACHLOROPHENOL	-
PENTAERYTHRITOLTETRANITRATE (PETN)	-
PERCHLORATE	-
PHENANTHRENE	-
PHENOL	-
POLYCHLORINATED BIPHENYLS (PCBs)	-
PROPICONAZOLE	-
PYRENE	-
SELENIUM	-
SILVER	-
SIMAZINE	-
STYRENE	-
TERBACIL	-
tert-BUTYL ALCOHOL	-
TETRACHLOROETHANE, 1,1,1,2-	-
TETRACHLOROETHANE, 1,1,2,2-	-
TETRACHLOROETHYLENE	-
TETRACHLOROPHENOL, 2,3,4,6-	-
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	-
THALLIUM	-
TOLUENE	-
TOXAPHENE	3.8E+01
TPH (gasolines)	5.0E+01
TPH (middle distillates)	5.0E+01

TABLE E. [1,2]ADDITIONAL SOIL SCREENING LEVELS FOR LEACHING CONCERNS AT SITES WITH THIN (<1m) SOIL COVER OVER BEDROCK
(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	**Soil Screening Level (mg/kg)**
TPH (residual fuels)	-
TRICHLOROBENZENE, 1,2,4-	-
TRICHLOROETHANE, 1,1,1-	-
TRICHLOROETHANE, 1,1,2-	-
TRICHLOROETHYLENE	-
TRICHLOROPHENOL, 2,4,5-	-
TRICHLOROPHENOL, 2,4,6-	-
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	-
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	-
TRICHLOROPROPANE, 1,2,3-	-
TRICHLOROPROPENE, 1,2,3-	-
TRIFLURALIN	-
TRINITROBENZENE, 1,3,5-	-
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	-
TRINITROTOLUENE, 2,4,6- (TNT)	-
VANADIUM	-
VINYL CHLORIDE	-
XYLENES	-
ZINC	-
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	-
Sodium Adsorption Ratio	-

Notes:

1. Additional soil screening levels for protection of highly vulnerable, drinking water aquifers in areas with thin soil covers (defined as <1m thick over bedrock); reflects increased concern for normally low-mobility chemicals in areas with thin soil cover and unconfined, bedrock aquifers (see Section and Appendix 1, Section 3.4).

2. Primarily affects organochlorine pesticides, PAHs and TPH. SPLP batch test recommended to evaluation chemical mobility if soil screening level exceeded (see Volume 1, Section 4.3).

TABLE F: SOIL VAPOR SCREENING LEVELS FOR EVALUATION OF VADOSE-ZONE LEACHATE CONDITIONS

Notes:
Used to evaluate volatile hydrocarbons, solvents, explosives and fumigants in vadose-zone leachate

TABLE F. SOIL VAPOR SCREENING LEVELS
FOR EVALUATION OF VADOSE-ZONE LEACHATE
(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	**[1]Target Groundwater Screening Level (µg/L)**	**Soil Vapor Screening Level (µg/m^3)**
ACENAPHTHENE	-	-
ACENAPHTHYLENE	-	-
ACETONE	1.4E+04	4.5E+05
ALDRIN	-	-
AMETRYN	-	-
AMINO,2- DINITROTOLUENE,3,6-	-	-
AMINO,4- DINITROTOLUENE,2,6-	-	-
ANTHRACENE	-	-
ANTIMONY	-	-
ARSENIC	-	-
ATRAZINE	-	-
BARIUM	-	-
BENOMYL	-	-
BENZENE	5.0E+00	2.5E+04
BENZO(a)ANTHRACENE	-	-
BENZO(a)PYRENE	-	-
BENZO(b)FLUORANTHENE	-	-
BENZO(g,h,i)PERYLENE	-	-
BENZO(k)FLUORANTHENE	-	-
BERYLLIUM	-	-
BIPHENYL, 1,1-	5.0E-01	1.3E+02
BIS(2-CHLOROETHYL)ETHER	1.4E-02	1.9E-01
BIS(2-CHLORO-1-METHYLETHYL)ETHER	3.7E-01	3.5E+01
BIS(2-ETHYLHEXYL)PHTHALATE	-	-
BORON	-	-
BROMODICHLOROMETHANE	1.4E-01	2.4E+02
BROMOFORM	-	-
BROMOMETHANE	7.6E+00	4.6E+04
CADMIUM	-	-
CARBON TETRACHLORIDE	5.0E+00	1.1E+05
CHLORDANE (TECHNICAL)	-	-
CHLOROANILINE, p-	-	-
CHLOROBENZENE	5.0E+01	1.3E+05
CHLOROETHANE	1.6E+01	1.4E+05
CHLOROFORM	1.0E+02	3.0E+05
CHLOROMETHANE	1.9E+02	1.4E+06
CHLOROPHENOL, 2-	1.8E-01	1.7E+00
CHROMIUM (Total)	-	-
CHROMIUM III	-	-
CHROMIUM VI	-	-
CHRYSENE	-	-
COBALT	-	-
COPPER	-	-
CYANIDE (Free)	-	-

TABLE F. SOIL VAPOR SCREENING LEVELS
FOR EVALUATION OF VADOSE-ZONE LEACHATE
(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	[1]Target Groundwater Screening Level (µg/L)	Soil Vapor Screening Level (µg/m^3)
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	-	-
DALAPON	-	-
DIBENZO(a,h)ANTHTRACENE	-	-
DIBROMO,1,2- CHLOROPROPANE,3-	2.0E-01	2.4E+01
DIBROMOCHLOROMETHANE	9.3E-01	5.9E+02
DIBROMOETHANE, 1,2-	5.0E-02	2.7E+01
DICHLOROBENZENE, 1,2-	1.0E+01	1.6E+04
DICHLOROBENZENE, 1,3-	1.8E+02	2.8E+05
DICHLOROBENZENE, 1,4-	5.0E+00	9.9E+03
DICHLOROBENZIDINE, 3,3-	-	-
DICHLORODIPHENYLDICHLOROETHANE (DDD)	-	-
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	-	-
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	-	-
DICHLOROETHANE, 1,1-	2.8E+00	1.3E+04
DICHLOROETHANE, 1,2-	5.0E+00	4.8E+03
DICHLOROETHYLENE, 1,1-	7.0E+00	1.5E+05
DICHLOROETHYLENE, Cis 1,2-	7.0E+01	2.4E+05
DICHLOROETHYLENE, Trans 1,2-	1.0E+02	7.6E+05
DICHLOROPHENOL, 2,4-	-	-
DICHLOROPHENOXYACETIC ACID (2,4-D)	-	-
DICHLOROPROPANE, 1,2-	5.0E+00	1.2E+04
DICHLOROPROPENE, 1,3-	5.0E-01	1.5E+03
DIELDRIN	-	-
DIETHYLPHTHALATE	-	-
DIMETHYLPHENOL, 2,4-	4.0E+02	-
DIMETHYLPHTHALATE	-	-
DINITROBENZENE, 1,3-	-	-
DINITROPHENOL, 2,4-	-	-
DINITROTOLUENE, 2,4- (2,4-DNT)	-	-
DINITROTOLUENE, 2,6- (2,6-DNT)	-	-
DIOXANE, 1,4-	-	-
DIOXIN (TEQ)	-	-
DIURON	-	-
ENDOSULFAN	-	-
ENDRIN	-	-
ETHANOL	-	-
ETHYLBENZENE	3.0E+01	1.9E+05
FLUORANTHENE	-	-
FLUORENE	-	-
GLYPHOSATE	-	-
HEPTACHLOR	-	-
HEPTACHLOR EPOXIDE	-	-
HEXACHLOROBENZENE	-	-
HEXACHLOROBUTADIENE	-	-

TABLE F. SOIL VAPOR SCREENING LEVELS
FOR EVALUATION OF VADOSE-ZONE LEACHATE
(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	**[1]Target Groundwater Screening Level (µg/L)**	**Soil Vapor Screening Level (µg/m^3)**
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	-	-
HEXACHLOROETHANE	-	-
HEXAZINONE	-	-
INDENO(1,2,3-cd)PYRENE	-	-
ISOPHORONE	-	-
LEAD	-	-
MERCURY	-	-
METHOXYCHLOR	-	-
METHYL ETHYL KETONE	5.6E+03	2.6E+05
METHYL ISOBUTYL KETONE	1.3E+03	1.5E+05
METHYL MERCURY	-	-
METHYL TERT BUTYL ETHER	5.0E+00	2.4E+03
METHYLENE CHLORIDE	5.0E+00	1.3E+04
METHYLNAPHTHALENE, 1-	-	-
METHYLNAPHTHALENE, 2-	-	-
MOLYBDENUM	-	-
NAPHTHALENE	1.7E+01	6.1E+03
NICKEL	-	-
NITROBENZENE	1.4E-01	2.8E+00
NITROGLYCERIN	-	-
NITROTOLUENE, 2-	3.5E-01	3.6E+00
NITROTOLUENE, 3-	2.0E+00	-
NITROTOLUENE, 4-	-	-
PENTACHLOROPHENOL	-	-
PENTAERYTHRITOLTETRANITRATE (PETN)	-	-
PERCHLORATE	-	-
PHENANTHRENE	-	-
PHENOL	-	-
POLYCHLORINATED BIPHENYLS (PCBs)	-	-
PROPICONAZOLE	-	-
PYRENE	-	-
SELENIUM	-	-
SILVER	-	-
SIMAZINE	-	-
STYRENE	1.0E+01	2.2E+04
TERBACIL	-	-
tert-BUTYL ALCOHOL	5.2E+00	5.0E+01
TETRACHLOROETHANE, 1,1,1,2-	6.1E-01	1.2E+03
TETRACHLOROETHANE, 1,1,2,2-	7.8E-02	2.3E+01
TETRACHLOROETHYLENE	5.0E+00	7.2E+04
TETRACHLOROPHENOL, 2,3,4,6-	-	-
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	-	-
THALLIUM	-	-
TOLUENE	4.0E+01	2.2E+05

TABLE F. SOIL VAPOR SCREENING LEVELS FOR EVALUATION OF VADOSE-ZONE LEACHATE
(Potential impacts to highly vulnerable drinking water aquifers)

CHEMICAL PARAMETER	**[1]Target Groundwater Screening Level (µg/L)**	**[2]Soil Vapor Screening Level ($\mu g/m^3$)**
TOXAPHENE	-	-
TPH (gasolines)	3.0E+02	8.2E+07
TPH (middle distillates)	4.0E+02	1.1E+08
TPH (residual fuels)	-	-
TRICHLOROBENZENE, 1,2,4-	7.0E+01	8.1E+04
TRICHLOROETHANE, 1,1,1-	2.0E+02	2.8E+06
TRICHLOROETHANE, 1,1,2-	5.0E+00	3.4E+03
TRICHLOROETHYLENE	5.0E+00	4.0E+04
TRICHLOROPHENOL, 2,4,5-	-	-
TRICHLOROPHENOL, 2,4,6-	-	-
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	-	-
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	-	-
TRICHLOROPROPANE, 1,2,3-	7.2E-04	2.0E-01
TRICHLOROPROPENE, 1,2,3-	6.2E-01	8.9E+03
TRIFLURALIN	-	-
TRINITROBENZENE, 1,3,5-	-	-
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	-	-
TRINITROTOLUENE, 2,4,6- (TNT)	-	-
VANADIUM	-	-
VINYL CHLORIDE	2.0E+00	4.4E+04
XYLENES	2.0E+01	1.1E+05
ZINC	-	-
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	-	-
Sodium Adsorption Ratio	-	-

Notes:

1 Lowest of drinking water goals based on toxicity and taste and odors. Focus on volatile petroleum hydrocarbons, chlorinated solvents, explosives or agricultural fumigants of potential concern or related breakdown products (refer also to Section 9 of the Hawai'i DOH Technical Guidance Manual (HDOH 2009). Petroleum fuels focus on BTEX, MTCE, naphthalene, TPHg and TPHmd.

2. Theoretical, equilibrium concentration of VOC in soil gas when concentration of VOC in soil moisture/leachate is equal to twenty times the target drinking water screening level (default atenuation/dilution factor; see Section 4.3.4).

TABLE G: INDOOR AIR AND SOIL VAPOR SCREENING LEVELS FOR VAPOR INTRUSION

Notes:

- Shallow soil vapor intended to reflect soil vapor zero to five feet below ground surface or the foundation of a building. Collection of soil vapor data from depths <3 feet below ground surface in open areas is generally not practical (see Section 4.5).

TABLE G. INDOOR AIR AND SOIL GAS SCREENING LEVELS FOR VAPOR INTRUSION

			INDOOR AIR SCREENING LEVELS		[2]SHALLOW SOIL GAS SCREENING LEVELS	
CHEMICAL PARAMETER	Physical State		[1]Residential (ug/m3)	Commercial/ Industrial (ug/m^3)	[1]Residential (ug/m3)	Commercial/ Industrial (ug/m^3)
ACENAPHTHENE	V	S	5.0E+01	2.1E+02	1.0E+05	8.4E+05
ACENAPHTHYLENE	V	S	3.3E+01	1.4E+02	6.7E+04	5.6E+05
ACETONE	V	L	6.5E+03	2.7E+04	1.3E+07	1.1E+08
ALDRIN	SV	S	5.7E-02	2.5E-01	1.1E+02	1.0E+03
AMETRYN	NV	S				
AMINO,2- DINITROTOLUENE,4,6-	NV	S				
AMINO,4- DINITROTOLUENE,2,6-	NV	S				
ANTHRACENE	V	S	2.5E+02	1.1E+03	5.0E+05	4.2E+06
ANTIMONY	NV	S				
ARSENIC	NV	S				
ATRAZINE	NV	S				
BARIUM	NV	S				
BENOMYL	NV	S				
BENZENE	V	L	3.6E-01	1.6E+00	7.2E+02	6.3E+03
BENZO(a)ANTHRACENE	SV	S	1.7E-01	2.0E+00	3.4E+02	8.2E+03
BENZO(a)PYRENE	NV	S				
BENZO(b)FLUORANTHENE	NV	S				
BENZO(g,h,i)PERYLENE	NV	S				
BENZO(k)FLUORANTHENE	NV	S				
BERYLLIUM	NV	S				
BIPHENYL, 1,1-	V	S	8.3E-02	3.5E-01	1.7E+02	1.4E+03
BIS(2-CHLOROETHYL)ETHER	V	L	8.5E-03	3.7E-02	1.7E+01	1.5E+02
BIS(2-CHLORO-1-METHYLETHYL)ETHER	V	L	2.8E-01	1.2E+00	5.6E+02	4.9E+03
BIS(2-ETHYLHEXYL)PHTHALATE	NV	S				
BORON	NV	S				
BROMODICHLOROMETHANE	V	L	7.6E-02	3.3E-01	1.5E+02	1.3E+03
BROMOFORM	SV	S	2.6E+00	1.1E+01	5.1E+03	4.5E+04
BROMOMETHANE	V	G	1.0E+00	4.4E+00	2.1E+03	1.8E+04
CADMIUM	NV	S				
CARBON TETRACHLORIDE	V	L	4.7E-01	2.0E+00	9.4E+02	8.2E+03
CHLORDANE (TECHNICAL)	SV	S	2.8E-01	1.2E+00	5.6E+02	4.9E+03
CHLOROANILINE, p-	NV	S				
CHLOROBENZENE	V	L	1.0E+01	4.4E+01	2.1E+04	1.8E+05
CHLOROETHANE	V	G	2.1E+03	8.8E+03	4.2E+06	3.5E+07
CHLOROFORM	V	L	1.2E-01	5.3E-01	2.4E+02	2.1E+03
CHLOROMETHANE	V	G	1.9E+01	7.9E+01	3.8E+04	3.2E+05
CHLOROPHENOL, 2-	V	L	4.2E+00	1.8E+01	8.3E+03	7.0E+04
CHROMIUM (Total)	NV	S				
CHROMIUM III	NV	S				
CHROMIUM VI	NV	S				
CHRYSENE	NV	S				
COBALT	NV	S				
COPPER	NV	S				
CYANIDE (Free)	V	S	1.7E-01	7.0E-01	3.3E+02	2.8E+03
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	NV	S				
DALAPON	NV	L				
DIBENZO(a,h)ANTHTRACENE	NV	S				
DIBROMO,1,2- CHLOROPROPANE,3-	V	L	1.7E-04	2.0E-03	3.4E-01	8.2E+00
DIBROMOCHLOROMETHANE	V	S	1.7E+01	7.0E+01	3.3E+04	2.8E+05
DIBROMOETHANE, 1,2-	V	S	4.7E-03	2.0E-02	9.4E+00	8.2E+01
DICHLOROBENZENE, 1,2-	V	L	4.2E+01	1.8E+02	8.3E+04	7.0E+05
DICHLOROBENZENE, 1,3-	V	L	2.5E+01	1.1E+02	5.0E+04	4.2E+05
DICHLOROBENZENE, 1,4-	V	S	2.6E-01	1.1E+00	5.1E+02	4.5E+03
DICHLOROBENZIDINE, 3,3-	NV	S				
DICHLORODIPHENYLDICHLOROETHANE (DDD)	NV	S				
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	SV	S	2.9E-02	1.3E-01	5.8E+01	5.1E+02
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	NV	S				
DICHLOROETHANE, 1,1-	V	L	1.8E+00	7.7E+00	3.5E+03	3.1E+04

TABLE G. INDOOR AIR AND SOIL GAS SCREENING LEVELS FOR VAPOR INTRUSION

			INDOOR AIR SCREENING LEVELS		[2]SHALLOW SOIL GAS SCREENING LEVELS	
CHEMICAL PARAMETER	Physical State		[1]Residential (ug/m3)	Commercial/ Industrial (ug/m^3)	[1]Residential (ug/m3)	Commercial/ Industrial (ug/m^3)
DICHLOROETHANE, 1,2-	V	L	1.1E-01	4.7E-01	2.2E+02	1.9E+03
DICHLOROETHYLENE, 1,1-	V	L	4.2E+01	1.8E+02	8.3E+04	7.0E+05
DICHLOROETHYLENE, Cis 1,2-	V	L	1.7E+00	7.0E+00	3.3E+03	2.8E+04
DICHLOROETHYLENE, Trans 1,2-	V	L	1.7E+01	7.0E+01	3.3E+04	2.8E+05
DICHLOROPHENOL, 2,4-	NV	S				
DICHLOROPHENOXYACETIC ACID (2,4-D)	NV	S				
DICHLOROPROPANE, 1,2-	V	L	7.6E-01	3.3E+00	1.5E+03	1.3E+04
DICHLOROPROPENE, 1,3-	V	L	7.0E-01	3.1E+00	1.4E+03	1.2E+04
DIELDRIN	NV	S				
DIETHYLPHTHALATE	NV	S				
DIMETHYLPHENOL, 2,4-	NV	S				
DIMETHYLPHTHALATE	NV	S				
DINITROBENZENE, 1,3-	NV	S				
DINITROPHENOL, 2,4-	NV	S				
DINITROTOLUENE, 2,4- (2,4-DNT)	NV	S				
DINITROTOLUENE, 2,6- (2,6-DNT)	NV	S				
DIOXANE, 1,4-	V	L	5.6E-01	2.5E+00	1.1E+03	9.8E+03
DIOXINS (TEQ)	SV	S	7.4E-06	3.2E-05	1.5E-02	1.3E-01
DIURON	NV	S				
ENDOSULFAN	SV	S				
ENDRIN	NV	S				
ETHANOL	V	L				
ETHYLBENZENE	V	L	1.1E+01	4.9E+01	2.2E+04	2.0E+05
FLUORANTHENE	NV	S				
FLUORENE	V	S	3.3E+01	1.4E+02	6.7E+04	5.6E+05
GLYPHOSATE	NV	S				
HEPTACHLOR	SV	S	2.2E-02	9.4E-02	4.3E+01	3.8E+02
HEPTACHLOR EPOXIDE	SV	S	1.1E-02	4.7E-02	2.2E+01	1.9E+02
HEXACHLOROBENZENE	SV	S	6.1E-03	2.7E-02	1.2E+01	1.1E+02
HEXACHLOROBUTADIENE	SV	S	1.3E-01	5.6E-01	2.6E+02	2.2E+03
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	NV	S				
HEXACHLOROETHANE	SV	S	2.6E-01	1.1E+00	5.1E+02	4.5E+03
HEXAZINONE	NV	S				
INDENO(1,2,3-cd)PYRENE	NV	S				
ISOPHORONE	NV	L				
LEAD	NV	S				
MERCURY	NV	S				
METHOXYCHLOR	NV	S				
METHYL ETHYL KETONE	V	L	1.0E+03	4.4E+03	2.1E+06	1.8E+07
METHYL ISOBUTYL KETONE	V	L	6.3E+02	2.6E+03	1.3E+06	1.1E+07
METHYL MERCURY	NV	S				
METHYL TERT BUTYL ETHER	V	L	1.1E+01	4.7E+01	2.2E+04	1.9E+05
METHYLENE CHLORIDE	V	L	1.0E+02	5.3E+02	2.0E+05	2.1E+06
METHYLNAPHTHALENE, 1-	V	S	5.8E+01	2.5E+02	1.2E+05	9.8E+05
METHYLNAPHTHALENE, 2-	V	S	3.3E+00	1.4E+01	6.7E+03	5.6E+04
MOLYBDENUM	NV	S				
NAPHTHALENE	V	S	6.3E-01	2.6E+00	1.3E+03	1.1E+04
NICKEL	NV	S				
NITROBENZENE	V	L	7.0E-02	3.1E-01	1.4E+02	1.2E+03
NITROGLYCERIN	NV	L				
NITROTOLUENE, 2-	V	S	7.5E-01	3.2E+00	1.5E+03	1.3E+04
NITROTOLUENE, 3-	NV	S				
NITROTOLUENE, 4-	NV	S				
PENTACHLOROPHENOL	NV	S				

TABLE G. INDOOR AIR AND SOIL GAS SCREENING LEVELS
FOR VAPOR INTRUSION

			INDOOR AIR SCREENING LEVELS		[2]SHALLOW SOIL GAS SCREENING LEVELS	
CHEMICAL PARAMETER	**Physical State**		**[1]Residential (ug/m3)**	**Commercial/ Industrial (ug/m^3)**	**[1]Residential (ug/m3)**	**Commercial/ Industrial (ug/m^3)**
PENTAERYTHRITOLTETRANITRATE (PETN)	NV	S				
PERCHLORATE	NV	S				
PHENANTHRENE	V	S	2.9E+01	1.2E+02	5.8E+04	4.9E+05
PHENOL	NV	S				
POLYCHLORINATED BIPHENYLS (PCBs)	SV	S	4.9E-02	2.2E-01	9.9E+01	8.6E+02
PROPICONAZOLE	NV	L				
PYRENE	V	S	2.5E+01	1.1E+02	5.0E+04	4.2E+05
SELENIUM	NV	S				
SILVER	NV	S				
SIMAZINE	NV	S				
STYRENE	V	L	2.1E+02	8.8E+02	4.2E+05	3.5E+06
TERBACIL	NV	S				
tert-BUTYL ALCOHOL	V	L	3.3E+00	1.4E+01	6.5E+03	5.7E+04
TETRACHLOROETHANE, 1,1,1,2-	V	L	3.8E-01	1.7E+00	7.6E+02	6.6E+03
TETRACHLOROETHANE, 1,1,2,2-	V	L	4.8E-02	2.1E-01	9.7E+01	8.5E+02
TETRACHLOROETHYLENE	V	L	4.6E-01	2.0E+00	9.2E+02	8.0E+03
TETRACHLOROPHENOL, 2,3,4,6-	NV	S				
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	NV	S				
THALLIUM	NV	S				
TOLUENE	V	L	1.0E+03	4.4E+03	2.1E+06	1.8E+07
TOXAPHENE	NV	S				
TPH (gasolines)	V	L	2.9E+02	1.2E+03	5.9E+05	4.9E+06
TPH (middle distillates)	V	L	1.3E+02	5.5E+02	2.6E+05	2.2E+06
TPH (residual fuels)	NV	L				
TRICHLOROBENZENE, 1,2,4-	V	S	4.2E-01	1.8E+00	8.3E+02	7.0E+03
TRICHLOROETHANE, 1,1,1-	V	L	1.0E+03	4.4E+03	2.1E+06	1.8E+07
TRICHLOROETHANE, 1,1,2-	V	L	4.2E-02	1.8E-01	8.3E+01	7.0E+02
TRICHLOROETHYLENE	V	L	4.2E-01	1.8E+00	8.3E+02	7.0E+03
TRICHLOROPHENOL, 2,4,5-	NV	S				
TRICHLOROPHENOL, 2,4,6-	NV	S				
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	NV	S				
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	NV	S				
TRICHLOROPROPANE, 1,2,3-	V	L	6.3E-02	2.6E-01	1.3E+02	1.1E+03
TRICHLOROPROPENE, 1,2,3-	V	L	6.3E-02	2.6E-01	1.3E+02	1.1E+03
TRIFLURALIN	SV	S				
TRINITROBENZENE, 1,3,5-	NV	S				
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	NV	S				
TRINITROTOLUENE, 2,4,6- (TNT)	NV	S				
VANADIUM	NV	S				

TABLE G. INDOOR AIR AND SOIL GAS SCREENING LEVELS FOR VAPOR INTRUSION

			INDOOR AIR SCREENING LEVELS		[2]SHALLOW SOIL GAS SCREENING LEVELS	
CHEMICAL PARAMETER	**Physical State**		**[1]Residential (ug/m3)**	**Commercial/ Industrial (ug/m^3)**	**[1]Residential (ug/m3)**	**Commercial/ Industrial (ug/m^3)**
VINYL CHLORIDE	V	G	1.7E-01	2.8E+00	3.4E+02	1.1E+04
XYLENES	V	L	2.1E+01	8.8E+01	4.2E+04	3.5E+05
ZINC	NV	S				
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)			not applicable	not applicable	not apploicable	not applicable
Sodium Adsorption Ratio			not applicable	not applicable	not applicable	not applicable

Notes:

1. Category "Residential Land Use" generally considered adequate for other sensitive uses (e.g., day-care centers, hospitals, etc.)
2. Soil Gas: Screening levels based on soil gas data collected within 1.5 meters (five feet) below a building foundation or the ground surface. Intended for evaluation of potential indoor-air impacts.

Screening levels also apply to areas over both contaminated soil and contaminated groundwater.

Source of soil ESLs: Refer to Tables E-2 and E-3 in Appendix 1.

TPH -Total Petroleum Hydrocarbons. TPH ESLs must be used in conjunction with ESLs for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Volume 1, Section 2.2 and Appendix 1, Chapter 5.

TABLE H: SURFACE WATER SCREENING LEVELS

TABLE H. SURFACE WATER SCREENING LEVELS

CHEMICAL PARAMETER	[2]Freshwater (ug/L)	[3]Marine (ug/L)	[4]Estuarine (ug/L)
ACENAPHTHENE	1.5E+01	2.0E+01	1.5E+01
ACENAPHTHYLENE	1.3E+01	3.1E+02	1.3E+01
ACETONE	1.7E+03	1.5E+03	1.5E+03
ALDRIN	5.0E-05	5.0E-05	5.0E-05
AMETRYN	1.8E+02	7.0E+02	7.0E+02
AMINO,2- DINITROTOLUENE,4,6-	1.8E+01	2.0E+01	1.8E+01
AMINO,4- DINITROTOLUENE,2,6-	1.1E+01	1.1E+01	1.1E+01
ANTHRACENE	2.0E-02	7.3E-01	2.0E-02
ANTIMONY	6.0E+00	5.0E+02	3.0E+01
ARSENIC	1.4E-01	1.4E-01	1.4E-01
ATRAZINE	3.4E-01	2.6E+01	1.2E+01
BARIUM	2.2E+02	2.2E+02	2.2E+02
BENOMYL	1.4E-01	1.4E-01	1.4E-01
BENZENE	5.0E+00	5.1E+01	5.1E+01
BENZO(a)ANTHRACENE	1.8E-02	1.8E-02	1.8E-02
BENZO(a)PYRENE	1.8E-02	1.8E-02	1.8E-02
BENZO(b)FLUORANTHENE	1.8E-02	1.8E-02	1.8E-02
BENZO(g,h,i)PERYLENE	1.3E-01	1.3E-01	1.3E-01
BENZO(k)FLUORANTHENE	1.8E-02	1.8E-02	1.8E-02
BERYLLIUM	4.0E+00	6.6E-01	6.6E-01
BIPHENYL, 1,1-	5.0E-01	5.0E-01	5.0E-01
BIS(2-CHLOROETHYL)ETHER	1.4E-02	5.3E-01	5.3E-01
BIS(2-CHLORO-1-METHYLETHYL)ETHER	3.7E-01	3.7E-01	3.7E-01
BIS(2-ETHYLHEXYL)PHTHALATE	2.2E+00	2.2E+00	2.2E+00
BORON	4.0E+03	1.0E+03	1.0E+03
BROMODICHLOROMETHANE	1.4E-01	3.4E+02	3.4E+02
BROMOFORM	1.0E+02	1.4E+02	1.4E+02
BROMOMETHANE	7.6E+00	1.6E+01	1.6E+01
CADMIUM	2.5E-01	8.8E+00	2.5E-01
CARBON TETRACHLORIDE	1.6E+00	1.6E+00	1.6E+00
CHLORDANE (TECHNICAL)	8.1E-04	8.1E-04	8.1E-04
CHLOROANILINE, p-	3.9E-01	1.9E+01	1.9E+01
CHLOROBENZENE	2.5E+01	5.0E+01	2.5E+01
CHLOROETHANE	1.6E+01	1.6E+01	1.6E+01
CHLOROFORM	1.0E+02	2.8E+01	2.8E+01
CHLOROMETHANE	1.9E+02	1.9E+02	1.9E+02
CHLOROPHENOL, 2-	1.8E-01	1.8E-01	1.8E-01
CHROMIUM (Total)	1.1E+01	5.0E+01	1.1E+01
CHROMIUM III	7.4E+01	2.0E+01	2.0E+01
CHROMIUM VI	4.3E-02	5.0E+01	1.1E+01
CHRYSENE	1.8E-02	1.8E-02	1.8E-02
COBALT	6.0E+00	2.3E+01	1.9E+01
COPPER	9.0E+00	3.1E+00	3.1E+00
CYANIDE (Free)	5.2E+00	1.0E+00	1.0E+00
CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)	7.1E-01	1.9E+02	7.9E+01
DALAPON	3.0E+02	3.0E+02	3.0E+02
DIBENZO(a,h)ANTHTRACENE	1.8E-02	1.8E-02	1.8E-02
DIBROMO,1,2- CHLOROPROPANE,3-	2.0E-01	2.0E-01	2.0E-01
DIBROMOCHLOROMETHANE	9.3E-01	1.3E+01	1.3E+01
DIBROMOETHANE, 1,2-	5.0E-02	1.4E+03	1.4E+03
DICHLOROBENZENE, 1,2-	1.0E+01	1.0E+01	1.0E+01

TABLE H. SURFACE WATER SCREENING LEVELS

CHEMICAL PARAMETER	[2]Freshwater (ug/L)	[3]Marine (ug/L)	[4]Estuarine (ug/L)
DICHLOROBENZENE, 1,3-	2.2E+01	7.1E+01	2.2E+01
DICHLOROBENZENE, 1,4-	5.0E+00	1.1E+01	9.4E+00
DICHLOROBENZIDINE, 3,3-	2.8E-02	2.8E-02	2.8E-02
DICHLORODIPHENYLDICHLOROETHANE (DDD)	3.1E-04	3.1E-04	3.1E-04
DICHLORODIPHENYLDICHLOROETHYLENE (DDE)	2.2E-04	2.2E-04	2.2E-04
DICHLORODIPHENYLTRICHLOROETHANE (DDT)	2.2E-04	2.2E-04	2.2E-04
DICHLOROETHANE, 1,1-	2.8E+00	4.7E+01	4.7E+01
DICHLOROETHANE, 1,2-	5.0E+00	3.7E+01	3.7E+01
DICHLOROETHYLENE, 1,1-	3.2E+00	3.2E+00	3.2E+00
DICHLOROETHYLENE, Cis 1,2-	7.0E+01	6.2E+02	6.2E+02
DICHLOROETHYLENE, Trans 1,2-	1.0E+02	2.6E+02	2.6E+02
DICHLOROPHENOL, 2,4-	3.0E-01	3.0E-01	3.0E-01
DICHLOROPHENOXYACETIC ACID (2,4-D)	7.9E+01	7.0E+01	7.0E+01
DICHLOROPROPANE, 1,2-	5.0E+00	1.0E+01	1.0E+01
DICHLOROPROPENE, 1,3-	5.0E-01	6.0E-02	6.0E-02
DIELDRIN	5.4E-05	5.4E-05	5.4E-05
DIETHYLPHTHALATE	2.2E+02	2.1E+02	2.1E+02
DIMETHYLPHENOL, 2,4-	4.0E+02	1.1E+02	1.1E+02
DIMETHYLPHTHALATE	1.1E+03	2.9E+03	1.1E+03
DINITROBENZENE, 1,3-	2.0E+00	1.0E+01	1.0E+01
DINITROPHENOL, 2,4-	4.0E+01	1.4E+01	1.4E+01
DINITROTOLUENE, 2,4- (2,4-DNT)	2.5E-01	3.4E+00	3.4E+00
DINITROTOLUENE, 2,6- (2,6-DNT)	5.2E-02	8.1E+01	8.1E+01
DIOXANE, 1,4-	4.6E-01	5.0E+04	5.0E+04
DIOXINS (TEQ)	3.1E-09	3.1E-09	3.1E-09
DIURON	4.0E+01	6.0E+01	6.0E+01
ENDOSULFAN	5.6E-02	8.7E-03	8.7E-03
ENDRIN	3.6E-02	2.3E-03	2.3E-03
ETHANOL	5.0E+04	5.0E+04	5.0E+04
ETHYLBENZENE	3.0E+01	7.3E+00	7.3E+00
FLUORANTHENE	8.0E-01	7.1E+00	8.0E-01
FLUORENE	1.9E+01	3.9E+00	3.9E+00
GLYPHOSATE	1.8E+03	1.8E+03	1.8E+03
HEPTACHLOR	7.9E-05	7.9E-05	7.9E-05
HEPTACHLOR EPOXIDE	3.9E-05	3.9E-05	3.9E-05
HEXACHLOROBENZENE	2.9E-04	2.9E-04	2.9E-04
HEXACHLOROBUTADIENE	2.0E-01	3.0E-01	3.0E-01
HEXACHLOROCYCLOHEXANE (gamma) LINDANE	6.3E-02	6.3E-02	6.3E-02
HEXACHLOROETHANE	4.0E-01	3.3E+00	3.3E+00
HEXAZINONE	6.6E+02	1.7E+04	1.7E+04
INDENO(1,2,3-cd)PYRENE	1.8E-02	1.8E-02	1.8E-02
ISOPHORONE	8.2E+01	9.2E+02	9.2E+02
LEAD	2.5E+00	8.1E+00	2.5E+00
MERCURY	3.0E-01	3.0E-01	3.0E-01
METHOXYCHLOR	3.0E-02	1.9E-02	1.9E-02
METHYL ETHYL KETONE	5.6E+03	8.4E+03	8.4E+03
METHYL ISOBUTYL KETONE	1.7E+02	1.7E+02	1.7E+02
METHYL MERCURY	2.8E-03	2.8E-03	2.8E-03
METHYL TERT BUTYL ETHER	5.0E+00	1.8E+02	1.8E+02
METHYLENE CHLORIDE	5.0E+00	5.9E+02	5.9E+02

TABLE H. SURFACE WATER SCREENING LEVELS

CHEMICAL PARAMETER	[2]Freshwater (ug/L)	[3]Marine (ug/L)	[4]Estuarine (ug/L)
METHYLNAPHTHALENE, 1-	2.1E+00	2.1E+00	2.1E+00
METHYLNAPHTHALENE, 2-	4.7E+00	1.0E+01	4.7E+00
MOLYBDENUM	1.0E+02	3.7E+02	3.7E+02
NAPHTHALENE	1.7E+01	1.2E+01	1.2E+01
NICKEL	5.2E+01	8.2E+00	8.2E+00
NITROBENZENE	1.4E-01	3.8E+02	3.8E+02
NITROGLYCERIN	2.0E+00	1.8E+01	1.8E+01
NITROTOLUENE, 2-	3.5E-01	7.1E+01	7.1E+01
NITROTOLUENE, 3-	2.0E+00	4.2E+01	4.2E+01
NITROTOLUENE, 4-	4.9E+00	4.6E+01	4.6E+01
PENTACHLOROPHENOL	1.0E+00	3.0E+00	3.0E+00
PENTAERYTHRITOLTETRANITRATE (PETN)	1.9E+01	2.2E+04	2.2E+04
PERCHLORATE	1.5E+01	6.0E+02	6.0E+02
PHENANTHRENE	6.3E+00	4.6E+00	4.6E+00
PHENOL	5.0E+00	5.8E+01	5.8E+01
POLYCHLORINATED BIPHENYLS (PCBs)	6.4E-05	6.4E-05	6.4E-05
PROPICONAZOLE	9.5E+01	9.5E+01	9.5E+01
PYRENE	4.6E+00	1.0E+01	4.6E+00
SELENIUM	5.0E+00	7.1E+01	5.0E+00
SILVER	6.0E-02	1.0E-01	6.0E-02
SIMAZINE	6.5E-01	9.0E+00	9.0E+00
STYRENE	1.0E+01	1.1E+01	1.1E+01
TERBACIL	2.6E+02	2.6E+02	2.6E+02
tert-BUTYL ALCOHOL	5.2E+00	1.8E+04	1.8E+04
TETRACHLOROETHANE, 1,1,1,2-	6.1E-01	1.1E+01	1.1E+01
TETRACHLOROETHANE, 1,1,2,2-	7.8E-02	4.0E+00	4.0E+00
TETRACHLOROETHYLENE	3.3E+00	3.3E+00	3.3E+00
TETRACHLOROPHENOL, 2,3,4,6-	1.2E+00	1.2E+00	1.2E+00
TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)	2.2E+02	3.3E+02	2.2E+02
THALLIUM	2.0E+00	6.3E+00	6.0E+00
TOLUENE	4.0E+01	9.8E+00	9.8E+00
TOXAPHENE	2.0E-04	2.0E-04	2.0E-04
TPH (gasolines)	1.0E+02	3.7E+03	5.0E+02
TPH (middle distillates)	1.0E+02	6.4E+02	6.4E+02
TPH (residual fuels)	1.0E+02	6.4E+02	6.4E+02
TRICHLOROBENZENE, 1,2,4-	7.0E+01	1.1E+02	1.1E+02
TRICHLOROETHANE, 1,1,1-	7.6E+01	1.1E+01	1.1E+01
TRICHLOROETHANE, 1,1,2-	5.0E+00	1.6E+01	1.6E+01
TRICHLOROETHYLENE	5.0E+00	3.0E+01	3.0E+01
TRICHLOROPHENOL, 2,4,5-	6.3E+01	1.1E+01	1.1E+01
TRICHLOROPHENOL, 2,4,6-	4.9E+00	6.5E+00	4.9E+00
TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)	2.0E+02	6.9E+02	6.9E+02
TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)	3.0E+01	5.0E+01	3.0E+01
TRICHLOROPROPANE, 1,2,3-	7.2E-04	1.4E+01	1.4E+01
TRICHLOROPROPENE, 1,2,3-	6.2E-01	6.2E-01	6.2E-01
TRIFLURALIN	1.1E+00	1.1E+00	1.1E+00
TRINITROBENZENE, 1,3,5-	1.1E+01	1.0E+01	1.0E+01
TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)	4.0E+01	4.0E+01	4.0E+01
TRINITROTOLUENE, 2,4,6- (TNT)	2.6E+00	2.0E+01	1.3E+01
VANADIUM	2.7E+01	8.1E+01	2.7E+01

TABLE H. SURFACE WATER SCREENING LEVELS

CHEMICAL PARAMETER	[2]Freshwater (ug/L)	[3]Marine (ug/L)	[4]Estuarine (ug/L)
VINYL CHLORIDE	2.0E+00	5.3E+02	5.3E+02
XYLENES	2.0E+01	1.3E+01	1.3E+01
ZINC	1.2E+02	8.1E+01	8.1E+01
Electrical Conductivity (mS/cm, USEPA Method 120.1 MOD)	not applicable	not applicable	not applicable
Sodium Adsorption Ratio	not applicable	not applicable	not applicable

Notes:

1. Source of Freshwater ESLs: Refer to Appendix 1, Table F-2a for basis.
2. Source of Marine ESLs: Refer to Appendix 1, Table F-2b for basis.
3. Source of Estuarine ESLs: Refer to Appendix 1, Table F-2c for basis.

Surface water screening levels lowest of drinking water goal (freshwater only), chronic aquatic habitat goal, goal to address bioaccumulation in aquatic organisms and subsequent consumption by humans, and general nuisance goal (odors, etc.). Refer to Section 2.7 of text for discussion.

Estuarine screening levels lowest of freshwater and marine screening levels.

Water ESLs for ethanol based on gross contamination concerns (see Appendix 1, Chapter 5 and related tables).

TPH -Total Petroleum Hydrocarbons. TPH ESLs must be used in conjunction with ESLs for related chemicals (e.g., BTEX, PAHs, oxidizers, etc.). See Section 2.2 and Appendix 1, Chapter 5.

TABLE I: CHEMICAL CAS NUMBERS

CAS Number	**CHEMICAL PARAMETER**
83-32-9	ACENAPHTHENE
208-96-8	ACENAPHTHYLENE
67-64-1	ACETONE
309-00-2	ALDRIN
834-12-8	AMETRYN
35572-78-2	AMINO,2- DINITROTOLUENE,4,6-
19406-51-0	AMINO,4- DINITROTOLUENE,2,6-
120-12-7	ANTHRACENE
7440-36-0	ANTIMONY
7440-38-2	ARSENIC
1912-24-9	ATRAZINE
7440-39-3	BARIUM
17804-35-2	BENOMYL
71-43-2	BENZENE
56-55-3	BENZO(a)ANTHRACENE
50-32-8	BENZO(a)PYRENE
205-99-2	BENZO(b)FLUORANTHENE
191-24-2	BENZO(g,h,i)PERYLENE
207-08-9	BENZO(k)FLUORANTHENE
7440-41-7	BERYLLIUM
92-52-4	BIPHENYL, 1,1-
111-44-4	BIS(2-CHLOROETHYL)ETHER
39638-32-9	BIS(2-CHLORO-1-METHYLETHYL)ETHER
117-81-7	BIS(2-ETHYLHEXYL)PHTHALATE
7440-42-8	BORON
75-27-4	BROMODICHLOROMETHANE
75-25-2	BROMOFORM
74-83-9	BROMOMETHANE
7440-43-9	CADMIUM
56-23-5	CARBON TETRACHLORIDE
12789-03-6	CHLORDANE (TECHNICAL)
106-47-8	CHLOROANILINE, p-
108-90-7	CHLOROBENZENE
75-00-3	CHLOROETHANE
67-66-3	CHLOROFORM
74-87-3	CHLOROMETHANE
95-57-8	CHLOROPHENOL, 2-
7440-47-3	CHROMIUM (Total)
16065-83-1	CHROMIUM III
18540-29-9	CHROMIUM VI
218-01-9	CHRYSENE
7440-48-4	COBALT
7440-50-8	COPPER
57-12-5	CYANIDE (Free)
121-82-4	CYCLO-1,3,5-TRIMETHYLENE-2,4,6-TRINITRAMINE (RDX)
75-99-0	DALAPON
53-70-3	DIBENZO(a,h)ANTHTRACENE
96-12-8	DIBROMO,1,2- CHLOROPROPANE,3-
124-48-1	DIBROMOCHLOROMETHANE
106-93-4	DIBROMOETHANE, 1,2-
95-50-1	DICHLOROBENZENE, 1,2-
541-73-1	DICHLOROBENZENE, 1,3-
106-46-7	DICHLOROBENZENE, 1,4-
91-94-1	DICHLOROBENZIDINE, 3,3-
72-54-8	DICHLORODIPHENYLDICHLOROETHANE (DDD)
72-55-9	DICHLORODIPHENYLDICHLOROETHYLENE (DDE)
50-29-3	DICHLORODIPHENYLTRICHLOROETHANE (DDT)
75-34-3	DICHLOROETHANE, 1,1-
107-06-2	DICHLOROETHANE, 1,2-

75-35-4	DICHLOROETHYLENE, 1,1-
156-59-2	DICHLOROETHYLENE, Cis 1,2-
156-60-5	DICHLOROETHYLENE, Trans 1,2-
120-83-2	DICHLOROPHENOL, 2,4-
94-75-7	DICHLOROPHENOXYACETIC ACID (2,4-D)
78-87-5	DICHLOROPROPANE, 1,2-
542-75-6	DICHLOROPROPENE, 1,3-
60-57-1	DIELDRIN
84-66-2	DIETHYLPHTHALATE
105-67-9	DIMETHYLPHENOL, 2,4-
131-11-3	DIMETHYLPHTHALATE
99-65-0	DINITROBENZENE, 1,3-
51-28-5	DINITROPHENOL, 2,4-
121-14-2	DINITROTOLUENE, 2,4- (2,4-DNT)
606-20-2	DINITROTOLUENE, 2,6- (2,6-DNT)
123-91-1	DIOXANE, 1,4-
1746-01-6	DIOXINS (TEQ)
330-54-1	DIURON
115-29-7	ENDOSULFAN
72-20-8	ENDRIN
64-17-5	ETHANOL
100-41-4	ETHYLBENZENE
206-44-0	FLUORANTHENE
86-73-7	FLUORENE
1071-83-6	GLYPHOSATE
76-44-8	HEPTACHLOR
1024-57-3	HEPTACHLOR EPOXIDE
118-74-1	HEXACHLOROBENZENE
87-68-3	HEXACHLOROBUTADIENE
58-89-9	HEXACHLOROCYCLOHEXANE (gamma) LINDANE
67-72-1	HEXACHLOROETHANE
51235-04-2	HEXAZINONE
193-39-5	INDENO(1,2,3-cd)PYRENE
78-59-1	ISOPHORONE
7439-92-1	LEAD
7487-94-7	MERCURY
72-43-5	METHOXYCHLOR
78-93-3	METHYL ETHYL KETONE
108-10-1	METHYL ISOBUTYL KETONE
22967-92-6	METHYL MERCURY
1634-04-4	METHYL TERT BUTYL ETHER
75-09-2	METHYLENE CHLORIDE
90-12-0	METHYLNAPHTHALENE, 1-
91-57-6	METHYLNAPHTHALENE, 2-
7439-98-7	MOLYBDENUM
91-20-3	NAPHTHALENE
7440-02-0	NICKEL
98-95-3	NITROBENZENE
55-63-0	NITROGLYCERIN
88-72-2	NITROTOLUENE, 2-
99-08-1	NITROTOLUENE, 3-
99-99-0	NITROTOLUENE, 4-
87-86-5	PENTACHLOROPHENOL
78-11-5	PENTAERYTHRITOLTETRANITRATE (PETN)
14797-73-0	PERCHLORATE
85-01-8	PHENANTHRENE
108-95-2	PHENOL
11097-69-1	POLYCHLORINATED BIPHENYLS (PCBs)
60207-90-1	PROPICONAZOLE
129-00-0	PYRENE
7782-49-2	SELENIUM
7440-22-4	SILVER

122-34-9	SIMAZINE
100-42-5	STYRENE
5902-51-2	TERBACIL
75-65-0	tert-BUTYL ALCOHOL
630-20-6	TETRACHLOROETHANE, 1,1,1,2-
79-34-5	TETRACHLOROETHANE, 1,1,2,2-
127-18-4	TETRACHLOROETHYLENE
58-90-2	TETRACHLOROPHENOL, 2,3,4,6-
2691-41-0	TETRANITRO-1,3,5,7-TETRAAZOCYCLOOCTANE (HMX)
7440-28-0	THALLIUM
108-88-3	TOLUENE
8001-35-2	TOXAPHENE
Gas	TPH (gasolines)
Diesel	TPH (middle distillates)
Oil	TPH (residual fuels)
120-82-1	TRICHLOROBENZENE, 1,2,4-
71-55-6	TRICHLOROETHANE, 1,1,1-
79-00-5	TRICHLOROETHANE, 1,1,2-
79-01-6	TRICHLOROETHYLENE
95-95-4	TRICHLOROPHENOL, 2,4,5-
88-06-2	TRICHLOROPHENOL, 2,4,6-
93-76-5	TRICHLOROPHENOXYACETIC ACID, 2,4,5- (2,4,5-T)
93-72-1	TRICHLOROPHENOXYPROPIONIC ACID, 2,4,5- (2,4,5-TP)
96-18-4	TRICHLOROPROPANE, 1,2,3-
96-19-5	TRICHLOROPROPENE, 1,2,3-
1582-09-8	TRIFLURALIN
99-35-4	TRINITROBENZENE, 1,3,5-
479-45-8	TRINITROPHENYLMETHYLNITRAMINE, 2,4,6- (TETRYL)
118-96-7	TRINITROTOLUENE, 2,4,6- (TNT)
7440-62-2	VANADIUM
75-01-4	VINYL CHLORIDE
1330-20-7	XYLENES
7440-66-6	ZINC