



Soil Cleanup Levels

In its 2000 session, the Wyoming Legislature created new opportunities, procedures, and standards for voluntary remediation of contaminated sites. These provisions, enacted as Articles 16, 17, and 18 of the Wyoming Environmental Quality Act and implemented by the Wyoming Department of Environmental Quality (DEQ), will govern future environmental cleanups in Wyoming.

The cleanup level look-up table provides a simple, easy-to-use method to evaluate whether site soil contamination is present at a level that may require further evaluation and/or remediation for protection of human health. This fact sheet describes how the soil cleanup values in the table were derived and presents general instructions for its use.

1. What is the cleanup level look-up table and where can I find it?

The soil portion of the cleanup level look-up table is a list of chemicals with precalculated screening levels based on: (1) direct contact with soil (which includes ingestion, skin contact, and inhalation) and, (2) the potential for soil contamination to migrate to groundwater. The look-up table provides a simple, easy-to-use method to evaluate whether site soil contamination is present at a level that may require further evaluation and/or remediation for protection of human health. If Volunteers choose to use the look-up table for default values rather than calculating site-specific residential soil and migration to groundwater cleanup values, the default values in the lookup table will function as the cleanup values for the site rather than as screening levels. The cleanup level look-up table is available in a spreadsheet and PDF format at <http://deq.wyoming.gov/shwd/voluntary-remediation-program/resources/fact-sheets/> under the tabs entitled Combined Cleanup Levels, Soil Cleanup Levels, and Groundwater Cleanup Levels, and is derived from EPA Region 9 Regional Screening Levels (RSLs), EPA Soil Screening Guidance, and EPA's EPI software suite. The EPI software suite is free and available at <http://www.epa.gov/opptintr/exposure/pubs/episuite.htm>. The RSLs are also sometimes referred to as Preliminary Remediation Goals (PRGs) on the EPA Region 9 website and are available on the Region 9 website at <http://www.epa.gov/region9/superfund/prg/index.html>.

2. What cleanup levels are included in the cleanup level look-up table?

The cleanup level look-up table includes a precalculated residential soil cleanup level for each chemical, and a precalculated migration to groundwater cleanup value for certain common, selected chemicals.

In the "residential contact" column, the soil cleanup level is based on direct human contact with soil, assuming no restrictions are placed on use of a site. Under the assumption of no site use restrictions, the most conservative type of exposure (i.e., the type of exposure that could result in the highest level of contact with the chemical) generally is a residential exposure scenario.

In the "migration to groundwater DAF = 1" column, the soil cleanup level is based on an assumption that a certain amount of the chemical will migrate through soil to the underlying groundwater. In this case, the

soil cleanup level is based on the amount of the chemical in groundwater that is acceptable either from a human health risk standpoint, assuming that groundwater will be used as a source of drinking water, or if a MCL for that contaminant has been established. The DAF is the dilution attenuation factor, which is defined as the ratio of soil leachate concentration to the underlying aquifer concentration within the source zone. Use of a DAF value of 1 assumes that no dilution occurs when the leachate enters the receiving aquifer.

The cleanup levels for one group of chemicals listed on this table (the petroleum products: gasoline, diesel, and crude oil) were derived using a modification of the methods previously described. Cleanup levels in the look-up table for gasoline, diesel, and crude oil were derived using methods outlined in the DEQ total petroleum hydrocarbons (TPH) soil cleanup guidance document: Cleanup Levels for Total Petroleum Hydrocarbons in Soil and Groundwater (see Appendix A), which is attached to this fact sheet.

3. How do I use the cleanup level look-up table?

The cleanup level look-up table provides conservative risk-based screening levels for all VRP sites, and conservative, risk-based cleanup levels for sites that meet all of the following criteria:

- Relatively few contaminants.
- No use control areas.
- Qualification for an ecological risk assessment exclusion based on completion of the VRP preliminary ecological exclusion assessment (Step 1) and/or the ecological scoping assessment (Step 2), as described in Fact Sheet #14 *Ecological Risk Assessment Steps 1 and 2 Ecological Exclusion and Scoping Assessments*.

The table was designed to accomplish two purposes. First, to provide a Volunteer who has adequately characterized a site a way to determine if present chemical concentrations indicate the need for further site evaluation and/or remediation (i.e., screening). Second, to provide Volunteers who are in the process of remediation a risk-based cleanup level that, if achieved, is likely to satisfy remediation requirements. Although the table is made up of precalculated cleanup levels, to appropriately apply those levels to a site you will need site-specific information. In particular, you will need site-specific information on the number of contaminants present in soil, and the range of contaminant concentrations observed. If you are addressing inorganic chemicals and wish to use natural background concentrations to establish cleanup levels, information on natural background concentrations will also be required. For more information on determining natural background concentrations, please see Fact Sheet #24 *Establishing Site-Specific Background Metals Concentrations in Soil* and also Fact Sheet #12 *Technical Memorandum #2*, which describes the potential use of statewide background values.

4. Which of the two soil look-up table values should I use?

In general, you should use the lower of the two values. In most cases, the cleanup level based on protection of groundwater is lower than the cleanup level based on direct human contact. If a chemical is present at your site, but does not have a precalculated migration to groundwater default value, the VRP requires that one be calculated using Equation A or B, as applicable and as described in the Technical Support Memorandum *Development of Migration to Groundwater Cleanup Levels, (Technical Support Memorandum)* June 2013. If a Volunteer demonstrates that groundwater is not present at a site, or that groundwater is not potentially impacted, then residential (direct human contact) soil cleanup levels apply.

5. What if I think the table values are too low for my site?

If you believe the soil values in the cleanup level look-up table are too low or otherwise not appropriate for your site, you can work with the DEQ to develop site-specific risk-based screening and cleanup levels. Note that site-specific cleanup levels must achieve the same risk reduction goals that were used to develop the table values; however, they may be different from table values due to use of actual site exposure or other factors rather than the conservative assumptions used to calculate table values. Volunteers who want to develop site-specific cleanup levels (rather than use the table values) should work with the DEQ to ensure that their site-specific methodology will be approved.

In addition, the DEQ has developed guidance on using site-specific parameters (rather than the default parameters used for the pre-calculated cleanup levels) to calculate site-specific, risk-based cleanup levels for both protection of human health (Fact Sheet #20 *Human Health Risk Assessment*) and groundwater (Fact Sheet #25 *Using Fate and Transport Models to Evaluate Cleanup Levels*). These fact sheets are posted on the VRP website at <http://deq.wyoming.gov/shwd/voluntary-remediation-program/>

6. Can I use the cleanup level look-up table for soils if my site has more than one contaminant?

Yes, however, you may need to adjust the look-up table values to account for the range of contaminants at your site.

It is important to understand that the cleanup levels based on direct human contact in the table use the entire “risk allowance” allowed under the VRP for site risk for each individual chemical. That is, the “residential contact” table values for each chemical are based on a one-in-one-million cancer risk for carcinogens and a hazard index of 1.0 for noncarcinogens, assuming that only a single chemical is present. Therefore, if there is more than one chemical contaminant at a site, the individual cleanup levels listed in the table must be adjusted to reallocate this “risk allowance” over the actual number of chemicals (and specific chemicals) present. The method for evaluating multiple contaminants and reallocating the site risk allowance is presented later in this fact sheet. However, if soil cleanup levels based on protection of groundwater are determined to be the appropriate levels for a site (see question 14), further evaluation to account for the presence of multiple contaminants is not necessary because of the conservative basis of these cleanup levels.

7. How do I develop site-specific contaminant levels to compare to the table values?

You develop site-specific contaminant levels to compare to the table values through sampling, testing and analysis carried out as part of site characterization.

Adequate site characterization is necessary before site-specific data can be compared to table values. Once the nature and extent of contamination at a site has been adequately characterized, the maximum detected value should be used for comparison to the table. In certain cases, risk assessment may be necessary; contact your DEQ project manager for further information. The table values must be met to a depth of 12 feet below ground surface, which is considered the maximum depth that will be excavated under conditions of residential land use.

Inorganic chemicals are naturally present in soil. Chemicals such as arsenic and selenium may be naturally present in Wyoming soil at levels above table values. For sites with metals contamination, it will be important to know the range of naturally occurring background concentrations so that cleanup levels can be adjusted accordingly. Under the VRP, cleanup is not required below naturally occurring background levels. However, to clean up to site-specific natural background levels above table values, Volunteers will have to work with the DEQ to calculate a site specific natural background level. For more information on assessing background, please refer to Fact Sheet #24 *Establishing Site-Specific Background Metals Concentrations in Soil* and also *Fact Sheet #12 Technical Memorandum #2*, which describes the potential use of statewide background values.

8. How were the chemicals in the look-up table chosen?

The cleanup level look-up table includes chemicals for which the U.S. Environmental Protection Agency (EPA) has approved a toxicity criterion, and the list of chemicals represents the most commonly encountered chemicals found at most VRP sites during environmental sampling. A toxicity criterion is a measure that relates the potential human exposure of a chemical to a health effect. Because a toxicity criterion has been developed, a screening level or cleanup level for the chemical in soil can be calculated. If a contaminant is not listed in the look-up table, refer to Section 12 in this document, or contact the VRP for further information.

The chemicals in the table are presented alphabetically by the common name for the individual chemical and grouped by major types of chemical compounds (e.g., polychlorinated biphenyls (PCBs)). Since a chemical may be called by multiple names (e.g., trichloroethylene, trichloroethene, and TCE are all the same chemical), the list also includes the chemical abstracts number (CAS number) for the constituent, which is unique for each individual chemical.

9. How were the soil cleanup levels calculated?

The cleanup levels in the “residential contact” column are based on direct contact of humans with soil. They were calculated using the EPA-approved toxicity criterion for the individual chemical and an exposure intake equation. An assumed acceptable level of risk (an excess upper-bound lifetime cancer risk of one-in-one million for carcinogenic chemicals, or a Hazard Index of 1.0 for noncarcinogenic chemicals) is assumed in the calculation, and the chemical concentration in soil that would result in that default risk level through exposure as defined by the equation is calculated.

Depending on the physiochemical qualities of the chemical (such as its volatility or ability to penetrate the skin), the soil cleanup level calculated includes consideration of the soil ingestion, dermal contact, and inhalation (volatile and particulate) exposure pathways. If toxicity criteria were available for an individual constituent for both carcinogenic and noncarcinogenic health effects, the more conservative (lower) cleanup level was calculated, which in most cases would be the cleanup level based on the carcinogenic health effects, and is presented in the table.

This method of calculating the cleanup level look-up table values based on direct human contact was selected because it establishes a cleanup level for an individual constituent that would be considered safe under most land use conditions, using calculation methods that have been reviewed by qualified technical experts and are widely accepted. The exposure equations and parameter assumptions used in these calculations are identical to those used by EPA Region 9 in their RSLs table. Background information on the equations and parameter values used are available at the EPA Region 9 website <http://www.epa.gov/region9/superfund/prg/index.html>.

The cleanup levels in the “migration to groundwater DAF=1” column are based on protection of groundwater. They are calculated using EPA’s Soil Screening Guidance equation, a simple linear equilibrium soil/water partition equation to estimate contaminant release in soil leachate (see Equations A and B in the Technical Support Memorandum). It also uses a dilution factor of one, which assumes no reduction of soil leachate concentration from mixing in an aquifer and no reduction from attenuation as leachate moves down through soil to the groundwater table. This mathematical model is used with an assumed acceptable concentration of the chemical in groundwater (assuming the water is used as a source of drinking water) to calculate a concentration of the constituent in soil that could contribute to that established safe concentration in groundwater. This method of calculating the soil cleanup level look-up table values based on migration of the chemical to groundwater was selected because it establishes a screening level for an individual constituent that would be considered safe if groundwater is used as a source of drinking water, using calculation methods that have been reviewed by qualified technical experts and are widely accepted. The equilibrium model used in these calculations is the model presented in EPA’s *Soil Screening Guidance: User’s Guide* (EPA, 1996).

Other acceptable approaches for determining site-specific leaching criteria are discussed in Fact Sheet #25 *Using Fate and Transport Models to Calculate Site-Specific Soil Cleanup Levels*. In addition, the Volunteer can propose an approach not specifically outlined in these fact sheets.

10. How often will the soil cleanup levels be updated and what impact will updated levels have on the remedy selection process?

As mentioned previously, cleanup level look-up table values are derived from EPA Region 9 RSLs. EPA Region 9 anticipates updating the RSLs semi-annually. The DEQ plans to update its table whenever the EPA Region 9 RSLs are updated, but Volunteers always have the ability to bring new information to the DEQ’s attention.

If the values in the table are updated during the remedy selection process (e.g., prior to remedy decision), the DEQ may require that updated values are taken into consideration and incorporated into the information used to determine remedial alternatives. However, cleanup goals already established in a Remedy Agreement or other enforceable administrative mechanism may not be revised without modification to the Remedy Agreement or mechanism.

11. Why are there no industrial cleanup levels on the table?

Industrial cleanup levels and other cleanup levels that are based on assumptions that restrict use of a site require review by the DEQ and by local governments. These types of cleanup levels and related land use decisions are site-specific and are not appropriate for a look-up table.

If you believe that land use restrictions are appropriate for your VRP site, you should contact your local government decision-making body to begin discussions of a use control area. Use Control Areas (UCAs) are put in place by local governments to limit the types of activities (i.e., land uses) that may occur on a site. In general, a UCA must be in place, approved by a local government, before the DEQ can enter into a remedy agreement that includes cleanup levels based on restricted site uses (e.g., industrial cleanup levels). The DEQ has developed standard exposure assumptions for sites where use is restricted to industrial activities. For more information on these standard assumptions and on restricted use cleanup levels and UCAs, contact the DEQ or refer to Fact Sheet #23 *Institutional Controls, Engineering Controls, and Use Control Areas*.

12. What do I do if a chemical that I have on my site is not in the table?

If a chemical is present on your site as a contaminant and a cleanup value is not provided on the table, you may (1) refer to the EPA Region 9 RSL Table to locate residential soil cleanup levels for that chemical; (2) if site specific information exists for your site, develop cleanup levels protective of groundwater for your specific site using a fate and transport model approved by the DEQ as described in Fact Sheet #25 *Using Fate and Transport Models to Evaluate Cleanup Levels*; or (3) use the information in the Technical Support Memorandum if no specific site specific information is available.

In addition, regardless of the method used for development of cleanup levels, the levels must be protective of ecological receptors as described in Fact Sheet #14 *Ecological Risk Assessment*. Before beginning, contact your DEQ Project Manager to discuss the method to use to develop cleanup levels at your site.

13. What do I do if multiple contaminants are present at my site?

The cleanup level look-up table can also be used as a tool to determine if a site with multiple chemical contaminants represents a potential human health risk that requires further evaluation or if the site can be determined to not represent a potential human health risk. It should be noted, however, that consideration of multiple contaminants should also include evaluation of soil cleanup levels protective of groundwater if a potential threat to groundwater is present. If soil cleanup levels based on protection of groundwater are determined to be the appropriate levels for a site, further evaluation to account for the presence of multiple contaminants is not necessary because of the conservative basis of these cleanup levels.

Under the VRP, risk-based cleanup levels must ensure that the upper bound of lifetime cancer risk to any exposed individual will not exceed a probability of developing cancer of one-in-one million (1×10^{-6}) to one-in-ten thousand (1×10^{-4}), with the one-in-one million risk level used as a point of departure or target risk goal. For chemicals that are non-carcinogens, the risk-based cleanup standard is to be based on a Hazard Index of 1.0. Each individual soil cleanup level provided in the "residential contact" column of the table is based on use of the entire site "risk allowance" preferred under the VRP. This means that, if the contaminant is a known or potential human carcinogen, the soil cleanup level presented in the table is based on an excess lifetime cancer risk of one-in-one million. If the chemical is a noncarcinogen, the soil cleanup level presented in the table is based on a Hazard Index of 1.0. Therefore, if you have multiple contaminants at your site, the soil cleanup levels presented in the "residential contact" column of the table cannot be used "as is," but must be adjusted to account for contribution to total risk from more than one chemical.

For the purpose of using the cleanup level look-up table to determine if chemical levels are below levels that would require further evaluation when multiple chemical contaminants are present, the DEQ has established the following procedures. Note that these procedures are oriented around achieving a total site risk for carcinogenic chemicals that is no more than one-in-one million, and a total site risk from noncarcinogens that is no more than a Hazard Index of 1.0 using standard, conservative exposure and fate and transport assumptions. As discussed in Fact Sheet #11 *Risk Assessment*, under certain circumstances, in the context of an evaluation of remedial alternatives and/or a site-specific risk assessment, the DEQ may approve remedies that do not achieve the risk goal of one-in-one million for all carcinogens and may approve alternative, site specific, exposure or fate and transport assumptions. If you are interested in this approach, you should contact your DEQ project manager.

To use the cleanup level look-up table (available at the “Combined Cleanup Levels” tab in the spreadsheet located at: <http://deq.wyoming.gov/shwd/voluntary-remediation-program/resources/fact-sheets/>) for multiple contaminants in soils, complete the following steps.

1. If the detection limit for an individual contaminant is at least as low as the cleanup level presented in the cleanup level look-up table for that contaminant and the detected concentration of the contaminant is below the table value, no further evaluation of that contaminant is necessary, assuming that adequate site characterization has been completed.
2. If the contaminant concentration is below the migration to groundwater value, then the contaminant is eliminated from further consideration in the multiple contaminant evaluation.
3. If chemicals are detected above the detection limits, carcinogenic and noncarcinogenic chemical contaminants will be evaluated separately.
4. For non-carcinogens and carcinogens, if any detected chemicals have a maximum detected concentration greater than their corresponding cleanup level look-up table value, further evaluation using site-specific risk assessment may be necessary.
5. For noncarcinogens, if more than one chemical is determined to be present and detected compounds are below cleanup level look-up table values but above the detection limits, the process outlined in the next section must be completed to determine if multiple chemicals could result in exceedance of the allowed Hazard Index of 1.0. If the multiple chemical evaluations indicate exceedance of a Hazard Index of 1.0, further evaluation using site-specific risk assessment may be necessary. If the multiple chemical evaluations indicate that the Hazard Index is less than 1.0, no further evaluation of noncarcinogens is necessary.
6. For carcinogens, if more than one chemical is determined to be present and detected compounds are below cleanup level look-up table values but above the detection limits, the process outlined in the next section must be completed to determine if multiple contaminants could result in exceedance of a cumulative cancer risk of one-in-one million. If the multiple contaminant evaluation indicates exceedance of a cancer risk of one-in-one million, further evaluation using site-specific risk assessment may be necessary. If the multiple chemical evaluations indicate that the cancer risk is less than one in one million, no further evaluation of carcinogens is necessary.

Evaluation Process for Multiple Contaminants

Contaminants in soil are evaluated on the basis of detection limits, background, and risk, as described below, to determine whether the total contaminant contribution to risk is high enough to require future evaluation of site conditions through site-specific risk assessment.

1. **Frequency of Detection.** Contaminants that are infrequently detected may be artifacts in the data due to sampling, analytical, or other errors. Contaminants detected in less than five percent of the soil samples need not be included in this evaluation process. Note that this assumes that detection limits are below the cleanup levels for both ecological and human health purposes and that adequate sampling has occurred.
2. **Background Concentration.** If the maximum detected concentration of a naturally-occurring contaminant is less than or equal to the concentration selected as a background value (derived from site-specific sampling as required by the DEQ, or through DEQ approval to use statewide background values as described in *Fact Sheet #12 Technical Memorandum #2*), it need not be selected for inclusion in this evaluation process. Note that the concept of background does not apply to anthropogenic (human-caused) inorganic or organic contaminants.

3. **Concentration-Risk Evaluation.** Any evaluation must take into consideration the potential for risk to be posed by exposure to individual contaminants or multiple contaminants simultaneously.
- Divide the detected chemicals into two groups: carcinogens and noncarcinogens.
 - Any individual contaminant in soil with $R_i > 1$, would require further evaluation, potentially through a site-specific risk assessment.

$$R_i = C_i / CTV_i$$

Where: R_i is the risk posed by contaminant "i"; C_i is the maximum concentration of contaminant "i" in soil, in mg/kg; and CTV_i is the soil cleanup level provided on the cleanup level look-up table, in mg/kg

- For multiple contaminants in soil, if the sum of the individual R_i values (R_i) > 1 , further evaluation would be required, potentially through site-specific risk assessment.

Note that prior to evaluation, concentrations of dioxins and furans may be adjusted using appropriate toxicity equivalency factors (TEF) [see EPA (2010) for further information]. If a soil cleanup level is not provided for a given contaminant, that contaminant must be identified and the DEQ consulted to identify next steps in the evaluation.

A hypothetical example of how the concentration risk evaluation process operates is provided in the attached Tables 1 and 2. Several chemicals evaluated in these examples do not appear in the 2013 VRP cleanup lookup table, but default values were obtained from the EPA Region 9 website at <http://www.epa.gov/region9/superfund/prg/>.

It should be noted that for both noncarcinogens and carcinogens, it is possible for a situation to exist where concentrations of individual chemicals in soil are all below their respective screening levels, but when considered collectively, the total hazard index value (for noncarcinogens) exceeds 1.0 or the total excess cancer risk (for carcinogens) exceeds one-in-one million. In these cases, the Volunteer should meet with the DEQ prior to initiating a site-specific risk assessment.

Consideration of Chemical Toxic Endpoint

If further evaluation is indicated to be necessary after conducting the multiple chemical analyses, the Volunteer may choose to conduct an interim step prior to starting a site-specific risk assessment, which involves identifying the basis of the toxicity criteria used to calculate the soil cleanup levels (e.g., contaminant toxicity to target organs). Additional information can be found in Fact Sheet #20 *Human Health Risk Assessment*.

14. What if the table values are below analytical reporting limits?

Often, more than one method is available for analyzing a sample for a specific constituent or group of constituents. The VRP requests that method detection limits (MDLs) be used to report data in the screening phase of site investigation. MDLs are always lower than reporting limits and are statistically derived for each laboratory. However, because the MDL is below the initial calibration curve, any concentration above the MDL but below the reporting limit is only an estimate. Typically, concentrations below the reporting limit should not be reported by the laboratory unless they are qualified as estimated values. MDLs should not be confused with reporting limits.

The analytical method should be selected based on reasonably achieving the lowest reporting limit relative to the VRP screening levels that can be obtained by that method. Efforts should be made to ensure that reporting limits are not greater than VRP screening levels for protection of human health, groundwater, and ecological receptors (see additional Fact Sheets #13 and #14). Reporting limits vary between laboratories and instruments. Typically, a reporting limit represents the lowest point of the initial calibration curve for a particular analysis and instrument.

Reporting limits for an analytical method may vary significantly among laboratories. Therefore, if reporting limits at or below VRP screening levels cannot be achieved by a given laboratory, reporting limits available from other methods and/or laboratories should be evaluated. Additionally, more than one method may be available to analyze for a compound or group of compounds. If choosing another laboratory or an alternative analytical method does not result in low enough reporting limits, the issue should be discussed with the DEQ project manager. The DEQ project manager may recommend using a surrogate compound for comparison to VRP screening levels or may allow use of the reporting limit as the screening level. Contaminants for which reporting limits are greater than screening levels should be specifically identified in the sampling and analysis plan.

In certain cases, a reporting limit may be raised during analysis of a project sample. The raised reporting limit is often due to matrix interferences or required dilutions during analysis. Raised reporting limits should be discussed with the DEQ project manager.

15. What if site concentrations exceed table values?

If a Volunteer finds that site concentrations exceed cleanup level look-up table values, cleanup to those values is not the only option. In those cases, the Volunteer may choose to follow any or all of the following options:

- Complete a site-specific risk assessment for the site to calculate risk under conditions of unrestricted use (generally residential). The results would then be compared to the acceptable risk limits established by the regulations to determine whether further action is necessary. A work plan and final document would be needed to complete this task, and both documents would require DEQ approval.
- For sites where soil cleanup levels based on direct human contact will not be met, you may be able to negotiate a remedy agreement with an associated use control area with the DEQ, which would allow for alternative, higher cleanup levels with access controls. For more information on use control areas, refer to Fact Sheet #23 *Institutional Controls, Engineering Controls, and Use Control Areas*.
- Cleanup the site to meet unrestricted use table values (residential soil look-up table values).

16. How do I get more information on the Voluntary Remediation Program?

To learn about VRP sites that may exist in your community, obtain copies of other VRP fact sheets/guidance documents, get answers to your questions, or volunteer for the program, contact the DEQ at (307) 777-7752 or through the VRP website at: <http://deq.wyoming.gov/shwd/voluntary-remediation-program/>.

The VRP website includes all of the fact sheets and other guidance documents for the VRP. This website is updated frequently and includes the latest information about the DEQ's progress in developing guidance, policy, and other supporting documents for the VRP.

17. References

For additional information regarding screening levels, the Volunteer is referred to the following documents.

Amherst Scientific Publishers, 1997, Total Petroleum Hydrocarbon Criteria Working Group Series, Volumes 1-5, Amherst, MA

EPA, 1996. Soil Screening Guidance: User's Guide. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency. EPA Publication 9355.4-23. July 1996.
<http://www.epa.gov/superfund/resources/soil/ssg496.pdf>.

EPA, 2010. Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin and Dioxin-Like Compounds. EPA/100/R 10/005. December 2010. <http://www.epa.gov/raf/hhtefguidance/>.

EPA Region IX Superfund Preliminary Remediation Goals (PRG) Website,
<http://www.epa.gov/region9/superfund//prg/index.html>.

Table 1. Example of Evaluation of Multiple Noncarcinogenic Contaminants in Soil

Soil Example A				Further Evaluation Needed? (is $R_i > 1$?)
Chemical Contaminant	CTVi	Ci	Ri (Ci/CTVi)	
1 Acetone	6.10E+04	1.80E+05	2.95E+00	yes
2 Barium	1.50E+04	1.80E+04	1.20E+00	yes
3 Benzyl alcohol	6.10E+03	6.19E+04	1.00E+01	yes
4 Acrolein	1.50E-01	7.41E-02	4.94E-01	no
5 Hexabromobenzene	1.20E+02	7.68E+01	6.4E-01	no
6 Hexachlorophene	1.80E+01	2.03E+01	1.1E+00	yes
7 Mercury (methyl)	7.80E+00	5.92E+00	7.59E-01	no
8 Methyl acrylate	1.50E+02	4.90E-01	2.13E-04	no
9 2-nitroaniline	6.10E+02	2.10E+03	1.17E+01	yes
10 Perchlorate	5.50E+01	2.77E+01	5.04E-01	no
Rj			2.13E+01	
Ni			10	
Notes CTVi Soil cleanup level for noncarcinogenic contaminant based on direct human contact Ci Maximum detected concentration of noncarcinogenic contaminant in soil Ri Ratio of Ci/CTVi Rj Sum of individual Ci/CTVi ratios Ni Number of noncarcinogenic contaminants detected				
Soil Example B				Further Evaluation Needed? (is $R_i > 1$?)
Chemical Contaminant	CTVi	Ci	Ri (Ci/CTVi)	
1 Acetone	6.1E+04	1.40E-04	2.30E-09	no
2 Aluminum	7.7E+04	5.70E+01	7.40E-04	no
3 Butylate	3.1E+03	1.35E+00	4.35E-04	no
4 Carbofuran	3.1E+02	6.80E-01	2.19E-03	no
5 Dichlorodifluoromethane	9.4E+01	4.97E-01	2.62E-03	no
6 Methanol	3.4E+04	3.00E-03	9.68E-08	no
7 p-Xylene	4.7E+03	4.65E+02	9.89E-02	no
8 Triasulfaron	6.1E+02	1.70E+01	2.79E-02	no
9 1,2,4-Trichlorobenzene	2.2E+01	9.40E-01	1.08E-02	no
10 Vinyl acetate	9.9E+02	1.50E-04	1.52E-07	no
Rj			1.44E-01	
Ni			10	
Notes CTVi Soil cleanup level for noncarcinogenic contaminant based on direct human contact Ci Maximum detected concentration of noncarcinogenic contaminant in soil Ri Ratio of Ci/CTVi Rj Sum of individual Ci/CTVi ratios Ni Number of noncarcinogenic contaminants detected				

Table 2. Example of Evaluation of Multiple Carcinogenic Contaminants in Soil

Soil Example A				Further Evaluation
Chemical Contaminant	CTVi	Ci	Ri (Ci/CTVi)	Needed? (is Ri > 1?)
1 Acetaldehyde	1.10E+01	1.21E+01	1.1E+00	yes
2 Aniline	8.50E+01	1.70E+03	2.0E+01	yes
3 Benzyl chloride	1.10E+00	1.42E+00	1.29E+00	yes
4 Bis(chloromethyl)ether	7.70E-05	8.20E-05	1.06E+00	no
5 1,1-dimethylhydrazine	1.10E+00	2.66E+00	2.4E+00	yes
6 Heptachlor	1.10E-01	1.05E-01	9.5E-01	no
7 Arochlor 1221	1.70E-01	9.46E-01	5.56E+00	yes
8 Arochlor 1242	2.20E-01	2.20E-03	1.0E-02	no
9 Benzo[a]anthracene	1.50E-01	1.18E+01	7.87E+01	yes
10 Benzo[a]pyrene	1.50E-02	1.36E-01	9.07E+02	yes
Rj			4.04E+03	
Ni			10	
Notes				
CTVi	Soil cleanup level for carcinogenic contaminant based on direct human contact			
Ci	Maximum detected concentration of carcinogenic contaminant in soil			
Ri	Ratio of Ci/CTVi			
Rj	Sum of individual Ci/CTVi ratios			
Ni	Number of carcinogenic contaminants detected			
Soil Example B				
Chemical Contaminant	CTVi	Ci	Ri (Ci/CTVi)	Further Evaluation
1 Hydrazine	2.10E-01	1.52E-04	7.24E-04	no
2 Kepone	3.00E-02	1.84E-04	6.13E03	no
3 N-nitroso di-n-propylamine	6.90E-02	6.62E-04	9.6E-03	no
4 Arochlor 1254	2.20E-01	6.38E-03	2.9E-02	no
5 RDX	5.50E+00	1.01E-01	1.84E-02	no
6 2,4,6-trichlorophenol	4.40E+01	2.29E-01	5.2E-03	no
7 1,2,3-trichloropropane	9.10E-02	3.78E-06	4.15E-05	no
Rj			6.91E-02	
Ni			7	
Notes				
CTVi	Soil cleanup level for carcinogenic contaminant based on direct human contact			
Ci	Maximum detected concentration of carcinogenic contaminant in soil			
Ri	Ratio of Ci/CTVi			
Rj	Sum of individual Ci/CTVi ratios			
Ni	Number of carcinogenic contaminants detected			

Appendix A: Cleanup Levels for Total Petroleum Hydrocarbons in Soil and Groundwater

1. Basis

The total petroleum hydrocarbon (TPH) cleanup levels incorporate a human health risk assessment component and contaminant fate and transport mechanisms based on data and information contained in the:

- a. TPH Criteria Working Group Series, Volumes 3 - 5 (Amherst Scientific Publishers, 1997), and
- b. Soil Attenuation and the Modified Organic Soil Screening Level (SSL) Fate and Transport Models in Appendix A, VRP Fact Sheet #25 (Using Fate and Transport Models to Evaluate Cleanup Levels).

The TPH Working Group consisted of nationally recognized experts in petroleum remediation and was guided by a steering committee which included representatives from industry, government and academia.

2. Applicability of TPH Cleanup Levels

Types of Sites

The TPH cleanup levels in this document can be used at non-voluntary and voluntary remediation sites regulated by the Solid and Hazardous Waste Division. The TPH cleanup levels are not intended for use at sites with hydrocarbon contamination resulting from a Leaking Underground Storage Tank, as these sites are remediated by the Solid and Hazardous Waste Division Aboveground/Underground Storage Tank Program.

The Wyoming Oil & Gas Conservation Commission (OGCC) is the state agency responsible for regulatory oversight of oilfield activities, which includes seismic operations, drilling of wells, and oil and gas production operations. Under this scope of responsibility, the OGCC regulates wastes and releases that are both intrinsic to and uniquely associated with exploration, development, or production activities, and not as part of a transportation or manufacturing operation. The OGCC has regulatory requirements and standards that are different than the TPH cleanup levels in this document. Therefore, the TPH cleanup levels in this document will not be used and do not replace cleanup criteria for releases regulated by the OGCC. However, if parties responsible for releases regulated by the OGCC choose to pursue assurances from the DEQ which may be available through the VRP, then VRP requirements would be applicable, including the TPH cleanup levels herein.

The TPH cleanup levels in this document may not be protective of ecological receptors. Sites that do not screen out (e.g., ecological receptors are unlikely to be significantly exposed to site-related chemicals) after performing Step 2 of the Ecological Risk Assessment process (see Fact Sheet #14) and TPH is a contaminant of interest, should be discussed further with the DEQ.

Types of petroleum releases

The TPH cleanup levels are based on fraction specific petroleum hydrocarbons and are applicable to releases of materials which clearly correspond to one of the following categories:

- Gasoline and Condensate Range Organics (GRO): In general, includes C₄ through C₉ hydrocarbons
- Diesel Range Organics (DRO): In general, includes C₁₀ through C₂₄ hydrocarbons

- Crude Oil: In general, includes C₅ through C₃₄ hydrocarbons

This document contains TPH cleanup levels for each of these carbon fraction ranges, with the exception of the groundwater level which applies to hydrocarbons in both the diesel range and crude oil range.

The TPH cleanup levels are not applicable as the sole cleanup levels at sites with waste oil contamination, historic releases of an unknown petroleum substance, a release of a complex mixture of refined petroleum products, or a mixture of petroleum with listed hazardous wastes, among others.

Additional sampling requirements and cleanup levels may be applicable for gasoline range, diesel range and crude oil range contamination when using the TPH cleanup levels as final cleanup levels. This document outlines the minimum requirements, but additional requirements may be imposed by the DEQ project managers on a site specific basis. Many factors, including the nature of the hydrocarbon, age of the spill and site characteristics will be taken into consideration by the DEQ project managers when establishing additional requirements. For example, gasoline releases may require sampling for MTBE, in addition to BTEX, naphthalenes, and TPH GRO. Crude oil spills may require sampling for metals, TPH DRO, TPH GRO and possibly BTEX and naphthalenes. Complex mixtures of refined hydrocarbons will likely require sampling for volatile and/or semi-volatile organic compounds as well as inorganic compounds.

3. Summary Tables for Petroleum Hydrocarbon Contamination

Groundwater Cleanup Levels

Product	Parameter/Constituent	Cleanup Level
Gasoline	TPH GRO	6.6 mg/L ^b
	Naphthalene ^c	0.667 mg/L
	2-Methylnaphthalene ^c	0.133 mg/L
Diesel or Crude Oil	TPH DRO	1.0 mg/L ^{a,b}
	Naphthalene ^c	same as gasoline
	2-Methylnaphthalene ^c	same as gasoline

a. Cleanup level based on protection of groundwater for non-cancer effects during drinking water use (Drinking Water Equivalent Level equation, Wyoming Solid and Hazardous Waste Division Rules and Regulations, Chapter 1 Storage Tank Program, Storage Tanks [July 2018]). This level is applicable when naphthalene and/or methylnaphthalenes along with the other chemicals of concern in the TPH-DRO carbon range are detected in groundwater above MCL/DWEL (assuming that reporting limits are adequate in comparison to cleanup levels) OR when there is free product present on the groundwater table.

b. If DRO and GRO are present at a site, then DRO and GRO cumulative concentrations must be below 10,000 ug/L.

c. These constituents are required for confirmation sampling on a site specific basis as described in Section 4 of this Appendix. PAH cleanup levels are taken from the Cleanup Level Look-up Table.

TPH Cleanup Levels for Soil

Product	Parameter/Constituent	Cleanup Level
Gasoline	TPH GRO ^a	Default value is 59 mg/kg ^a
	TPH GRO ^b	Ranges from 59 mg/kg up to 15,600 mg/kg ^b
Diesel or Crude Oil	TPH DRO	2300 mg/kg ^c
Other constituents based on site specific circumstances; See Section 4		Lower of the human health and migration to groundwater, as tabulated in the VRP Soil Cleanup Level Look-Up Table

^a Cleanup levels are based on fate and transport evaluation for protection of groundwater to the TPH GRO groundwater level, and depend upon two site specific parameters: depth to seasonal high groundwater table and thickness of the contaminated zone. See Gasoline Range Organics Cleanup Levels Calculation in Section 5.2.1.

^b This range of cleanup values is available on a site-specific basis and is based on non-cancer effects of oral ingestion of contaminated soil and are also protective of human health; maximum concentration is 15,600 mg/kg, which is based on non-cancer effects of oral ingestion of contaminated soil. Soil cleanup levels for any carcinogenic components (for both human health and migration to groundwater) of the petroleum (such as benzene), if present at the site, must also be met. This determination will be based on site specific circumstances, such as age and level of weathering of petroleum contaminants, among others. Soil cleanup levels for noncarcinogens (such as toluene, ethylbenzene, xylene, and MTBE), may also need to be met if these substances are found to exceed groundwater cleanup levels at the site. See Section 4 for Summary of Testing for Petroleum Releases when using TPH Cleanup Levels.

^c Cleanup level based on non-cancer effects of oral ingestion of contaminated soil. This level is also protective of the groundwater to TPH DRO cleanup level. Soil cleanup levels for any carcinogenic components of the petroleum (such as benzene), if present at the site, must also be met. This determination will be based on site specific circumstances, such as age and level of weathering of petroleum contaminants, among others. Soil cleanup levels for noncarcinogens (such as toluene, ethylbenzene, xylene, and MTBE), may also need to be met if these substances are found to exceed groundwater cleanup levels at the site. See Section 4 for Summary of Testing for Petroleum Releases when using TPH Cleanup Levels.

NOTE: If all applicable contaminants of concern are below their respective soil cleanup levels (assuming adequate reporting limits), but TPH values are not, there are three possibilities under the Voluntary Remediation Program:

1. Establish a Use Control Area if applicable and appropriate (See VRP Fact Sheet #23 or talk to a DEQ VRP Project Manager for more information); or
2. Petition for a technical impracticability determination, if applicable and appropriate, (See VRP Fact Sheet #27 or talk to a DEQ VRP Project Manager for more information); or
3. TPH fractional analysis could be performed to establish what risk the remaining TPH above cleanup levels may pose. Talk to a DEQ VRP Project Manager if you are interested in pursuing this approach.

4. Summary of Testing for Petroleum Releases when using TPH Cleanup Levels

	Gasoline Range Organics (GRO) and condensate ⁽¹⁾	Diesel Range Organics (DRO) ⁽²⁾	Crude Oil	Waste Oils and Unknown Oils ⁽³⁾
Volatile Petroleum Compounds				
Benzene	X ⁽⁴⁾	X ⁽⁴⁾	X ⁽⁴⁾	T
Toluene	X ⁽⁴⁾	X ⁽⁴⁾	X ⁽⁴⁾	T
Ethyl benzene	X ⁽⁴⁾	X ⁽⁴⁾	X ⁽⁴⁾	T
Xylenes	X ⁽⁴⁾	X ⁽⁴⁾	X ⁽⁴⁾	T
Fuel Additives and Blending Compounds				
Methyl tertiary-butyl ether (MTBE)	T			T
Total lead and other additives	T ⁽⁷⁾	T ⁽⁷⁾		T
Other Petroleum Components				
Carcinogenic PAHs		T ⁽⁶⁾	T ⁽⁶⁾	T
Naphthalene and 2-Methylnaphthalene	X ⁽⁵⁾	X ⁽⁵⁾	X ⁽⁵⁾	T
Other Compounds				
Metals			T	T
Halogenated Volatile Organic Compounds (VOCs)				T
Other	T	T	T	T

Soil sampling results are to be compared to both the TPH cleanup levels and the Soil Cleanup Level Lookup Table for the Voluntary Remediation Program (for both human health and fate and transport).

An "X" in the box indicates that testing should be done for soil and groundwater if a release is known or suspected to have impacted that medium, unless otherwise specified in the footnotes. Note that testing for TPH GRO and/or TPH DRO should be done for every type of petroleum release depending on the type of petroleum product.

A "T" in the box indicates that testing for this parameter depends on site specific circumstances.

- The following petroleum products are examples of GRO: automotive and aviation gasolines, mineral spirits, stoddard solvents, and naphtha. Products such as jet fuel, diesel No. 1, kerosene, and heating oil may require analysis as both GRO and DRO.

2. The following petroleum products are common examples of DRO: Diesel No. 2, fuel oil No. 2, and light oil. This category may also include non-waste (i.e. unused) motor oils, lube oils, and hydraulic fluids. Products such as jet fuel, diesel No. 1, kerosene, and heating oil may require analysis as both GRO and DRO.
3. The waste oil category applies to waste oil, oily wastes, and unknown petroleum products, complex mixtures of refined petroleum products and mixtures of petroleum and non-petroleum substances. Analysis of chemical components (such as solvents) other than those listed may be required based on site specific information. Mixtures of identifiable petroleum products (such as gasoline and diesel) may be analyzed based on the presence of individual products and need not be treated as waste or unknown oils.
4. Testing groundwater for BTEX is required for both GRO and DRO when impacts to groundwater are known or suspected. If BTEX is found in groundwater, testing for BTEX in soil is likely required. Testing soil for benzene will likely be required for GRO and may be required for DRO; the soil cleanup level for any carcinogenic components of the petroleum (such as benzene), if present at the site, must also be met. Soil cleanup levels for noncarcinogens (such as toluene, ethylbenzene, xylene, and MTBE) may also need to be met if these substances are found to exceed groundwater cleanup levels at the site.
5. If naphthalene is found in groundwater, then soil should also be tested.
6. Testing for carcinogenic PAHs is likely to be required for DRO, except for the following products for which adequate information exists to indicate their absence: Diesel No. 1 and 2, home heating oil, kerosene, jet fuels, and electric insulating mineral oils. The carcinogenic PAHs include: benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(a)anthracene, and benzo(b)fluoranthene.
7. Sampling for lead is likely to be required when leaded gasoline products are or were present at a site.

5. Calculations

TPH Cleanup Levels for Groundwater

Because federal drinking water Maximum Contaminant Levels do not exist for the TPH parameter, the following procedures and calculations establish fraction specific TPH cleanup levels based on toxicological data from the TPH Criteria Working Group and the risk assessment Drinking Water Equivalent Level equation contained in Wyoming Solid and Hazardous Waste Division Rules and Regulations, Chapter 1 Storage Tank Program, Storage Tanks.

5.1.1 Calculation of TPH Groundwater Cleanup Levels

The following calculation is based on protection of human health for non-cancer effects when groundwater is used for drinking water:

$$DWEL = (RfD)(ABW)(HQ)/(DWI)(AB)(FOE)$$

where:

DWEL = Wyoming Drinking Water Equivalent Level, mg/L

RfD = Reference Dose, mg/kg/day

ABW = Average Body Weight, Adult, kg =

80

HQ = Hazard Quotient =

1

DWI = Drinking Water Intake, L/day =

2.5

AB = Absorbed Dose Fraction =

1

FOE = Frequency of Exposure, (350 days/365 days) =

0.96

The following parameters are from Volume 4 of the Total Petroleum Hydrocarbon Criteria Working Group Series, Development of Fraction Specific Doses (RfDs) and Reference Concentrations (RfCs) for Total Petroleum Hydrocarbons (TPH), (Amherst Scientific Publishers, 1997):

GRO C₅ - C₈ petroleum hydrocarbons:

RfD_{0,GRO} = 0.2 mg/kg/day (worst case)

DRO: C₉ - C₃₄ petroleum hydrocarbons:

RfD_{0,DRO} = 0.03 mg/kg/day (worst case)

Calculate **worst** case GRO and DRO fraction TPH groundwater level:

Gasoline Range Organics:

DWEL_{o,GRO} = 6.6 mg/L

Diesel Range Organics:

DWEL_{o,DRO} = 1.0 mg/L

TPH Cleanup Levels for Soil

The following methodology is applicable for calculating TPH soil cleanup levels only. For information on how to calculate soil cleanup levels for specific contaminants, see Fact Sheet #25, *Using Fate and Transport Models to Evaluate Cleanup Levels*.

5.2.1 Calculation of Gasoline Range Organics TPH Soil Cleanup Levels

Fate and Transport Calculation: Gasoline range petroleum is a complex mixture of hydrocarbon compounds. The following physical and chemical properties of petroleum hydrocarbons have been taken from Table 3, Volume 3, Selection of Representative TPH Fractions Based on Fate and Transport Considerations from the TPH Criteria Working Group Series (Amherst Scientific Publishers, 1997). This soil remediation level includes those primary hydrocarbons with weight percentage compositions greater than 0.1%. All weight percentages have been rounded off to the nearest 0.1%. The Fate and Transport Evaluation Table and calculations follow:

GRO TPH Fate and Transport Evaluation Table

Compound Class	Carbon Number	Compound	Wt %	K _{oc}	Wt%(K _{oc})	H'	Wt%(H')
n-Alkanes	4	n-butane	4.7	341	1603	3.87E+01	182
	5	n-pentane	10.9	1358	14802	5.17E+01	564
	6	n-hexane	3.5	3830	13405	7.39E+01	259
	7	n-heptane	2	48195	96390	8.43E+01	169
Branched alkanes	5	iso-pentane	10.2	900	9180	1.93E+02	1969
	6	methylpentanes	6.2	3830	23746	7.11E+01	441
	7	methylhexanes	3.2	697	2230	1.40E+02	448
	7	dimethylpentanes	5.9	6699	39524	1.29E+02	761
	8	trimethylpentanes	9.4	3830	36002	1.24E+02	1166
	8	methylheptanes	2.1	30409	63859	1.41E+02	296
Alkenes	5	pentenes	2	304	608	1.63E+01	33
Branched alkenes	5	methylbutenes	2	221	442	2.21E+01	44
Alkyl - aromatics	6	benzene	3.5	65	228	2.25E-01	0.788
	7	toluene	21.8	240	5232	2.74E-01	5.97
	8	ethylbenzene	2.9	681	1975	3.58E-01	1.04
	8	xylene	8.4	697	5855	2.95E-01	2.48
	9	trimethylbenzenes	1.3	2150	2795	3.15E-01	0.41
Totals			100		3.18E+5		6.34E+03
Weighted averages				3.18E+03		6.34E+1	

The weighted averages for K_{oc} and H' derived from this analysis were then used with the following two equations from VRP Fact Sheet #25 (Using Fate and Transport Models to Evaluate Cleanup Levels) to calculate the soil cleanup level for TPH GRO.

Soil Attenuation Model Equation

$$C_{w2} \text{ (mg/L)} = C_{w1} \times \frac{L_2}{L_1} \quad \text{(Equation 1 in VRP Fact Sheet \#25)}$$

Soil Attenuation Model Input Parameters

Parameter/Definition (units)	Site-Specific	Default
C_{w1} concentration of COC in soil leachate discharged to underlying water-bearing unit (mg/L)	NA	6.6
C_{w2} initial soil-water leachate concentration (mg/L) prior to adjustment for soil attenuation (the target soil-water leachate concentration)	-	-
L_1 thickness of affected soil zone (cm)	allowed	152
L_2 distance from top of affected soil zone to top of water bearing unit (cm)	allowed	152

Modified Organic Soil Screening Level (SSL) Fate and Transport Model Equation

$$C_t = C_{w2} \left\{ (K_{oc} f_{oc}) + \frac{\theta_w + \theta_a H'}{\rho_b} \right\} \quad \text{(Equation 3 in Fact Sheet \#25)}$$

Parameter/Definition (units)	Default
C_t cleanup level in soil (mg/kg)	-
C_{w2} target soil-water leachate concentration (mg/L)	Use value calculated from Equation 1
K_{oc} soil organic carbon-water partition coefficient (L/kg)	3180
f_{oc} organic carbon content of the soil (kg/kg)	0.001 (0.1%)
θ_w water-filled soil porosity (L_{water}/L_{soil})	0.3 (30%)
θ_a air-filled soil porosity (L_{air}/L_{soil})	0.13
n total soil porosity (L_{pore}/L_{soil})	$1 - \frac{\rho_b}{\rho_s} = 0.43$
ρ_b dry soil bulk density (kg/L)	1.5
ρ_s soil particle density (kg/L)	2.65

H' dimensionless Henry's law constant	63.4
---------------------------------------	------

A spreadsheet calculator is provided with VRP Fact Sheet #25, on the VRP website at <http://deq.wyoming.gov/shwd/voluntary-remediation-program/> that can be used to determine the TPH GRO soil cleanup level for any depth from the contaminated zone to the seasonal high groundwater table.

The following is a sample calculation using the VRP Fact Sheet #25 spreadsheet calculator:

Calculate using GRO groundwater level of 6.6 mg/L

$C_t = C_{soil} = 59 \text{ mg/kg}$

Human Health Risk Assessment Calculation: The following calculation (equation from Volume 5, Human Health Risk-Based Evaluation of Petroleum Release Sites from the TPH Criteria Working Group Series (Amherst Scientific Publishers, 1997)) is based on protection of human health for non-cancer effects from oral ingestion of soil:

$$C_{soil} = (RfD)(ABW_2)(UCF)(HQ)/(SIR_2)(AB)(FOE)$$

where;

RfD = TPH Reference Dose, mg/kg-day

RfD_{o,GRO} = (worst case), oral ingestion, mg/kg-day, GRO: C₅ - C₈ 0.2

ABW₂ = Average Body Weight, Child, kg 15

UCF = Unit Conversion Factor, mg/kg 1000000

HQ = Hazard Quotient (exposure dose is the absorbed dose) 1

SIR₂ = Daily Oral Soil Intake Dose for Child, mg/day 200

AB = (total absorption into body) 1

FOE = Frequency of Exposure (350 days/365 days) 0.96

$C_{soil} = 15,600 \text{ mg/kg}$

Therefore, the GRO soil cleanup concentration has been established using the above fate and transport evaluation numbers. This TPH cleanup level for soil protects groundwater quality to the GRO cleanup level for groundwater of 6.6 mg/L. The range of the GRO soil cleanup level is from 59 mg/kg to 15,600 mg/kg. If exposure parameters at a site are different than those described in the calculation above, Volunteers should calculate a site-specific human health risk-based cleanup level for GRO in soil.

As the TPH levels are meant to be conservative, the TPH GRO calculation should be performed using the thickest (i.e., greatest vertical extent) area of contamination coupled with the smallest distance to groundwater, even if these do not occur in the same location. In terms of establishing a continuum of cleanup levels for a site with several impacted areas that are not continuous in nature, this determination should be made on a site specific basis and as approved by the DEQ project manager.

5.2.2 Calculation of Diesel Range Organics TPH Soil Cleanup Level

Fate and Transport Calculation: Diesel range organics is a complex mixture of organic compounds and other substances as defined by ASTM. The following physical and chemical properties of petroleum hydrocarbons have been taken from Table 3, Selection of Representative TPH Fractions Based on Fate and Transport Considerations from the TPH Criteria Working Group (Amherst Scientific Publishers, 1997). This TPH cleanup level for soil contains hydrocarbons in the carbon range C₁₀ and C₂₄. All other

hydrocarbon compounds which may exist within this carbon number range are below 0.1% weight percent and have little effect on the K_{oc} calculation. The Fate and Transport Evaluation Table and calculations follow:

DRO TPH Fate and Transport Evaluation Table

Compound Class	Carbon Number	Compound	Wt %	K_{oc}	Wt%(K_{oc})	H'	Wt%(H')
n-Alkanes	10	n-Decane	1.7	857038	1456965	1.93E+02	328
	11	n-Undecane	7.7	4197590	32321443	7.49E+01	577
	12	n-Dodecane	2.5	5500000	13750000	3.17E+02	793
	13	n-Tridecane	5	17906059	89530295	*	*
	14	n-Tetradecane	2.7	7638358	20623567	1.56E+02	421
	15	n-Pentadecane	3.1	205589060	637326086	*	*
	16	n-Hexadecane	1.5	85703785	128555678	1.57E+02	236
	17	n-Heptadecane	2.9	236047823	684538687	*	*
	18	n-Octadecane	2	1006931669	2013863338	2.51E+02	502
	19	n-Nonadecane	1.5	26485001390	39727502085	*	*
	20	n-Eicosane	1	89742879450	89742879450	8.00E+01	80
Alkyl aromatics	10	n-Butylbenzene	0.038	8770	333	5.38E-01	0.02
	10	Tetramethylbenzene	1.1	5284	5812	6.51E-04	0.0007
	12	Triethylbenzenes	1.6	81846	130954	*	*
	14	Octylbenzene	0.61	1054387	643176	*	*
Branched alkanes	11	Methyldecane	1.4	1156112	1618557	*	*
	12	Methylundecane	1.7	2904023	4936839	*	*
	13	Dimethylundecane	2	9840111	19680222	*	*
	13	Methyldodecane	0.52	1156112242	601178366	*	*
	14	Methyltridecane	0.3	1156112242	346833673	*	*
Cycloalkanes	15	Methyltetradecane	0.63	1156112242	728350712	*	*
	10	n-Butylcyclohexane	0.74	138995	102856	*	*
	12	Hexylcyclohexane	0.93	1595879	1484167	*	*
	12	Phenylcyclohexane	0.87	47098	40975	*	*
Naphthalenes	13	Heptylcyclohexane	1	6353309	6353309	*	*
	10	Naphthalene	0.8	962	770	1.74E-02	0.0139
	11	Methylnaphthalenes	2.8	3570	9996	2.07E-02	0.056
	12	Dimethylnaphthalenes	3.2	9840	31488	*	*
	12	Ethylnaphthalenes	0.2	12106	2421	3.15E-02	0.0043
Polynuclear Aromatics	13	Trimethylnaphthalenes	0.4	48195	19278	*	*
	14	Anthracene	0.001	13500	14	1.60E-03	1.6E-06
	14	Naphthenobenzenes	9.8	24155	236719	*	*
	14	Phenanthrene	0.3	17906	5372	1.31E-03	3.93E-04
	15	Methylphenanthrenes	0.8	66527	53222	*	*
	16	Dimethylphenanthrenes	0.09	66527	5987	*	*
	16	Pyrene	0.015	36580	549	3.71E-04	5.6E-06
	18	Chrysene	2.2	363245	799139	1.80E-04	3.96E-04
	20	Benzo(a)pyrene	0.0004	554240	222	8.07E-06	3.0E-09

* Indicates there is no value in TPHC Working Group Series, Volume 3	Totals	65.6 & (26.6)	134804872720	2937
	Weighted averages		2054952328	110

Using the above calculated values for K_{oc} and H' , the DRO TPH cleanup level for a groundwater cleanup level of 1.0 mg/L:

$$C_t = C_{soil} = 2.1E+06 \text{ mg/kg (100\% pure product, diesel range fuel)}$$

Human Health Risk Assessment Calculation: The following calculation (equation from Volume 5, Human Health Risk-Based Evaluation of Petroleum Release Sites from the TPH Criteria Working Group Series (Amherst Scientific Publishers, 1997)) is based on protection of human health for non-cancer effects from oral ingestion of soil:

$$C_{soil} = (RfD)(ABW_2)(UCF)(HQ)/(SIR_2)(AB)(FOE)$$

where;

RfD = TPH Reference Dose, mg/kg-day

RfD_{o,DRO} = (worst case), mg/kg-day, oral ingestion, DRO: C₉ - C₂₄ 0.03

ABW₂ = Average Body Weight, Child, kg 15

UCF = Unit Conversion Factor, mg/kg 1000000

HQ = Hazard Quotient (exposure dose is the absorbed dose) 1

SIR₂ = Daily Oral Soil Intake Dose for Child, mg/day 200

AB = (total absorption into body) 1

FOE = Frequency of Exposure, (350 days/365 days) 0.96

$$C_{soil} = 2344 \text{ mg/kg}$$

Therefore, the DRO TPH cleanup level for soil has been established based upon the risk assessment evaluation. This soil concentration, 2344 mg/kg, ensures protection of groundwater quality to 1.1 mg/L TPH and also protects human health in the event of oral ingestion of contaminated soil for non-carcinogenic effects. Based on the number of significant figures in the calculation, the DEQ believes that is appropriate that a TPH soil concentration of 2300 mg/kg be used as a TPH cleanup level for diesel range organics from petroleum releases.

5.2.3 Calculation of Crude Oil TPH Soil Cleanup Levels

Fate and Transport Calculation: Petroleum crude oil fraction was defined as those hydrocarbons with carbon numbers between C₅ and C₃₄. The following physical and chemical properties of petroleum hydrocarbons have been taken from Table 3, Volume 3, Selection of Representative TPH Fractions Based on Fate and Transport Considerations from the TPH Criteria Working Group Series (Amherst Scientific Publishers, 1997). The Fate and Transport Evaluation Table lists the chemical composition of a typical crude oil as defined by ASTM. Because the chemical composition in a crude oil for those numerous compounds with carbon numbers greater than 20 was less than 0.1%, those compounds were not used in the table. Further, since there is interest in the potential impact of polynuclear aromatic hydrocarbons, these compounds were entered into the table to indicate their effect. The impact of the polynuclear aromatics on the K_{oc} calculation was negligible. The major impact for the petroleum crude fraction occurs with the high molecular weight alkanes. When crude oil is refined, additional lower weight molecular compounds are either formed or liberated from the crude oil complex mixture.

Crude Oil TPH Fate and Transport Evaluation Table

Compound Class	Carbon Number	Compound	Wt %	K _{oc}	Wt%(K _{oc})	H'	Wt%(H')
Alkenes	5	pentenes	2	304	608	1.63E+01	32.6
Alkyl benzenes	6	benzene	0.4	65	26	2.25E-01	0.09
	7	toluene	2.5	240	600	2.74E-01	0.685
	8	ethylbenzene	0.3	681	204	3.58E-01	0.1074
	8	xylene	3.4	697	2370	5.76E+00	19.584
	9	trimethylbenzenes	1.2	2150	2580	2.30E-01	0.276
	9	isopropylbenzene	0.09	2056	185	5.92E-01	0.05328
	9	methylethylbenzenes	0.6	1380	828	2.02E-01	0.1212
	9	trimethylbenzenes	1	2150	2150	2.30E-01	0.23
	10	tetramethylbenzenes	0.07	5284	370	1.03E+00	0.0721
	10	dimethylethylbenzenes	0.05	6653	333	*	*
	10	indane	0.07	1030	72	*	*
	10	tert-butylbenzene	0.1	6209	621	5.17E-01	0.0517
Branched alkanes	5	iso-pentane	10.2	900	9180	1.93E+02	1969
	6	methylpentanes	0.8	1300	1040	7.11E+01	56.88
Branched alkanes	6	dimethylbutanes	0.2	3184	637	8.05E+01	16.1
	7	dimethylpentanes	0.7	6653	4657	1.29E+02	90.3
	7	methylhexanes	1.2	8974	10769	1.40E+02	168
	8	dimethylhexanes	0.3	22542	6763	*	*
	8	ethylcyclohexane	0.2	12106	2421	*	*
	9	dimethylheptanes	2.6	76384	198598	*	*
	9	methyloctanes	0.9	100693	90624	4.06E+02	365
Cycloalkanes	6	cyclohexane	0.7	1330	931	7.84E+00	5.488
	6	methylcyclopentanes	0.9	1400	1260	1.48E+01	13.32
	7	dimethylcyclopentanes	1.8	3258	5864	*	*
	7	ethylcyclopentane	0.2	3334	667	*	*
	8	trimethylcyclopentanes	0.9	10789	9710	*	*
	8	dimethylcyclohexanes	0.4	11830	4732	3.14E+01	12.56
	8	ethylcyclohexane	0.2	12106	2421	*	*
n-Alkanes	5	n-pentane	10.9	1358	14802	5.17E+01	563.53
	6	n-hexane	1.8	3830	6894	7.39E+01	133.02
	7	n-heptane	2.3	48195	110849	8.43E+01	193.89
	8	n-octane	1.9	68077	129346	1.26E+02	239.4
	9	n-nonane	1.9	215278	409028	1.34E+02	254.6
	10	n-decane	1.8	857038	1542668	1.93E+02	347.4
	11	n-undecane	1.7	4197590	7135903	7.49E+01	127.33
	12	n-dodecane	1.7	5500000	9350000	3.17E+02	539
	13	n-tridecane	0.5	17906059	8953030	*	*
	14	n-tetradecane	0.4	7638358	3055343	1.56E+02	62.4
	15	n-pentadecane	0.4	205589060	82235624	*	*

Compound Class	Carbon Number	Compound	Wt %	K _{oc}	Wt%(K _{oc})	H'	Wt%(H')
	16	n-hexadecane	0.4	85703785	34281514	1.57E+02	62.8
	17	n-heptadecane	0.3	236047823	70814347	*	*
	18	n-octadecane	0.3	1006931669	302079501	2.51E+02	75.3
	19	n-nonadecane	0.3	26485001390	795E+09	*	*
	20	n-eicosane	0.2	89742879450	1.79E+10	8.00E+01	16
Naphthalenes	10	naphthalene	0.1	962	96		*
	11	methylnaphthalenes	1	3570	3570	2.07E-02	0.0207
	12	dimethylnaphthalenes	1.9	9840	18696	*	*
	12	ethylnaphthalenes	0.2	12106	2421	3.15E-02	0.0063
	13	trimethylnaphthalenes	0.9	48195	43376	2.31E-02	0.02079
Polynuclear Aromatics	12	acenaphthene	0.006	4819	29	*	*
	14	anthracene	0.001	13500	14	1.60E-03	1.6E-06
	14	phenanthrene	0.06	17906	1074	1.31E-03	7.86E-05
	15	methylphenanthrenes	0.15	66527	9979	*	*
	16	dimethylphenanthrenes	0.1	66527	6653	*	*
	16	fluoranthene	0.0006	382666	230	*	*
	16	pyrene	0.002	36580	73	3.71E-04	7.42E-07
	18	chrysene	0.002	363245	726	1.80E-04	3.6E-07
	20	benzo(a)pyrene	0.0004	554240	222	1.86E-05	7.0E-09
* Indicates there is no value in TPHC Working Group Series, Volume 3		Totals	65.2 for K _{oc} & 55 for H'		2.64E+10		5365
		Weighted averages		4.05E+08		98	

Using the above calculated values for K_{oc} and H', the Crude Oil TPH cleanup level for a groundwater cleanup level of 1.1 mg/L:

$$C_t = C_{\text{soil}} = 4.1\text{E}+05 \text{ mg/kg}$$

Human Health Risk Assessment Calculation: The same fate and transport analysis in addition to the risk assessment analysis is performed using the crude oil K_{oc}. The results show that the soil DRO TPH cleanup level for crude oil should be established using the risk assessment evaluation. This soil concentration, 2344 mg/kg, ensures protection of groundwater quality to 1.1 mg/L TPH and also protects human health due to the potential for oral ingestion of contaminated soil (for non-cancer effects). Based on the number of significant figures in the calculation, the DEQ believes that it is appropriate that a TPH soil concentration of 2,300 mg/kg DRO be used for a TPH cleanup level for crude oil releases

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