GEORGIA RISK-BASED CORRECTIVE ACTION

GRBCA WORKBOOK

Background Process Research & Reference Documentation

The purpose of this document is to provide the research and reference material used to produce the GRBCA Model. The attached appendices provide information from background reviews, development of screening levels, properties of Chemicals of Concern including biodegradation rates and toxicology, Soil composition and Hydrogeology to public works cited.

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Appendix A- Background Review of GA USTMP COCs

A. The USTMP and RAU staff reviewed the historic COCs used by this program and evaluated if COC changes were warranted based on its history as well as other state UST programs. A COC review of various publications was completed including a 2012 document from the Association of Environmental Health and Sciences (AEHS) Foundation, which compiled UST program COCs by state. Several significant influences in the COC review process were identified as follows:

a. What COCs have been analytically absent from the history in the GA UST program?
b. What COCs have been analytically present and what is their toxicological value in a risk-based evaluation?
c. What COCs have been historically analyzed that have no toxicological data?
d. What COCs with toxicological data have not been historically analyzed and if included, would enhance characterization of petroleum product releases at petroleum sites?

The COCs for the USTMP have been revised. The applicable USTMP COCs are detailed in REFERENCE 1 and REFERENCE 2 in this Guidance. Notable differences are as follows:

- Modified use of Total Petroleum Hydrocarbons (TPH): TPH - Gasoline Range Organics (GRO) and Diesel Range Organics (DRO) have no toxicological values and will no longer be used in favor of other surrogates that have toxicological value. The TPH fractions were evaluated and do have toxicological value. TPH GRO could be represented by TPH Aliphatic Low, however the RBTL is at saturation. With a concentration so high, using this COC has little value. TPH GRO can effectively be represented with BTEX and naphthalene for soil and groundwater. TPH Aliphatic Medium (toxicity is based on n-nonane) will represent soil DRO during UST system closures. TPH Aliphatic High (toxicity is based on white mineral oil) represents an effective range for used oil and will be analyzed for used oil soil samples during UST system closures. Naphthalene can be analyzed using Method 5030 8260B/C. TPH Aliphatic High and Medium are analyzed by Method 8015C.

- Elimination of most non-carcinogenic Polynuclear Aromatic Hydrocarbons (PAHs): The typical suite of PAHs for the USTMP is mostly and historically absent from UST site analyses or, if present, are in such low concentrations as to question the value of the analysis. Additionally, the low volatility and immobile nature of most of these compounds further support its elimination. Of the typical PAH suite, Naphthalene is an exception and is significantly present in most UST analyses and has already been identified as a COC, above. 1-Methylnaphthalene and 2-Methylnaphthalene have been added as COCs based on published information. Benzo(a)pyrene and other carcinogenic PAHs have significant toxicity and will remain as COCs. They are evaluated using a toxicity-weighted approach. See Section 2.8 of Appendix B for further details on this approach. It should be noted that 1 and 2-Methylnaphthalene and Benzo(a)pyrene TEQ will be analyzed at drinking water sites or where ISWQS apply to surface water direct exposure pathways. 1 and 2-Methylnaphthalene and Benzo(a)pyrene are analyzed by Method 8270C; and

- Addition of Methyl tert-butyl ether (MTBE): Although MTBE has not been a fuel additive for several years, it is consistently present in the environment at UST sites and for the foreseeable future will be a COC. MTBE is analyzed by Method 5030 8260B/C.

B. This section outlines the risk assessment procedures to support the administrative rule for Georgia EPD's USTMP and supports the development of soil and groundwater RBTLs and SSTLs for the COCs listed in REFERENCE 2. The RBTLs and SSTLs are based upon the current and anticipated future use of the site (e.g., residential or non-residential) and potentially complete routes of exposure for land use.

USTMP has soil RBTLs and SSTLs for the following pathways:

- direct contact with soil,
- soil leaching to groundwater used for drinking purposes,
- soil leaching to groundwater used for non-drinking water use,
- soil vapors and dust to outdoor air, and
- soil to indoor air.

USTMP has groundwater RBTLs and SSTLs for the following pathways:

- direct contact with groundwater,
- groundwater vapors to outdoor air, and
- groundwater vapors to indoor air.

Appendix B- Development of GA USTMP RBTLs and SSTLs

1.0 Risk-based Threshold Level (RBTL) Screening Level Evaluation

This evaluation is intended to achieve the following objectives:

- to demonstrate that the site or portions of the site do not pose a threat to human health and the environment and do not require any further evaluation,
- to determine the lateral and vertical extent of contamination, and
- to identify areas of the site that require further evaluation.

The screening-level residential RBTLs, which are also the designated delineation criteria for the petroleum COCs listed in REFERENCE 1, are based on EPA's Regional Screening Level Summary Table[1] (EPA, 2016). These are conservative risk-based target concentrations based on standardized unrestricted/residential exposure factors currently recommended by USEPA OSWER[2] (EPA, 2014) combined with toxicity values obtained from the latest version of USEPA's Regional Screening Level (RSL) Summary Table, and with the following considerations:

- receptors will be residential,
- conservative exposure parameter values,
- acceptable target individual excess cancer risk of $1X10^{-6}$, and
- target hazard quotient (THQ) of 1.0.

At hazardous waste facilities, it is common practice to apply the adjusted RSLs set at one-tenth of the non-cancer EPA RSL to account for additive effects from exposure to multiple chemicals acting on the same target organ or body system. However, given the reduced amount of COCs commonly found at UST/AST sites and the fact that most petroleum compounds do not act through similar modes of action or have the same critical effect, a THQ of (one) 1 likely represents a health protective threshold. Receptor-specific exposure factors, toxicity factors, risk algorithms used to develop the media- and receptor-specific RBTLs are provided in Appendix C.

Screening levels are the lowest target concentrations for the following exposure pathways and routes for soil, groundwater, and soil vapor, where applicable:

- Subsurface soil concentrations protective of exposure via groundwater ingestion at maximum contaminant levels (MCLs) or residential risk-based concentrations (if MCL unavailable) at the down gradient edge of the source assuming a default dilution attenuation factor of 20,
- Subsurface soil concentrations protective of exposure via indoor inhalation of vapors emanating from soil for a residential scenario, and
- Soil concentrations protective of combined ingestion, dermal contact, and outdoor inhalation exposures (direct) for a residential scenario.

[1]USEPA 2016. Regional Screening Level (RSL) Summary Table. Available online at: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016. May 2016.
[2] USEPA 2015. Update of Standard Default Exposure Factors. OSWER Directive 9200.1-120. Available online at: https://www.epa.gov/risk/update-standard-default-exposure-factors. February 2014.

Screening levels for groundwater are the more conservative (lower value) of the following concentrations:

- EPA's tap water RSLs for consumptive use of water in a residential scenario for chemicals that have tap water RSLs or MCLs for chemicals where the MCL is less than the designated tap water RSL, or
- Groundwater concentrations protective of exposure via indoor inhalation of vapors emitted from groundwater for a residential scenario.

Screening levels for soil vapor are protective of exposure via indoor inhalation of vapors emitted from contaminated soil or groundwater. Screening levels for sub-slab and deeper (i.e., >3-5 feet below ground surface) soil vapor are derived by applying the default attenuation factor of 0.03 to the USEPA Regional Screening Level (RSL) for residential ambient air. Table B-1 lists the screening levels for residential (unrestricted use) exposure to soil and groundwater for all the exposure pathways listed above.

Because of the methods and assumptions used in the development of the screening levels and the current limitations of laboratory analytical methods, the calculated screening levels may be lower than the practical quantitation limit reported by a laboratory for selected chemicals. In these situations, site-specific review by EPD will be required based on a set of defined criteria. In almost all cases, the chemical should be conservatively considered a chemical of potential concern and further evaluated in the site-specific risk evaluation.

1.1 Comparison of COC Concentrations to RBTLs (Screening Levels)

This step involves the comparison of the maximum media-specific concentration of each chemical and the screening levels presented in Table B-1. There is a screening level for each contaminant in each media. The overall screening level is the lowest of the relevant media-specific (soil, soil vapor, and/or groundwater) risk-based concentrations for the applicable exposure pathways. Screening levels are considered criteria that, if met (i.e., the maximum value for all chemicals is below the applicable screening level), will allow unrestricted (residential) use of the property. Since exposure to these low levels (below the screening levels) of contaminants do not pose a threat to human health, if the owner/operator chooses to meet these criteria, they will not be required to evaluate a site-specific risk evaluation, and no land use restrictions will be needed on the property. However, it should be noted that this screening process is not designed to eliminate any chemical as a COC in subsurface soil relative to protection of groundwater. Thus, the potential for chemicals in subsurface soil to leach to groundwater must be evaluated. Typically, chemicals that exceed the generic Protection of Groundwater SSL (soil screening level) values from the RSL table are evaluated on a site-specific basis. More detailed information on the leachability evaluation and how to derive impact to groundwater soil remediation standards is provided in REFERENCE 3D.

Applicable threshold levels will be established when a petroleum release has been adequately characterized and the GRBCA workbook completed. EPD will not require any further action of the owner/operator related to the release if the maximum concentrations in soil, surface water, and groundwater do not exceed the screening levels (RBTLs) in Table B-1 (below), and may not subject to other applicable requirements (i.e. monitoring). If any of the maximum soil, groundwater, or soil vapor concentrations exceeds the screening levels, the owner/operator may either:

- Adopt the RBTLs and develop a CAP-Part B to achieve these levels. Owners/operators who choose to cleanup a GUST Trust Fund covered petroleum release to a lower threshold level compared to established threshold levels may do so, but these costs are not GUST Trust Fund reimbursable; or,
- Request the AOC and AOPC SSTLs be approved as the Alternate Concentration Limits (ACL). COCs that exceed the ACLs will result in preparation and submittal of a CAP-Part B.

Table B-1: Residential and Non-residential RBTLs (TR=1E-05 and THQ=1.0, unitless)[A]													
		Soil RBTLs (mg/kg)						Groundwater RBTLs (µg/L)					
Chemical of Concern (COC)	CAS No.	Current or Future Resident† - Direct Exposure	Key	Excavation Worker[a,b]	Key	Groundwater Protection Standard[c] (DAF=1)	Groundwater Protection Standard[c] (DAF=20)	Current or Future Resident†[d] - Direct Exposure	Key	Current or Future Resident† Vapor Intrusion	Onsite Indoor Worker[e] Vapor Intrusion	Excavation Worker[a] - Direct Exposure	Key
VOCs													
Benzene	71-4-32	12	c	941	nc	0.003	0.1	5	MCL	16	69	620	c
Toluene	108-88-3	4,900	nc	71,500	nc	1.0 [0.7	14	1,000	MCL	26,000	110,000	41,257	nc
Ethyl benzene	100-41-4	80	c	9,230	c	1.0 [0.8]	16	70	MCL	48	210	2,467	c
Xylenes (Total)	1330-20-7	580	nc	7,990	nc	10	200	10,000	MCL	530	2,200	3,625	nc
Polycyclic Aromatic Hydrocarbons (PAHs)													
Naphthalene[f]	91-20-3	129	nc	719,000	nc	20	400	6	nc	172	722	34	c
1-Methyl, naphthalene	90-12-0	180	c	50,200	c	0.06	1.2	11	c	NTV	NTV	15,264	c
1,2,4-Trimethyl, benzene	91-57-6	300	nc	5,150	nc	0.08	2	56	nc	360	1,500	680	nc
Benzo(a)pyrene TEQ[g]	50-32-8	1.2	c	1,460	c	0.24	4.8	0.2	MCL	NV	NV	4	c
TPH Fractions[i]													
TPH - aliphatic medium; (DRO)[h]	NA	96	nc	170,000	nc	1.5	30	102	nc	NV	NV	821	nc
TPH - aliphatic high; (RRO)[h]	NA	230,000	nc	50,900,000	nc	2,400	48,000	60,200	nc	NV	NV	787,746	nc
Oxygenates													
Methyl *tert*-butyl ether (MTBE)	1634-04-4	470	c	40,100	nc	0.03	1.0	140	c	5,700	25,000	24,227	nc

Table B-1: Residential and Nonresidential (Worker) RBTLs

[A]*Table B-1 continues the next page. All references cited above are listed below the end of the table.*

Table B-1 (continued): Residential and Non-residential (Worker) RBTLs (TR=1E-05 and THQ=1.0, unitless)

Chemical of Concern (COC)	CAS No.	Receptor-specific Soil RBTLs (mg/kg)						Receptor-specific Groundwater RBTLs (µg/L)					
		Current or Future Resident† - Direct Exposure	Key	Excavation Worker[a,b]	Key	Groundwater Protection Standard[c] (DAF=1)	Groundwater Protection Standard[c] (DAF=20)	Current or Future Resident†[d] - Direct Exposure	Key	Current or Future Resident† Vapor Intrusion	Onsite Indoor Worker[e] Vapor Intrusion	Excavation Worker[a] - Direct Exposure	Key
Lead and Lead Scavengers													
Lead[k,l]	7439-92-1	400	--	1,578	--	13.5	270	15	MCL	NV	NV	15	MCL
1,2-Dibromoethane (ethylene dibromide) or (EDB)	106-93-4	0.507	c-adult	271	c	0.000014	0.0003	0.05	MCL	2	110	4	c
1,2-Dichloroethane (ethylene dichloride) or (EDC)	107-06-2	6.3	c-adult	1,100	nc	0.0014	0.03	5	MCL	29	830	59	c

c - cancer effects
nc - non-cancer effects
s – saturation limit
TR - Target Risk
TH - Target Hazard Quotient
†Residential RBTLs are based on the most conservative value of the adult and child risks.
NV - not volatile. The chemical does not meet EPA's volatility criteria (i.e., vapor pressure > 1 mm Hg or Henry's Law constant >1E-05 atm-m³/mole), and therefore, does not have a Regional Screening Level for ambient air.
NTV - The chemical is volatile but lacks inhalation toxicity data for a quantitative vapor evaluation.
[a]For soil, the Excavation Worker scenario includes potential exposure to constituents via ingestion, dermal contact, and inhalation of particulates and vapors potentially released from the soil during excavation activities (ED = 0.5 year; EF = 30 days/year per ASTM 2015). For shallow groundwater (<15 feet BGS only), the worker is assumed to contact contaminants via incidental ingestion, dermal contact, and inhalation of VOCs while digging in a trench. VDEQ model consulted for derivation of chemical-specific volatilization factors (trench dimensions assumed at the algorithm's default value of 8 ft. (length) x 3 ft. (width) x 8 ft. (depth). If groundwater table greater than 15 feet, the excavation worker's exposure to groundwater pathway should be considered incomplete.
[b]Given the nature of the site, most overall soil cleanup/threshold levels are expected to be driven by risk to the future excavation worker. Residents and indoor commercial workers (i.e., gas station workers) are anticipated to have infrequent direct contact with petroleum-related contaminants in soil and groundwater media.
[c]Groundwater protection standards are based on a default dilution attenuation factor of 20 due to the typically small size (<0.5 acres) of the contaminant source area. In the event, groundwater impacts are noted, the groundwater protection standard should be based on a DAF of 1 or a site-specific DAF should be calculated.
[d]The groundwater RBTLs assume potable/consumptive use of groundwater and are based on the MCL, and when unavailable, a site-specific risk-based concentration. However, the final residential RBTL should be based on the vapor intrusion screening level (VISL) whenever less than the groundwater RBTL listed for potable use.

[e]Onsite indoor commercial workers are not expected to be in direct contact with groundwater. Therefore, direct contact with groundwater is considered incomplete (i.e., not applicable). The groundwater evaluation must conform to the methods prescribed in EPA's Petroleum Vapor Intrusion Guidance. Thus, all groundwater RBTLs for this receptor are based on EPA's chemical-specific VISLs at a target risk of 1E-05 and THQ of 1.0.

[f]There is some uncertainty associated with the inhalation unit risk (IUR) currently listed in the EPA RSL Table on which the RSLs for naphthalene are based. Although toxicological data indicate that there is the potential for naphthalene to induce carcinogenic effects in laboratory animals, current scientific research demonstrates that the IUR factor is not relevant to human health risk assessment. USEPA headquarters and Region 4 EPA have also expressed uncertainty regarding human carcinogenic potential from exposure to naphthalene via the inhalation route. Due to this uncertainty, EPD has selected to establish health-based criteria on the non-cancer endpoint only.

[g]Benzo(a)pyrene selected as an indicator compound for all individual PAH constituents. Due to its toxicity, it is assumed that addressing benzo(a)pyrene also addresses other PAHs.

[g]Benzo(a)pyrene (BaP) was selected as an indicator compound for all individual PAH constituents associated with diesel fuel. Seven carcinogenic PAHs (cPAHs) are commonly evaluated in human health risk assessments. Concentrations of cPAHs should be converted to BaP toxic equivalent (BaP-TEQ) concentrations using U.S. EPA's Potency Equivalency Factors (PEFs) with BaP as the index compound. BaP-EQ concentrations should then be summed and compared to the RBTL listed for BaP TEQ.

[h]TPH indicator compounds should only be analyzed for samples containing detectable levels of TPH-DRO or TPH-RRO/ORO. TPH fraction analysis should also be considered using Mass DEP EPH/VPH methods.

[i]TPHs are evaluated during UST system closure only. Carbon ranges for DRO/ORO do not correlate with TPH ranges. EPD has no policy on how to extrapolate from DRO/ORO data to TPH values. However, it is suggested that the RBTLs for aliphatic medium and aliphatic high be applied for diesel-range organics (DRO) and residual-range organics (RRO), respectively. This approach has also been adopted in other states and EPA regions.

[k]For residential exposure, RBTL listed is based on U.S. EPA's Integrated Exposure-Uptake Biokinetic Model (IEUBK). USEPA has no consensus RfD or CSF for inorganic lead, so it is not possible to calculate risk-based screening levels as conducted for other chemicals. Therefore, the soil RBTL is based on EPA's evaluation of lead using blood-lead modeling.

[l]For nonresidential exposure, RBTL was calculated using the Georgia Adult Lead Model (GALM) based on assumed incidental water ingestion rate of 0.05 L/day, soil and dust ingestion rate of 0.33 g/day, and exposure frequency of 30 days/year representative of typical exposure conditions for excavation workers at UST sites (ASTM 2015). Protective concentration in groundwater assumed at 15 µg/L (i.e., the MCL).

2.0 SSTL Risk Evaluation

A site-specific risk evaluation is needed only if the site fails the comparison of site COC concentrations to RBTLs or the owner/operator chooses to use the default residential or non-residential RBTLs (protective of direct exposures, future consumptive use of groundwater and indoor air vapor intrusion pathways) as the remediation standards. The GRBCA standards by exposure scenario are presented in Table B-1.

Conducting a site-specific risk evaluation requires the completion of several important steps. These include identifying the chemicals present in environmental media of concern, the potentially complete exposure pathways, toxicity values, and characterizing risks from COCs. Results of the exposure and toxicity assessments were analyzed and combined to develop risk based SSTLs.

2.1 Target Risk Level

A risk-based decision process requires the specification of a target risk level for both carcinogenic and non-carcinogenic health effects. For carcinogenic effects, EPD adopts an individual's excess lifetime cancer risk (ELCR) of 1 x 10^{-5} for both current and future receptors. This falls within the National Contingency Plan's (NCP, 40 CFR 300.430) generally acceptable risk range of $1x10^{-6}$ to $1x10^{-4}$ for CERCLA site cleanups. The $1x10^{-5}$ risk level is considered protective based on the overall generally conservative nature of the exposure assumptions. Furthermore, petroleum COCs in soil and groundwater are subject to biodegradation thus allowing for a continued reduction in concentrations over time. Hence, the risk of exposure to unacceptable concentrations (except for new releases) should reduce over time at most UST sites.

For non-carcinogenic effects, the acceptable level is a hazard quotient of one (1) for current and future receptors. The NCP gives no analogous recommended range for non-carcinogenic risks. Although other EPD cleanup programs may require a more stringent screening using non-cancer-based screening levels adjusted to 0.1, due to there being a limited number of COCs at most regulated petroleum release sites, additivity of risk due to multiple chemicals and multiple routes of exposure is not factored.

2.2 Chemical-Specific Toxicological Factors

The toxicity of chemicals with carcinogenic or adverse health effects is quantified using cancer slope factors (CSF) for oral and dermal route of exposure, or inhalation unit risk (IUR) for the inhalation route. A CSF is an upper-bound estimate of the probability of a response (developing cancer) per unit intake of a chemical over a lifetime. The IUR is the upper-bound excess cancer risk estimated to result from continuous exposure to a chemical at a concentration of 1 $\mu g/m^3$ in air.

For chemicals that cause non-carcinogenic health effects, toxicity is typically quantified by reference doses (RfD) for oral and dermal route of exposure, and reference concentrations (RfC) for the inhalation route of exposure. The RfD is an estimate of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without risk of adverse health effects during a lifetime. Since RfDs are based on oral exposure, they are modified for use in dermal exposure assessment to take account of differences between gastrointestinal and dermal absorption. The RfC is

an estimate of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of adverse health effects over a lifetime.

The primary source of information for toxicity factors of petroleum COCs is the EPA RSL tables (RSL) (EPA, 2016). Given the biannual updates of the RSL Tables, EPD will complete periodic reviews of the toxicity data for COCs and will update as necessary those toxicity factors in need of updating. EPD requires that the peer-reviewed toxicity values provided by EPA in the RSL Table be used in all site-specific risk evaluations. For TPH fractions, a surrogate compound for which adequate toxicological information exists is selected to represent each fraction. The selected surrogate is then used to calculate the health-protective concentration of that fraction. Toxicity factors selected from EPA's RSL Summary Table for petroleum COCs are presented in Appendix C.

2.3 Exposure Pathways

A complete exposure pathway involves a source of petroleum products, release and transport mechanisms, routes of exposure, and potential receptors. The definition of complete exposure pathways starts with knowledge of the release, petroleum COCs, and site physical conditions, and then combines these with assumptions about land use and likely receptors. The pathway is **incomplete** if some, but not all, of the following elements are present. For a pathway to be **complete**, all the following must be present:

- a source of petroleum
- a mechanism by which the petroleum is released into the environment
- a transport medium through which petroleum travels from the point of release (source) to the receptor location (air, soil, groundwater, vapor migration through soil and utilities)
- a potential receptor or a point of potential contact of the receptor with the medium (e.g., drinking water wells)
- an exposure route by which the petroleum chemical enters the receptor's body (ingestion, inhalation, or dermal contact)

The Conceptual Site Model (CSM) should identify each of these components in its description of exposure pathways for current site conditions and for future anticipated use (if different from the current use). One example of a common exposure pathway would be leaching of petroleum chemicals from a gasoline release in soils (source) to the groundwater with subsequent transport (fate and transport) to a residential well where water is extracted for drinking and ingested by residents (land use and likely receptors). Another would be volatilization of petroleum chemical vapors from a soil source with subsequent transport through the soil and into the air in an occupied structure where they are inhaled. The potentially exposed population could include onsite resident, offsite resident, and a commercial/industrial worker.

EPD has identified the most commonly encountered exposure pathways for various environmental media for which an evaluation must be conducted. These pathways are discussed in the following sections and summarized in Table B-2 below. At sites where receptors, exposure pathways, or route of exposure other than those discussed are important, the owner/operator must identify them and discuss their quantitative evaluation with EPD. In some cases, it may be determined that one or more of the pathways are incomplete and, therefore, do not need to be quantitatively evaluated. For instance, if the migration of petroleum chemicals to a receptor or contact by a receptor is not possible (e.g., due

to formal engineering controls such as a paved site that will prevent human contact with petroleum-contaminated soil) under current and most likely future land use conditions, the site-specific petroleum COC concentrations may not pose a risk. Note that adequate justification for exclusion of these pathways must be provided to and approved by EPD.

Exposure pathways and routes of exposure are described and discussed in more detail in the GRBCA guidance. **Note: If a release has been identified from more than one tank pit/area of the site, a separate Risk Analysis Report (RAR) workbook must be completed and submitted for each tank pit/area.**

Table B-2: Summary of Media, Exposure Pathways and Applicable Standards

Media	Pathway(s)	Standards
Soil	Direct Contact (ingestion, dermal contact, and inhalation of ambient vapors and fugitive dust)	Residential and Non-residential RBTLs (Direct Contact)
	Groundwater Impacts	Soil to Groundwater Leaching Standards
Groundwater	Direct Contact (ingestion, dermal contact and inhalation of ambient vapors)	Residential and Nonresidential RBTLs
Surface Water	Human Health (direct contact; consumption of water and organisms)	Georgia In Stream Water Quality Standards (Rule 391-3-6-.03); if not available, EPA's Nationally Recommended Water Quality Criteria followed by EPA's Tap Water Regional Screening Levels (TR 10^{-5} and THQ 1.0)
	Ecological	Consult EPA Region 4 Ecological Risk Assessment Supplemental Guidance
Sediment	Direct Contact (see Soil)	See Soil
Indoor Air	Groundwater and Near Surface Sub-slab Soil Gas	USTMP Soil Gas Survey Guidance Document (*when published*)

2.4 Potentially Exposed Populations/Receptors

The objective of the risk evaluation is to quantify the adverse health effects to current and potential future receptors both onsite and offsite. The following definitions should be used:

- Onsite: The area located within the legal property boundaries within which the source of the release is located. This includes soil, groundwater, surface water, and air within those boundaries. Adjacent property purchased subsequent to the release will be considered offsite.
- Offsite: The areas of concern located outside the boundaries of the property where the release source is located. This includes soil, groundwater, surface water, and air located outside the property boundaries.

In a residential exposure scenario, risk is evaluated for either a child or adult receptor, depending on the specific exposure route, and whether the petroleum COC is non-carcinogenic, carcinogenic, or carcinogenic with a mutagenic mode of action. For benzo(a)pyrene, the route-specific risk calculations incorporate modifications based on exposure occurring at different life stages.

For land uses other than residential, a typical receptor might be a commercial or industrial worker where the risk to adults is considered. Finally, under a construction scenario, adult construction workers are considered. If warranted by site-specific conditions, other types of receptors may need to be defined and evaluated accordingly.

2.5 Pathways for Subsurface Soils (i.e., >3-5 feet below ground surface to water table)

Subsurface soils are defined as soils extending from 3 feet below the ground surface to the water table. The exposure pathways associated with subsurface soils include:

- Indoor inhalation of vapor emissions from soil,
- Groundwater protection (leaching of petroleum chemicals from soil to groundwater with subsequent potential ingestion of groundwater), and
- Surface water protection (leaching of petroleum chemicals from soil to groundwater with subsequent migration to a surface water body).

2.6 Pathways for Groundwater

Potentially complete exposure pathways for impacted groundwater include:

- Ingestion of groundwater, and
- Indoor and outdoor inhalation of vapor emissions from groundwater.

2.7 Pathways for Surface Water and Sediments

Depending on the beneficial use designation of impacted surface waters, complete pathways for surface water include:

- Intentional ingestion of surface water and ingestion of fish when surface water is used as a drinking water supply,

- Incidental ingestion of water and organisms while swimming/wading, and
- Ingestion of fish from surface waters designated for recreational use.

The hierarchy for selecting surface water RBTLs is:

1. GA EPD In Stream Water Quality Standards, Rule 391-3-6-.03,
2. USEPA National Recommended Water Quality Criteria for Human Health (consumption of water and organisms). Available at: https://www.epa.gov/wqc/national-recommended-water-quality-criteria-human-health-criteria-table, and
3. USEPA Tap Water RSLs (10^{-5} risk and THQ 1). Values are based on chronic freshwater criteria. If coastal and marine estuarine waters exist, the ISWQS for lead should be 8.1 µg/L.

2.8 Benzo(a)pyrene-equivalent Carcinogenicity and Mutagenicity Risks

The only COC identified as inducing carcinogenicity via a mutagenic mode of action is benzo(a)pyrene (BaP). BaP should only be considered in the drinking water risk evaluation if there are samples containing detectable levels of TPH aliphatic medium (DRO) or TPH aliphatic high (RRO/ORO). PAHs typically occur in mixtures making it difficult to establish the risk that the mixture may pose. As a result, EPD has established health-based levels for the BaP Toxic Equivalence Quotient (TEQ) which is protective of all other carcinogenic PAHs (cPAHs) that may be present as part of the PAH mixture. Therefore, a risk-based evaluation is not required for each individual member of this chemical group. Instead, the reporting of the BaP TEQ is recommended for the seven (7) cPAHs in EPA's RSL Table (EPA, 2016). A TEQ expresses an aggregate measure of toxicity based on several contributing compounds. Contributing components are then assigned a weighted factor, termed the Toxic Equivalence Factor (TEF), relative to the most toxic component contributing to the aggregate. TEFs allow the toxicity of a PAH mixture to be expressed as a single value representing the equivalent concentration of the most toxic or carcinogenic congener, BaP. Thus, the BaP TEQ provides a toxicity-weighted sum of cPAH concentrations in order to provide a single number for comparison to the RBTL. In accordance with the World Health Organization (WHO, 2005), the TEF of each carcinogenic PAH that weights its toxicity relative to that of BaP is noted in the table below:

Table B-3: BaP Toxicity Equivalence Factors

cPAH	Toxic Equivalence Factor (TEF)*
Benzo(a)pyrene	1
Benz(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.1
Chrysene	0.01
Dibenz(a,h)anthracene	1
Indeno(1,2,3-c,d)pyrene	0.1

*WHO 2005. The TEF for each cPAH is an estimate of the relative toxicity of the cPAH compound compared to BaP.

Exposure to mutagenic carcinogens carries greater risk when it occurs early in life. Therefore, the age at which exposure occurs must be considered for residential receptors. For these receptors, the 26-year exposure duration is divided into four periods: exposures occurring between the ages of 0–2 years, 2–6 years, 6–16 years, and 16–26 years (EPA, 2005).

Different multipliers (early life exposure adjustments) are incorporated for these time periods so that early-life exposure is weighted more heavily. The 10-fold (0-2 years) and 3-fold (2-16 years) age-dependent adjustments in slope factor are combined with age-specific exposure estimates when estimating cancer risks from early life exposure to carcinogens that act through a mutagenic mode of action. The 0-2 year and 2-6-year exposure periods use the child-specific values for several exposure parameters: body weight, soil ingestion rate, soil-to-skin adherence factor, and skin surface area for dermal contact. The corresponding adult-specific values are used for the 6-16 year and 16-26-year exposure periods. Age-dependent adjustment factors are only relevant in risk evaluations where a child receptor is involved such as a residential scenario (EPA, 2005). The supporting equations used to compute mutagenic cancer risks for a typical resident from BaP is as follows (adapted from EPA's RSL Calculator):

Residential Soil Mutagenic Dermal Risk:

$$SL_{mu\text{-}derm}\ (mg/kg) = \frac{TR\ (10^{-5})\ x\ AT_{cancer}\ (365\ d/yr\ x\ 70\ years)}{CSF_o\ [1(mg/kg\text{-}day)^{-1}]/GIABS\ x\ DFSM_{res\text{-}adj}\ (428{,}260\ mg/kg)\ x\ ABS_d\ x\ 10^{-6}\ kg/mg}$$

where,

$DFSM_{res\text{-}adj}$ = Age-adjusted Soil Dermal Factor for Mutagenicity

$$DFSM_{res\text{-}adj}\ (428{,}260\ mg/kg) = \{(EF_{0\text{-}2}\ (350\ d/yr)\ x\ ED_{0\text{-}2}\ (2\ years)\ x\ AF_{0\text{-}2}\ (0.2\ mg/cm^2)\ x\ SA_{0\text{-}2}\ (2373\ cm^2)\ x\ 10)/BW_{0\text{-}2}\ (15\ kg)\} + \{EF_{2\text{-}6}\ (350\ d/yr)\ x\ ED_{2\text{-}6}\ (4\ years)\ x\ AF_{2\text{-}6}\ (0.2\ mg/cm^2)\ x\ SA_{2\text{-}6}\ (2373\ cm^2)\ x\ 3)/BW_{2\text{-}6}\ (15\ kg)\} + \{(EF_{6\text{-}16}\ (350\ d/yr)\ x\ ED_{6\text{-}16}\ (10\ years)\ x\ AF_{6\text{-}16}\ (0.07\ mg/cm^2)\ x\ SA_{6\text{-}16}\ (6032\ cm^2)\ x\ 3)/BW_{6\text{-}16}\ (80\ kg)\} + \{(EF_{16\text{-}26}\ (350\ d/yr)\ x\ ED_{16\text{-}26}\ (10\ years)\ x\ AF_{16\text{-}26}\ (0.07\ mg/cm^2)\ x\ SA_{16\text{-}26}\ (6032\ cm^2)\ x\ 1)/BW_{16\text{-}26}\ (80\ kg)\}$$

Soil Mutagenic Ingestion Risk for a Resident:

$$SL_{mu\text{-}ing}\ (mg/kg) = \frac{TR\ (10^{-5})\ x\ AT_{cancer}\ (365\ d/yr\ x\ 70\ years)}{CSF_o\ [1(mg/kg\text{-}day)^{-1}]\ x\ IFSM_{res\text{-}adj}\ (166{,}833\ mg/kg)\ x\ 10^{-6}\ kg/mg}$$

where,

$IFSM_{res\text{-}adj}$ = Age-adjusted Soil Ingestion Factor for Mutagenicity

$$IFSM_{res\text{-}adj}\ (166{,}833\ mg/kg) = \{(EF_{0\text{-}2}\ (350\ d/yr)\ x\ ED_{0\text{-}2}\ (2\ years)\ x\ IRS_{0\text{-}2}\ (200\ mg/day)\ x\ 10)/BW_{0\text{-}2}\ (15\ kg)\} + \{(EF_{2\text{-}6}\ (350\ d/yr)\ x\ ED_{2\text{-}6}\ (4\ years)\ x\ IRS_{2\text{-}6}\ (200\ mg/day)\ x\ 3)/BW_{2\text{-}6}\ (15\ kg)\} + \{(EF_{6\text{-}16}\ (350\ d/yr)\ x\ ED_{6\text{-}16}\ (10\ years)\ x\ IRS_{6\text{-}16}\ (100\ mg/day)\ x\ 3)/BW_{6\text{-}16}\ (80\ kg)\} + \{(EF_{16\text{-}26}\ (350\ d/yr)\ x\ ED_{16\text{-}26}\ (10\ years)\ x\ IRS_{16\text{-}26}\ (100\ mg/day)\ x\ 1)/BW_{16\text{-}26}\ (80\ kg)\}$$

Soil Mutagenic Inhalation Risk for a Resident:

$$SL_{mu\text{-}inh}\ (mg/kg) = \frac{TR\ (10^{-5})\ x\ AT_{cancer}\ (365\ d/yr\ x\ 70\ years)\ x\ (VF + PEF)}{IUR\ [6E^{-4}(\mu g/m^3)^{-1}]\ x\ InhFSM_{res\text{-}adj}\ x\ 10^3\ \mu g/mg}$$

where,

$InhFSM_{res\text{-}adj}$ = Age-adjusted Soil Inhalation Factor for Mutagenicity

$InhFSM_{res\text{-}adj}$ = {$EF_{0\text{-}2}$ (350 d/yr) x $ED_{0\text{-}2}$ (2 years) x $ET_{0\text{-}2}$ (24 hour/day x 1 day/24 hours) x 10} + {$EF_{2\text{-}6}$ (350 d/yr) x $ED_{2\text{-}6}$ (4 years) x $ET_{0\text{-}2}$ (24 hour/day x 1 day/24 hours) x 3} + {$EF_{6\text{-}16}$ (350 d/yr) x $ED_{6\text{-}16}$ (10 years) x $ET_{0\text{-}2}$ (24 hour/day x 1 day/24 hours) x 3} + {$EF_{16\text{-}26}$ (350 d/yr) x $ED_{16\text{-}26}$ (10 years) x $ET_{0\text{-}2}$ (24 hour/day x 1 day/24 hours) x 1}

Soil Mutagenic Total Risk for a Resident:

$SL_{Total} = \{1/(1/SL_{derm}) + (1/SL_{ing}) + (1/SL_{inh})\}$

2.9 Establishing Exposure Point Concentrations

Exposure point concentrations are the representative petroleum chemical concentrations which receptors could be exposed over a specified duration within a specified geographical area. The geographical area which a receptor moves, and which contacts contaminated media during the specified exposure duration is termed an exposure unit. The AOC and/or AOPC of all receptors must be considered and described. The spatial area over which a given receptor is likely to be exposed, must be established for AOC and AOPC receptors and for each exposure pathway or route of exposure. The same site may have different AOC and/or AOPC for current and future use scenarios.

The risk evaluation report should clearly identify and provide rationales for specific data and methods used to estimate the exposure point concentrations. The following information should be provided in a table:

- Media,
- Exposure Route(s) and Pathway(s),
- Receptor(s),
- Data used, and
- Method of estimation.

2.10 Estimation of Chemical Intake

Risk evaluation requires quantifying the magnitude, frequency, and duration of exposure for the receptor populations and exposure pathways selected for analysis. Oral exposures are quantified on a dose per unit body weight basis while inhalation exposure is based on concentration in air. The equations used to evaluate the applicable and relevant routes of exposure per medium are presented in Appendix B.

In order to determine receptor- and pathway-specific intake estimates, it is necessary to select values for a number of exposure parameters in the equations used to calculate intake. Most of the exposure factors used in the risk evaluation represents the upper bounds or conservative values. Some physiological variables (e.g., skin surface area and body weight) are the mean values, as recommended by USEPA (EPA, 1989). Given the standards are calculated using exposure point concentrations, all of the ingested soil intake is assumed to be derived from the contaminated source and is, therefore, set equal to 100 percent. The selection of values for the following parameters is based on an assessment of recommendations in various EPA guidance documents, as well as the open scientific literature.

Exposure factors describe the physiological and behavioral characteristics of the receptor. These factors include the following:

- Water and soil ingestion rates
- Body weight
- Exposure duration for each route of exposure
- Exposure frequency
- Averaging Time
- Exposure times for indoor/outdoor inhalation[3]
- Soil to skin adherence factor
- Skin surface area for dermal contact with soil and groundwater
- Soil-to-skin adherence factor
- Event frequency for dermal contact with water

A list of default exposure factors and justification for their selection is presented in Appendix D.

2.11 Other Relevant Exposure Pathways

Other complete or potentially complete exposure pathways, such as ingestion of fish and shellfish, contact with contaminated sediments, or use of groundwater for irrigation purposes, should be evaluated on a case-by-case basis. If applicable, the owner/operator should contact EPD for further guidance.

[3] Residential soil ingestion is not dependent on exposure time. Commercial/Industrial and Construction/Excavation soil ingestion is calculated based on an hourly soil ingestion rate.

Table B-4: Comparison of the factors used for the RBTL and SSTL evaluations

Factors	Screening Level Risk Evaluation	Site-Specific Risk Evaluation
Exposure Parameters	Default (backward-mode calculation)	Default (backward-mode calculation)
Toxicity Factors	Contaminant-specific (EPA Superfund hierarchy)	Contaminant-specific (EPA Superfund hierarchy)
Physical and Chemical Properties	Default/EPD accepted values	Default/EPD accepted values
Fate and Transport Parameters	Default	Default or Site-specific
Fate and Transport Models	Default (based on linear partitioning at DAF=20; USEPA's RSL Table, 2016 and *Supplemental Soil Screening Guidance, 2002*)	Default (Domenico) or other advanced models acceptable by EPD (e.g. SESOIL, MODFLOW, VLEACH, etc.)
Exposure Point Concentrations	Maximum Detected Value (single point compliance)	Maximum Detected Value (single point compliance)
Acceptable Target Risk	$1X10^{-6}$	$1X10^{-5}$
Acceptable Target Hazard Quotient/Hazard Index	HQ = 1.0	HQ = 1.0
Groundwater Target Concentration term for soil to groundwater migration	Maximum Contaminant Level or if unavailable, the Target Residential Risk-based Groundwater Concentration	Maximum Contaminant Level or Target Risk-based Concentration
Soil Concentration Protective of Groundwater	Default model with point of exposure at source	Default model with point of exposure at source (flexibility in model may be used subject to EPD approval)
Outcome of Evaluation	Either: 1. Petition for site closure based on compliance with RBTLs, or 2. Compare to SSTLs and submit Corrective Action Plan to achieve SSTLs	Either: 1. Petition for site closure based on compliance with RBTLs, or 2. Compare to SSTLs and submit Corrective Action Plan to achieve SSTLs 3. Refine Risk Evaluation through forward

		risk calculation (will require consultation with EPD's Risk Assessment Unit)
Surface water classification	Georgia ISWQS (see Section 2.7 if not available)	Georgia ISWQS (see Section 2.7 if not available)

3.0 Ecological Risk Considerations

In addition to identifying potential impacts to human receptors, the CSM should also attempt to identify potential pathways by which sensitive habitats, such as wetlands, surface water bodies, or other ecologically significant environments near the site, may be impacted by the release. As appropriate, a walking survey in the vicinity of the site may be necessary to identify ecological receptors. All sites evaluated must be screened for the presence of ecological receptors and/or their habitats, except for those sites where initial sampling data indicates that petroleum COC concentrations are below the Georgia ISWQS and/or the Region 4 sediment refinement ecological screening values and the site poses no imminent threat to ecological receptors. In instances where a sensitive habitat or sensitive resources are impacted, containment measures and habitat management to minimize exposure should be implemented.

If comparison of site-specific soil, groundwater seeps, surface water or sediment concentrations indicates that applicable generic screening benchmarks are exceeded, available options include:

- Performance of a site-specific risk evaluation
- Interim removal
- Further tier evaluation
- Submit a CAP for active cleanup, or,
- Submit a CAP to collect and submit sufficient data to statistically conclude that concentrations of COC will not present a risk to human health or the environment using natural biodegradation and/or other natural attenuation mechanisms

Threatened and endangered species that may be exposed to site-specific chemicals should be identified. Note that within the risk evaluation process, protection of surface waters and streams is independent of a site-specific risk evaluation, which should be developed in accordance with the Region 4 Ecological Risk Assessment Supplemental Guidance (Interim Draft; https://www.epa.gov/risk/region-4-ecological-risk-assessment-supplemental-guidance). A site-specific risk evaluation will require the development of a site-specific, detailed work plan and approval of EPD prior to its implementation. When an investigation warrants development of a site-specific risk evaluation, please contact EPD to obtain additional guidance.

4.0 RBTL Algorithms

The soil and groundwater direct exposure RBTLs have been calculated using exposure assumptions consistent with both residential and occupational land use and are presented in Table B-1 Residential and Nonresidential (Worker) RBTLs. For situations where there is evidence that soil may be serving as a source of contamination for groundwater, soil cleanup goal concentrations for organic chemicals based on leaching from soil to groundwater are also provided as part of this table.

For evaluation of direct exposure to petroleum COCs in soils, incidental ingestion, dermal contact, and inhalation is considered. Soil RBTL concentrations are calculated using the following standardized risk equation.

General Risk Equation:	Where:
$C_s = \dfrac{TR \times BW \times AT_c \text{ (or } AT_{nc})}{EF \times ED \times FI \times [A + B + C]}$	C_s = Soil concentration[mg/kg] TR = Target cancer risk [unitless] BW = Body weight [kg] AT = Averaging time for carcinogens or noncarcinogens [years] EF = Residential exposure frequency [days/year] FI = Fraction ingested [unitless]. Assume 100%. RfC = Chemical-specific inhalation reference concentration [mg/m^3] **For Potential Cancer Effects:** A= Ingestion intake, (CSF_o x IR_o x 10^{-6} kg/mg) B = Dermal intake, (CSF_d x SSA x SAF x DA x 10^{-6} µg/mg) C= Inhalation intake, (IUR x (1/VF + 1/PEF)) **For Potential Non-Cancer Effects:** A= Ingestion intake, (1/RfD_o x IR_o x 10^{-6} µg/mg B= Dermal intake, (CSF_d x SSA x SAF x DA x 10^{-6} µg/mg) C= Inhalation intake, (1/RfC x (1/VF+1/PEF)
Source: USEPA, RAGS, Part B, *Development of Risk-based Preliminary Remediation Goals* (1991)	

The equations, exposure variables, and parameter values are summarized in the tables below, which also includes a detailed breakdown of the intake components by land use, receptor, and route of exposure.

4.1 RBTL Soil Algorithms

4.1.1 Direct Ingestion of Soil RBTL Algorithm

$RBTL_{soil\text{-}ing}$: Risk-based cleanup level for direct ingestion of soil [mg/kg] Carcinogenic Effects $RBTL_{soil\text{-}ing} = \frac{TR \times BW \times AT_c \times 365}{CSF_o \times EF \times ED \times IR_s \times FI \times 10^{-6}}$ Non-carcinogenic Effects $RBTL_{soil\text{-}ing} = \frac{THQ \times RfD_o \times AT_{nc} \times 365}{EF \times ED \times ET}$ **Source:** USEPA, RAGS, Part B, *Development of Risk-based Preliminary Remediation Goals* (1991)	Where: TR = Target cancer risk [unitless] THQ = Target hazard quotient for individual constituents [unitless] AT_c = Averaging time for carcinogens [years] AT_{nc} = Averaging time for non-carcinogens [years] ED = Exposure duration for resident [years] EF = Residential exposure frequency [days/year] FI = Fraction ingested [unitless] (assume 100%) RfD_o = Chemical-specific oral reference dose [mg/m^3] IUR = Chemical-specific inhalation unit risk [µg/m^3]$^{-1}$ 365 = Conversion factor [days/year]

4.1.2 Dermal Contact with Soil RBTL Algorithm

$RBTL_{soil\text{-}derm}$: Risk-based cleanup level dermal contact with soil [mg/kg] Carcinogenic Effects $RBTL_{soil\text{-}derm} = \frac{TR \times BW \times AT_c \times 365}{CSF_d \times SSA \times SAF \times ABS_d \times EF \times ED \times 10^{-6}}$ Non-carcinogenic Effects $RBTL_{soil\text{-}derm} = \frac{THQ \times RfD_d \times BW \times AT_{nc} \times 365}{SSA \times SAF \times EF \times ED \times 10^{-6}}$ **Source:** USEPA, RAGS, Part E, *Supplemental Guidance for Dermal Risk Assessment (Final)* (2004)	Where: TR = Target cancer risk [unitless] BW = Body weight [kg] AT_c = Averaging time for carcinogens [years] 365 = Conversion factor [days/year] CSF_d = Chemical-specific oral cancer slope or potency factor adjusted to the absorbed dose $[mg/(kg\text{-}day)]^{-1}$; $CSF_d = CSF_o$/Oral Absorption Efficiency SSA = Skin surface area $[cm^2/event]$ SAF = Soil-to-skin adherence factor $[mg/cm^2]$ ABS_d = Dermal absorption factor [unitless] EF = Residential exposure frequency [days/year] ED = Exposure duration for resident [years] 10^{-6} = Conversion factor [µg/mg] THQ = Target hazard quotient for individual constituents [unitless] RfD_d = Chemical-specific oral reference dose adjusted to the absorbed dose [mg/(kg-day)] ; $RfD_d = RfD_o$ x Oral Absorption Efficiency RfD_o = Chemical-specific oral reference dose [mg/(kg-day)] AT_{nc} = Averaging time for non-carcinogens [years]

4.1.3 Inhalation of Vapors and Particulates from Soil RBTL Algorithm

$RBTL_{soil\text{-}inh}$: Residential risk-based cleanup level for inhalation of vapors and particulates from soil [mg/m^3]

Carcinogenic Effects

$$RBTL_{soil\text{-}inh} = \frac{TR \times AT_c \times 365 \times (VF + PEF)}{EF \times ED \times ET \times 0.042 \times IUR \times 10^3}$$

Non-carcinogenic Effects

$$RBTL_{soil\text{-}inh} = \frac{THQ \times RfC \times AT_{nc} \times 365 \times (VF + PEF)}{EF \times ED \times ET \times 0.042}$$

Source: USEPA, RAGS, Part F, *Supplemental Guidance for Inhalation Risk Assessment* (2009) and RAGS, Part B, *Development of Risk-based Preliminary Remediation Goals* (1991)

Where:
TR = Target cancer risk [unitless]
AT_c = Averaging time for carcinogens [years]
365 = Conversion factor [days/year]
VF = Volatilization factor [L/kg]
PEF = Particulate emissions factor [m^3/kg]
EF = Exposure frequency [days/year]
ED = Exposure duration [years]
ET = Outdoor exposure time interval [hours/day]
0.042 = Conversion factor [days/hour]
IUR = Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$]
10^3 = Conversion factor [µg/mg]
THQ = Target hazard quotient for individual constituents [unitless]
RfC = Chemical-specific inhalation reference concentration [mg/m^3]
AT_{nc} = Averaging time for non-carcinogens [years]

4.2 RBTL Groundwater Algorithms

4.2.1 Direct Ingestion of Groundwater RBTL Algorithm

$RBTL_{gw\text{-}ing}$: Risk-based cleanup level for ingestion of groundwater [mg/L-H_2O] Carcinogenic Effects $RBTL_{gw\text{-}ing} = \frac{TR \times BW \times AT_c \times 365}{IRw \times FI \times EF \times ED \times CSF_o}$ Non-carcinogenic Effects $RBTL_{gw\text{-}ing} = \frac{THQ \times BW \times AT_{nc} \times 365}{IR_w \times FI \times EF \times ED \times [1/RfD_o]}$ **Source:** USEPA, RAGS, Part B, *Development of Risk-based Preliminary Remediation Goals* (1991)	Where: TR = Target cancer risk [unitless] BW = Body weight [kg] AT_c = Averaging time for carcinogens [years] 365 = Conversion factor [days/year] IR_w = Ingestion rate of groundwater [L/day] FI = Fraction ingested [unitless]. Assume 100%. EF = Exposure frequency for a resident [days/year] ED = Resident child exposure duration [year] CSF_o = Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$ THQ = Target hazard quotient for individual constituents [unitless] AT_{nc} = Averaging time for non-carcinogens [years] RfD_o = Chemical-specific oral reference dose [mg/(kg-day)]

4.2.2 Dermal Contact with Groundwater RBTL Algorithm

$RBTL_{gw\text{-}derm}$: Risk-based cleanup level for dermal contact with groundwater [mg/L-H_2O] Carcinogenic Effects $RBTL_{gw\text{-}derm} = \frac{TCR \times BW \times AT_c \times 365}{SSA_{gw} \times DA \times EF \times ED \times CSF_d}$ Non-carcinogenic Effects $RBTL_{gw\text{-}derm} = \frac{THQ \times BW \times AT_{nc} \times 365}{SSA_{gw} \times DA \times EF \times ED \times [1/RfD_d]}$ **Source:** USEPA RAGS, Part E, *Supplemental Guidance for Dermal Risk Assessment (Final)* (2004)	Where: TR = Target cancer risk [unitless] BW = Body weight [kg] AT_c = Averaging time for carcinogens [years] 365 = Conversion factor [days/year] SSA_{gw}= Skin surface area for groundwater contact [cm^2] DA = Dermal Absorption Factor [$L/cm^2/day$]; calculated using equations from EPA RAGS, Part E EF = Exposure frequency for a resident [days/year] ED = Resident child exposure duration [year] CSF_d = Chemical-specific oral cancer slope or potency factor adjusted to the absorbed dose $[mg/(kg\text{-}day)]^{-1}$; $CSF_d = CSF_o$/Oral Absorption Efficiency CSF_o = Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$ THQ = Target hazard quotient for individual constituents [unitless] AT_{nc} = Averaging time for non-carcinogens [years] RfD_d = Chemical-specific oral reference dose adjusted to the absorbed dose [mg/(kg-day)]; $RfD_d = RfD_o$ x Oral Absorption Efficiency RfD_o = Chemical-specific oral reference dose [mg/(kg-day)]

4.2.3 Inhalation of Volatiles from Household Use of Groundwater RBTL Algorithm

$RBTL_{gw\text{-}inh}$: Risk-based cleanup level for inhalation of VOCs in groundwater [mg/L-H_2O] <u>Carcinogenic Effects</u> $RBTL_{gw\text{-}inh} = \frac{TR \times AT_c \times 365}{VF_{res} \times EF \times ED \times IUR \times 10^3}$ <u>Non-carcinogenic Effects</u> $RBTL_{gw\text{-}inh} = \frac{THQ \times AT_{nc} \times 365}{VF_{res} \times EF \times ED \times [1/RfC]}$ **Note:** *VF* is assumed to be 0.5 [L/m^3] for volatilization from water to air based upon studies by Andelman, 1990. For the purposes of this document, VOCs are those organic chemicals having a Henry's Law Constant greater than $1X10^{-5}$ [atm-m^3/mol] and a molecular weight less than 200 [g/mol] **Source:** USEPA RAGS, Part F, *Supplemental Guidance for Inhalation Risk Assessment* (2009)	Where: TR = Target risk [unitless] AT_c = Averaging time for carcinogens [years] 365 = Conversion factor [days/year] AT_{nc} = Averaging time for non-carcinogens [years] RfC = Chemical-specific Reference Concentration [mg/m^3] IUR = Chemical-specific Inhalation Unit Risk [1/µg/m^3] EF = Exposure frequency [days/year] ED = Exposure duration [year] VF_{res} = Residential volatilization factor for household tap water (0.5 [L/m3]); applicable only for volatile organic compounds (EPA 1991; Andelman 1990) 10^3 = Conversion factor [µg /mg]

4.2.4 Advisory Levels for Construction/Utility Worker Inhalation of Volatiles in a Trench

$C_{Trench} = C_{GW} \times VF$

$$VF_{Trench} = \frac{K_i \times A \times F \times CF1 \times CF2 \times CF3}{ACH \times V}$$

Where,

$K_i = 1/(1/k_{iL}) + [(RT)/(H_i \times k_{iG})]$

$k_{iL} = (MW_{O2}/MW_i)^{0.5} \times (T/298) \times k_{LO2}$

$k_{iG} = (MW_{H2O}/MW_i)^{0.335} \times (T/298)^{1.005} \times k_{g,\,H2O}$

Note: Groundwater <15 feet bgs

Source: Virginia Department of Environmental Quality Unified Risk Assessment Model (VURAM) User's Guide (VDEQ, 2016)

Where:
C_{Trench} = Airborne concentration of a contaminant in a trench
VF_{Trench} = Volatilization factor for a trench (L/kg)

K_i = Mass transfer coefficient [cm/sec]
A = Trench dimension area:
Length = 8 ft. (2.44 m)
Width = 3 ft. (0.91 m)
Depth = 8 ft. (2.44 m)
Width/Depth = 0.375 [unitless]
V = Volume of trench [m^3]

For Emission Flux and Concentration in Trench,
F = 1 [unitless], Emission flux, fraction of the floor through which the contaminant can enter
$CF1$ = 1E-03 [L/cm^3] (CF = Conversion Factor)
$CF2$ = 1E+04 [$cm^{2/}m^2$]
$CF3$ = 3600 [s/hr]
ACH = 2 hr^{-1} Air changes per hour

For mass-transfer coefficients,
R = 8.2E-05 [atm-$m^{3/}$mol-K], Ideal gas constant
T = 77 ° Fahrenheit [F], Average system absolute temperature
T = 298° Kelvin [K], Average system absolute temperature
H_i = Henry's Law Constant [atm/$m^{3/}$mol]
k_{iG} = Gas Phase Mass transfer coefficient [cm/sec]
MW_{H2O} = 18 [g/mol], Molecular weight of water
MW_i = Molecular Weight of component i
$k_{g,H2O}$ = 0.833 [cm/s], Gas Phase Mass Transfer [cm/sec] of water vapor at 25° Celsius
k_{iL} = Liquid Phase Mass transfer coefficient [cm/sec]
MW_{O2} = 32, Molecular Weight of Oxygen
k_{LO2} = 0.002, Liquid Phase Mass transfer coefficient [cm/sec] of Oxygen

4.3 Indoor Air Inhalation of Volatiles from Groundwater RBTL Algorithm

$RBTL_{IAVI\text{-}res}$: Residential risk-based target level in indoor air [µg/m^3] Carcinogenic Effects $RBTL_{IAVI\text{-}res} = \frac{TR \times AT_c \times 365}{EF \times ED \times ET \times 0.042 \times IUR}$ Non-carcinogenic Effects $RBTL_{IAVI\text{-}res} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 1000}{EF \times ED \times ET \times 0.042}$ **Note:** Attenuation Factor (AF = 0.001) and Soil Gas (AF = 0.03) (divide by the appropriate default attenuation factor to obtain RBTL for this pathway **Source:** USEPA RAGS, Part F, *Supplemental Guidance for Inhalation Risk Assessment* (2009) and Vapor Intrusion Screening Level (VISL) Calculator User's Guide (EPA, 2014)	Where: TR = Target cancer risk [unitless] AT_c = Averaging time for carcinogens [years] 365 = Conversion factor [days/year] EF = Exposure frequency [days/year] ED = Exposure duration [years] ET = Indoor exposure time interval [hours/day] 0.042 = Conversion factor [days/hour] IUR = Chemical-specific inhalation unit risk [µg/m^3]$^{-1}$ THQ = Target hazard quotient for individual constituents [unitless] RfC = Chemical-specific inhalation reference concentration [mg/m^3] AT_{nc} = Averaging time for non-carcinogens [years] 10^3 = Conversion factor [µg /mg]

4.4 Soil-to-Groundwater Migration Factor RBTL Supporting Algorithm

Groundwater Dilution Attenuation Factor (*DAF*): $$DAF = 1 + \frac{Kid}{IL}$$ Partitioning Equation for Soil-to-Groundwater Migration: $$C_S = C_w \times [K_d \times \frac{(\theta_w + \theta_a H)}{\rho_b}]$$ Where: C_w = Target groundwater concentration x *DAF* **Source:** USEPA, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* (2002)	For *DAF*, *DAF* = Dilution attenuation factor in the mixing zone [unitless] *K* = Aquifer hydraulic conductivity [m/yr] *i* = Hydraulic gradient [m/m] *d* = Mixing zone depth [m] *I* = Infiltration rate [m/yr] *L* = Source length parallel to groundwater flow [*m*] For soil to groundwater migration, C_S= Protective Soil Screening Level [mg/kg] C_w = Target leachate concentration [mg/L] $K_d = foc \times Koc$ = Chemical-specific soil-water sorption coefficient [cm^3-H_2O/g-soil] θ_w = Volumetric water content in vadose zone soils [cm^3 -H_2O/cm^3 - soil] θ_a = Air-filled soil porosity (L_{air}/L_{soil}); $\theta_a = n-\theta_w$ *H* = Chemical-specific Henry's Law Constant [(L-H_2O)/(*L-air*)] ρ_b = Dry soil bulk density [g-soil/cm^3 -soil] **Note:** A default *DAF* of 20 was applied in the derivation of the generic leach based RBTLs since most sites are expected to have source areas less than 0.5 acres. A site-specific *DAF* using the Domenico Model may be required for sites where known groundwater impacts exist or shallow depth to groundwater occurs.

4.5 Groundwater-to-Surface Water Migration Pathway RBTL Supporting Algorithm

$DF_{gw\text{-}sw}$: Dilution factor for groundwater to surface water [unitless] $DF_{gw\text{-}sw} = [1 + (Q_{sw}/Ki\delta_{sw} \times W_{gw\text{-}sw})]$ **Source:** Domenico, P.A., An Analytical Model for Multidimensional Transport of a Decaying Contaminant Species. *Journal of Hydrology*, 91(1-2): 49-58. 1987	Where: Q_{sw} = Surface water flow rate [cm/s] *K* = Aquifer hydraulic conductivity [m/ year] *i* = Hydraulic gradient [m/m] δ_{sw} = Thickness of groundwater plume at surface water interface [cm] $W_{gw\text{-}sw}$ = Width of groundwater plume at surface water interface [cm]

5.0 SSTL Groundwater Algorithms and Supporting Algorithms

5.1 Air Inhalation SSTL Supporting Algorithm

$RBTL_{air}$: Risk-based threshold level in indoor air [µg/m^3]

Carcinogenic Effects

$$RBTL_{air} = \frac{TR \times AT_c \times 365}{EF \times ED \times ET \times 0.042 \times IUR}$$

Non-carcinogenic Effects

$$RBTL_{air} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 1000}{EF \times ED \times ET \times 0.042}$$

Source: ASTM E1739-95 (reapproved 2015)
(modified to use *IUR* in lieu of RfD_i, *BW* and IR_{air}. *ET* added)

Where:
TR = Target cancer risk [unitless]
AT_c = Averaging time for carcinogens [years]
365 = Conversion factor [days/year]
AT_{nc} = Averaging time for non-carcinogens [years]
EF = Exposure frequency [days/year]
ED = Exposure duration [years]
ET = Indoor exposure time interval [hours/day]
0.042 = Conversion factor [days/hour]
IUR = Chemical-specific inhalation unit risk [µg/m^3]$^{-1}$
THQ = Target hazard quotient for individual constituents [unitless]
RfC = Chemical-specific inhalation reference concentration [mg/m^3]
1000 = Conversion factor [µg/mg]

5.2 Volatilization Factor from Groundwater to Indoor Air Inhalation SSTL Supporting Algorithm

VF_{wesp}: Volatilization Factor for groundwater to enclosed space air [mg/m^3]

$$VF_{wesp} = \frac{H \times \left[\frac{D_{ws}^{eff} / L_{GW}}{ER \times L_B}\right]}{1 + \left[\frac{D_{ws}^{eff} / L_{GW}}{ER \times L_B}\right] + \left[\frac{D_{ws}^{eff} / L_{GW}}{\left(D_{crack}^{eff} / L_{crack}\right) \times \eta}\right]} \times 10^3$$

Source: ASTM E1739-95 (reapproved 2015)

Where:
H = Chemical specific Henry's Law constant [(L-H_2O)/(L-air)]
D_{ws}^{eff} = Effective diffusion coefficient between groundwater and soil surface [cm^2/s]
L_{GW} = Depth to groundwater [cm]
ER = Enclosed space air exchange rate [L/s]
L_B = Enclosed space volume/infiltration area ratio [cm]
L_{crack} = Enclosed space foundation or wall thickness [cm]
D_{crack}^{eff} = Effective diffusion coefficient through foundation cracks [cm^2/s]
η = areal fraction of cracks in foundation and/or walls [cm^2-cracks/cm^2-total area]
10^3= Conversion factor [L/m^3]

5.3 Effective Diffusion Coefficients SSTL Supporting Algorithm

D_s^{eff}: Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] $$D_s^{eff} = D^a \times \frac{\theta_{as}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{ws}^{3.33}}{\theta_T^{2.0}}$$ **Source:** ASTM E1739-95 (reapproved 2015)	Where: D^a = Chemical-specific diffusion coefficient in air [cm^2/s] θ_{as} = Volumetric air content in vadose zone [cm^3-air/cm^3-soil] θ_T = Total soil porosity in the impacted zone [cm^3/cm^3-soil] D^w = Chemical-specific diffusion coefficient in water [cm^2/s] H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)] θ_{ws} = Volumetric water content in vadose zone [cm^3-H_2O/cm^3-soil]
D_{ws}^{eff}: effective diffusion coefficient between groundwater and surface soil [cm^2/s] $$D_{ws}^{eff} = (h_{cap} + h_v) \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$$ **Source:** ASTM E1739-95 (reapproved 2015)	Where: h_{cap} = Thickness of capillary fringe [cm] h_v = Thickness of vadose zone [cm] D_{cap}^{eff} = Effective diffusion coefficient through capillary fringe [cm^2/s] D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] L_{GW} = Depth to groundwater ($h_{cap} + h_v$) [cm]
D_{cap}^{eff}: effective diffusion coefficient for the capillary fringe [cm^2/s] $$D_{cap}^{eff} = D^a \times \frac{\theta_{acap}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcap}^{3.33}}{\theta_T^{2.0}}$$ **Source:** ASTM E1739-95 (reapproved 2015)	Where: D^a = Chemical-specific diffusion coefficient in air [cm^2/s] θ_{acap} = Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil] θ_T = Total soil porosity [cm^3/cm^3-soil] D^w = Chemical-specific diffusion coefficient in water [cm^2/s] H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]θ_{wcap} = Volumetric water content in capillary fringe soils [cm^3-H_2O/cm^3-soil]

5.3 Effective Diffusion Coefficients SSTL Supporting Algorithm (continued)

D_{crack}^{eff}: effective diffusion coefficient through foundation cracks [cm^2/s] $$D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^{2.0}}$$ **Source:** ASTM E1739-95 (reapproved 2015)	Where: D^a = Chemical-specific diffusion coefficient in air [cm^2/s] θ_{acrack} = Volumetric air content in foundation/wall cracks [cm^3-air/cm^3-ttl volume] θ_T = Total soil porosity [cm^3/cm^3-soil] D^w = Chemical-specific diffusion coefficient in water [cm^2/s] H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)] θ_{wcrack} = Volumetric water content in foundation/wall cracks [cm^3-H_2O/cm^3-ttl volume]

5.4 Groundwater to Indoor Air Inhalation SSTL Algorithm

$RBTL_{gw}$: Risk-based threshold level for groundwater to indoor air [µg/L] Carcinogenic Effects $RBTL_{gw} = \frac{RBTL_{air} \times 10^{-3}}{VF_{wesp}}$ Non-carcinogenic Effects $RBTL_{gw} = \frac{RBTL_{air} \times 10^{-3}}{VF_{wesp}}$ **Source:** ASTM E1739-95 (reapproved 2015)	Where: $RBTL_{gw}$ =Risk-based threshold level for groundwater to indoor air [µg/L $RBTL_{air}$ = Risk-based threshold level in indoor air [mg/m^3 10^{-3}= Conversion factor [L/m^3] VF_{wesp} = Volatilization factor for groundwater to enclosed space air

5.5 Steady-state Groundwater Attenuation SSTL Algorithm

$\frac{C(x)}{C_{source}}$: [(g/cm^3-$H_2$0)/g/cm^3-$H_2$0)] along the centerline (x, y = 0, z = 0) of a dissolved plume:

$$\frac{C(x)}{C_{source}} = exp\left[\frac{x}{2\alpha_x}\left[1-\sqrt{1+\frac{4\lambda\alpha_x}{u}}\right]\right]\times erf\left[\frac{S_w}{4\sqrt{\alpha_y x}}\right]\times erf\left[\frac{S_d}{4\sqrt{\alpha_z x}}\right]$$

Where:

$u = (K_s \text{ x } i)/\theta_s$

And:

$C_{source} = C_{leaching} + C_{max\ gw}$

And:

$C_{leaching} = C_{max\ soil} \text{ x } LF_{sw}$

Source: ASTM E1739-95 (reapproved 2015)

where:
$C(x)$ = Dissolved-phase concentration [mg/L]
C_{source} = Dissolved hydrocarbon concentration in dissolved plume source area [mg/L]
x = Distance along the centerline from the plume source zone or source well [cm]
λ = First-order degradation constant [1/year]
u = Specific discharge [cm/day]
α_x = Longitudinal dispersivity [cm] (0.10x)
α_y = Transverse dispersivity [cm] (α_x/3)
α_z = Vertical dispersivity [cm] (α_x/20)
S_w = Groundwater source width perpendicular to flow in the horizontal direction [cm]
S_d = Groundwater source depth perpendicular to flow in the vertical direction [cm]
K_s = Saturated hydraulic conductivity [cm/day]
i = Groundwater gradient [cm/cm]
θ_s = Volumetric water content of saturated zone [cm^3-H_2O/cm^3-soil]
$C_{max\ gw}$ = Maximum groundwater COC concentration [µg/L)
$C_{max\ soil}$ = Maximum soil COC concentration [mg/kg]

5.6 Soil to Groundwater Leachate Pathway SSTL Supporting Algorithm

LF_{sw}: Soil to groundwater leaching factor [mg/kg-soil]

$$LF_{SW} = \frac{\rho_s}{[\theta_{ws} + K_s \rho_s + H \times \theta_{as}] \times \left(1 + \frac{U_{gw} \times \delta_{gw}}{IW}\right)}$$

Where:

$$K_s = f_{oc} \text{ x } k_{oc}$$

And:

$$C_{leaching} = C_{max\ soil} \text{ x } LF_{sw}$$

Source: ASTM E1739-95 (reapproved 2015)

where:
ρ_s = Soil bulk density [g-soil/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
Ks = Saturated hydraulic conductivity [cm/day]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
U_{gw} = Groundwater Darcy Velocity [cm/year]
δ_{gw} = Groundwater mixing zone thickness [cm]
I = Infiltration rate of water through soil [cm/year]
W = Width of soil source area parallel to groundwater flow [cm]
k_{oc} = Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil]
f_{oc} = Fractional organic carbon content in the unsaturated zone [(g-C)/(g-soil)]
$C_{leaching}$ = COC concentration in groundwater contributed by leaching from soil [mg/kg]
$C_{max\ soil}$ = Maximum soil COC concentration [mg/kg]

5.7 Soil Concentration at Saturation SSTL Supporting Algorithm

C_{soil}^{sat}: Soil concentration at which dissolved pore-water and vapor phases become saturated [mg/kg-soil] $C_{soil}^{sat} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_s \rho_s]$ Where: $K_s = f_{oc}$ x k_{oc} **Source:** ASTM E1739-95 (reapproved 2015)	where: S = Pure component solubility in water [mg/L-H_2O] ρ_s = Dry soil bulk density [g-soil/cm^3-soil] H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)] θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil] θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil] Ks = Saturated hydraulic conductivity [cm/day] k_{oc} = Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil] f_{oc} = Fractional organic carbon content in the unsaturated zone [(g-C)/(g-soil)]

Appendix C.1. - Chemical and Physical Properties of Chemicals of Concern*

Chemicals of Concern (COCs)	Pure Component Solubility in H_20 (S) [mg/L]	Henry's Law Constant (H) [L-H_20/L-air]	Carbon-H_20 Sorption Coeff. (k_{oc}) [mL/g]	Soil-H_20 Sorption Coeff. (k_s) [mL/g]	Diffusion Coefficient		Soil Saturation Concen. ($C_{satsoil}$) [mg/kg]
					in air (D^{air}) [cm^2/s]	in H_20 (D^{wat}) [cm^2/s]	
ORGANICS							
Benzene	1.75E+03	2.30E-01	8.30E+01	8.30E-01	9.30E-02	1.10E-05	1.67E+03
Toluene	5.30E+02	2.70E-01	2.30E+02	2.30E+00	7.80E-02	9.20E-06	7.94E+02
Ethyl benzene	1.70E+02	3.20E-01	4.50E+02	4.50E+00	6.80E-02	8.50E-06	1.98E+03
Xylenes (mixed)	1.10E+02	2.70E-01	3.800E+02	3.80E+00	6.90E-02	8.50E-06	5.03E+02
MTBE**	5.10E+04	2.40E-02	1.20E+01	1.20E-01	7.50E-02	8.60E-06	1.02E+04
Naphthalene	3.10E+01	4.90E-02	1.29E+03	1.29E+01	7.20E-02	9.40E-06	4.03E+02
1-Methylnaphthalene	2.60E+01	2.10E-02	2.50E+03	2.50E+01	5.30E-02	7.80E-06	2.08E+02
1,2,4-Trimethylbenzene	5.70E+01	2.50E-01	6.10E+02	2.50E+04	6.10E-02	7.90E-06	1.1E+02[A]
Benzo(a)pyrene	1.60E-03	1.9E-05	3.89E+05	3.89E+03	5.00E-02	5.80E-06	4.67E+00
EDB	3.90E+03	2.66E-02	4.00E+01	4.00E-01	4.30E-02	1.00E-05	8.32E+03
EDC	8.60E+03	4.80E-02	4.00E+01	4.00E-01	8.60E-02	1.10E-06	2.27E+03
METALS							
Lead	NA	0.00E+00	1.22E+02	9.30E-01	NA	NA	NA

*ASTM 1739-95 (Reapproved 2015) unless otherwise noted
US EPA (May 2018) Regional Screening Levels (RSLs) Chemical-specific Parameters Supporting Table
[A] Michigan DEQ (May 2007Revision) RRD Operational Memorandum No. 1, Attachment 8, Appendix 1

Appendix C.2. Biodegradation Rates

Chemicals of Concern (COCs)	First Order Degradation Rate (λ) [day ^{1}]
Benzene†	0.035
Toluene†	0.062
Ethyl benzene†	0.060
Xylenes (mixed)†	0.026
Naphthalene††	0.039
1-Methylnaphthalene†††	0.039
1,2,4-Trimethylbenzene	0.020
Benzo(a)pyrene†	0.003
MTBE†	0.004
EDB†	0.021
EDC†	0.004

† Howard, P. Handbook of Environmental Degradation Rates, Lewis Publishing, 1991 (Range averaged values applied and rounded to 3 decimal places). ASTM 1739-95 (Reapproved 2015), includes Howard Reference for some COCs. The Howard reference was consulted for the remaining values, unless otherwise noted.

(Note: From Howard, λ [day^{-1}] = (0.693/$t_{1/2}$)

††Illustrated Handbook of Physical Properties and Environmental Fate for Organic Chemicals, Volume I, II, & III, Mackay, D. Lewis Publishing, 1991

†††value for Naphthalene used

Appendix D - Toxicological Properties of COCs†

Chemicals of Concern (COCs)		Cancer Toxicity		Non-cancer Toxicity	
		Oral (*CSF_o*) [kg-day/mg]	Inhal. (*IUR*) [µg/m^3]$^{-1}$	Oral (*RfD_o*) [mg/kg-day]	Inhal. (*RfC*) [mg/m^3]
CAS No.	**ORGANICS**				
71-4-32	Benzene	5.50E-02	7.80E-06	4.00E-03	3.00E-02
108-88-3	Toluene	NA	NA	8.00E-02	5.00E-00
100-41-4	Ethyl benzene	1.10E-02	2.50E-06	1.00E-01	1.00E-00
1330-20-7	Xylenes (Total)	NA	NA	2.00E-01	1.00E-01
91-20-3	Naphthalene	NA	NA	2.00E-02	3.00E-03
90-12-0	1-Methylnaphthalene	2.90E-02	NA	7.00E-02	2.90E-02
91-57-6	1,2,4-Trimethylbenzene	NA	NA	1.0E-02	6.0E-02
1634-04-4	Methyl Tert-Butyl Ether (MTBE)	1.80E-03	2.60E-07	NA	3.00E-00
50-32-8	Benzo(a)pyrene	7.3	1.10E-03	NA	NA
106-93-4	1,2-Dibromoethane (EDB)	2.00E-00	0.60E-04	9.00E-03	9.00E-03
107-06-2	1,2-Dichloroethane (EDC)	9.10E-02	2.60E-05	6.00E-03	7.00E-03
CAS No.	**TOTAL PETROLEUM HYDROCARBONS (TPH)**				
--	DRO (TPH - aliphatic medium)	NA	NA	1.00E-02	1.00E-01
--	RRO/ORO (TPH - aliphatic high)	NA	NA	3.00E-00	NA
CAS No.	**METALS**				
7439921	Lead	NA	NA	NA	NA

†All values obtained from USEPA Regional Screening Level Summary Table (May 2016)

Appendix E – Receptor Exposure Factors

Exposure Parameter	Symbol	Unit	RBTL Value	SSTL Value	Source[C,D]
Averaging Time for Carcinogen	AT_c	year	70	70	ASTM 2015
Averaging Time for Non-Carcinogen	AT_{nc}		= ED	= ED	ASTM 2015
Body Weight:					
Resident Child	*BW*	kg	15	15	EPA 2015
Resident Adult			80	80	EPA 2015
Nonresidential Worker			80	80	EPA 2015
Exposure Duration:					
Resident Child	*ED*	year	6	6	ASTM 2015
Resident Adult			26	26	EPA 2015
Nonresidential Worker			25	25	ASTM 2015
Excavation Worker - Soil			1	NA	BPJ
Excavation Worker - Trench Groundwater			1	NA	VDEQ
Mutagenic Exposure Duration:					
Resident - Mutagenic Exposure Duration (0-2 years)	*ED*	year	2	2	ASTM 2015
Resident - Mutagenic Exposure Duration (2-6 years)			4	4	ASTM 2015
Resident - Mutagenic Exposure Duration (6-16 years)			10	10	ASTM 2015
Resident - Mutagenic Exposure Duration (16-26 years)			10	10	ASTM 2015
Mutagenic Age Adjustment Factor:					
Resident - Mutagenic Age-Dependent Adjustment Factor (0-2 years)	*EF*	year	10	10	ASTM 2015
Resident - Mutagenic Age-Dependent Adjustment Factor (2-6 years)			3	3	ASTM 2015
Resident - Mutagenic Age-Dependent Adjustment Factor (6-16 years)			3	3	ASTM 2015
Resident - Mutagenic Age-Dependent Adjustment Factor (16-26 years)			1	1	ASTM 2015
Exposure Frequency:					
Resident Child	*EF*	days/year	350	350	ASTM 2015
Resident Adult			350	350	ASTM 2015
Nonresidential Worker			250	250	ASTM 2015
Excavation Worker - Soil			30	NA	ASTM 2015
Excavation Worker - Trench Groundwater			125	NA	VDEQ 2016

Groundwater Ingestion Rate					
Resident Child	IR_w	L/day	0.78	0.78	EPA 2015
Resident Adult			2.5	2.5	EPA 2015
Nonresidential Worker			1	1	ASTM 2015
Excavation Worker - Trench Groundwater			0.02	NA	VDEQ 2016
Skin Surface Area for Dermal Contact with Water:					
Resident Child	SA_w	cm^2	6,365	6,365	EPA 2015
Resident Adult			19,652	19,652	EPA 2015
Nonresidential Worker			3,527	3,527	EPA 2015
Exposure Time for Dermal Contact with Water:					
Resident Child	t_{event}	hours/event	0.54	0.54	EPA 2015
Resident Adult			0.71	0.71	EPA 2015
Nonresidential Worker			1	1	EPA 2015
Event Frequency for Dermal Contact with Water:					
Resident Child	t_{event}	hours/event	0.54	0.54	EPA 2015
Resident Adult			0.71	0.71	EPA 2015
Soil Ingestion Rate:					
Resident Child	*IRs*	mg/day	200	200	EPA 2015
Resident Adult			100	100	EPA 2015
Nonresidential Worker			100	100	ASTM 2015
Excavation Worker			330	330	VDEQ 2016
Skin Surface Area for Dermal Contact with Soil:					
Resident Child	SA_{soil}	cm^2	2,373	0.78	EPA 2015
Resident Adult			6,032	2.5	EPA 2015
Nonresidential Worker			3,527	1	ASTM 2015
Excavation Worker			3,527	NA	VDEQ 2016
Soil to Skin Adherence Factor:					
Resident Child	*AF*	mg/cm^2	0.2	0.2	EPA 2015
Resident Adult			0.07	0.07	EPA 2015
Nonresidential Worker			0.12	0.12	ASTM 2015
Excavation Worker			0.3	0.3	VDEQ 2016
Hourly Indoor Inhalation Rate:					
Resident Child	$IR_{air\text{-}Indoor}$	m^3/d	15	15	EPA 2015
Resident Adult			15	15	EPA 2015
Non-Residential Worker			20	20	EPA 2015
Exposure Time for Hourly Indoor Inhalation Rate:					
Resident	*ET*	hr/day	24	24	ASTM 2015
Nonresidential Worker			8	12[F]	EPA 2015
Excavation Worker - Soil			10	NA	ASTM 2015
Excavation Worker - Trench Groundwater			4	NA	VDEQ 2016

Target Risk Level for Ingestion[E] and/or Inhalation:					
Resident	*TR*	unitless	1.00E-06	1.00E-05	EPD
Nonresident			1.00E-06	1.00E-05	EPD
Target Hazard Quotient:	*THQ*	unitless	1	1	EPD

BPJ - Best professional judgment
NA - not available or not applicable
A - All values obtained from USEPA Regional Screening Level Summary Table (May 2016).
B - TPHs are evaluated during UST system closure only. Carbon ranges for DRO/ORO do not correlate with TPH ranges. EPD has no policy on how to extrapolate from DRO/ORO data to TPH values. However, RBTLs for aliphatic medium and aliphatic high have been applied for diesel-range organics (DRO) and residual-range organics (RRO), respectively. This approach has also been adopted in other states and EPA regions.
C - ASTM Standard Guide for Risk -based Corrective Action Applied at Petroleum Release Sites - Designation E1739-95 (reapproved 2015).
D - EPA OSWER Directive 9200.1-120 Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors (2015).
E - Target Risk Level for Ingestion source is ASTM.
F. – Best Professional Judgment. The USTMP recognizes the changing demographic of UST facility ownership during the history of the program. The value selected conservatively recognizes many owners operating or managing their facility in excess of the 8-10-hour day.

Appendix F: GA USTMP Determination of Soil Classes

Soil properties significantly impact the algorithms used in any risk evaluation process. Examples of soil properties are volumetric air content, volumetric water content, saturated porosity, effective porosity, hydraulic conductivity, fraction of organic carbon, soil bulk density, etc. Nationally, regulatory agencies have the choice to integrate field collected soil property data from the petroleum release investigation results, adopt soil property literature values published from numerous nationally credible sources or integrate both.

The GRBCA Workbook soil and groundwater evaluation processes integrate soil property data selected from several leading and nationally recognized organizations. Literature value source may include, but are not limited to:

1. Professional and/or national standards organizations' published default values.
2. Federal, State and/or Local Government agency defined criteria (including regionally specific criteria),
3. Published literature values derived from research using laboratory or field-controlled experiments; and/or,
4. Site-specific approval of field collected data including specific test methods and/or sample collection and analysis procedures.

Adoption of default soil property values that impact the overall outcome of the site risk evaluation has practical and cost related benefits in the application of a risk evaluation process; however, inherent uncertainties exist with either site-specific, field collected data and/or adoption of published literature value ranges. Specifically, soil heterogeneities endemic at almost any given UST sites can be confirmed or determined by soil property laboratory analysis for analyzed soil samples, but where or how soil samples were collected, may or may not be representative of the more predominant soil conditions present.

Alternatively, adopted literature value or range results for a soil type or class may have improved accuracy for the defined soil textures, but does little to confirm what site-specific analysis might otherwise provide. With disparity in mind and in consideration of developing a streamlined and cost effective risk evaluation process for all petroleum sites, soil property data in the GRBCA workbook will use a combination of National Standards Organizations' published default values, research driven literature value ranges and/or may include some site-specific data. This will expedite the USTMP risk evaluation process. How soil properties are evaluated in the GRBCA process is presented below. The approach taken is reflective of any given site's propensity for heterogeneities within a given soil lithology, including any relict structure within the soil profile inherited from the parent formation or depositional environment.

The primary data source for the soil property evaluation is **Documentation for EPA's Implementation of the Johnson and Ettinger Model to Evaluate Site Specific Vapor Intrusion Into Buildings, Version 6.0**, Prepared by: US Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation, Revised September 2017. Other documentation and support are provided the **Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites, ASTM E1739-95 (Rapproved2015)**.

USTMP Soil Texture Triangle Evaluation Process Leading to Soil Class Determinations

The soil texture triangle (Figure 1) is a well published and referenced resource with twelve (12) textures representing the ratio or percent volume of Clay, Silt and Sand plus soil properties unique to each defined soil texture. The named soil textures within the triangle also occupy a volume of the total triangle. Figure 1 depicts the soil textures and contains 100 sub-triangles comprising the total triangle volume. Each soil texture is composed of a defined volume of these sub-triangles.

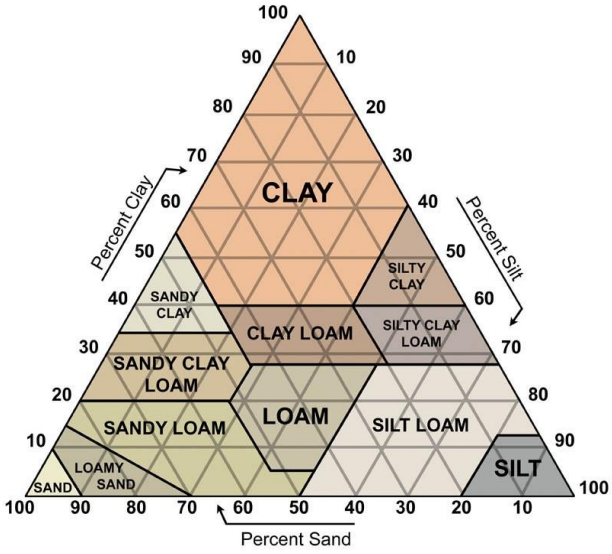
Figure 1 evaluates the inorganic component ratios of Sand, Silt and Clay and each of the twelve (12) soil textures is defined by a specific ratio. The USTMP evaluated whether to use the existing soil texture classifications, or to define soil classes using a combination of soil textures. Many soil textures to choose from requires high accuracy and volume in field data collection from a media that is inherently heterogeneous. Alternatively combining soil textures into a large soil class requires less accuracy and volume of field collected data with only minor to moderate adjustments in soil property values. In keeping the initial consideration of developing a streamlined and cost-effective risk evaluation process for all petroleum sites, soil property data in the GRBCA workbook will use three (3) USTMP defined soil classes (CLAY, SILT and SAND) in addition to Bedrock (default) parameters.

Loam is a key soil texture and is present near the center of the soil texture triangle. Loam includes similar proportions of Silt and Clay (~40%) and Sand about half (~20%) of the Silt or Clay values. Some sources also define Loam as equal proportions of Clay, Silt and Sand. Because of the relative balance of the components found in Loam, the USTMP decided to omit Loam from further evaluation within the soil triangle for the remaining three soil class evaluation.

The USTMP process to determine which soil textures are included within each Soil Class is listed below. The following steps use "CLAY" as an example, however the same steps apply to "SILT" and "SAND":

1. Determine the volume of each soil texture within the overall soil triangle (Table 1)
2. Identify all soil textures that include "CLAY" within the texture title and the aggregate the CLAY Class
   (Rule: Any two (2) Soil Classes that include a qualifier from another primary triangle texture (CLAY, SILT, SAND) may share a soil texture between classes. For example, Silty Clayey SAND shares both "Silt" and "Clay" as qualifiers in the SAND name. The soil is primarily a LOAM, indicating a standard ratio of Sand, Silt and Clay defining LOAM; however, the texture also includes qualified levels of Silt and Clay. Therefore, the texture qualifier may allow the Texture to be included for the qualifier(s) listed.)
3. For the newly defined CLAY Class, the volume of the class was determined through application of #1 and #2 above, to the soil texture triangle. The resulting weight percent value of the total Class was determined, as well as, the individual weight percent value of each contributing texture within the Class.
4. The weight percent of the individual texture was then applied to the published soil property values for the texture; and,
5. The last step was to then sum the weight percent fractions of all related soil texture properties within the defined CLAY Class to determine the final set of soil property values for the CLAY Class.

Figure 1: Soil Texture Triangle



Source: Dingman Physical Hydrology, Second Edition, 2002©

Table 1 Individual Soil Texture Area within Total Soil Triangle

Table 1: Individual Soil Texture Area within Total Soil Triangle	
Soil Texture	**# of ▲'s**
Clay	29.75
Clay Loam	6.19
Loam	8.25
Loamy Sand	3.50
Sand	1.00
Sandy Clay	4.00
Sandy Clay Loam	7.63
Sandy Loam	10.75
Silt	3.44
Silt Loam	16.50
Silty Clay	4.00
Silt Clay Loam	5.00
Soil Text. Sub-Total:	**100.00**
Soil Text. ▲ Total:	**100.00**

Soil Class: CLAY

Soil Class – **CLAY**: Soil textures within this reddish-brown shaded zone below define CLAY. The resulting soil property values listed in Table 2, 3A and 3B (below), apply to Item #1 of the AOC SSTL Report in the GRBCA Workbook. Each soil texture within the defined soil class, contributes individual properties by property weight percent. For each soil property, the sum of all the weight percent values determines the total value for each soil property within the class.

Figure 2: Soil Class CLAY Soil Textures

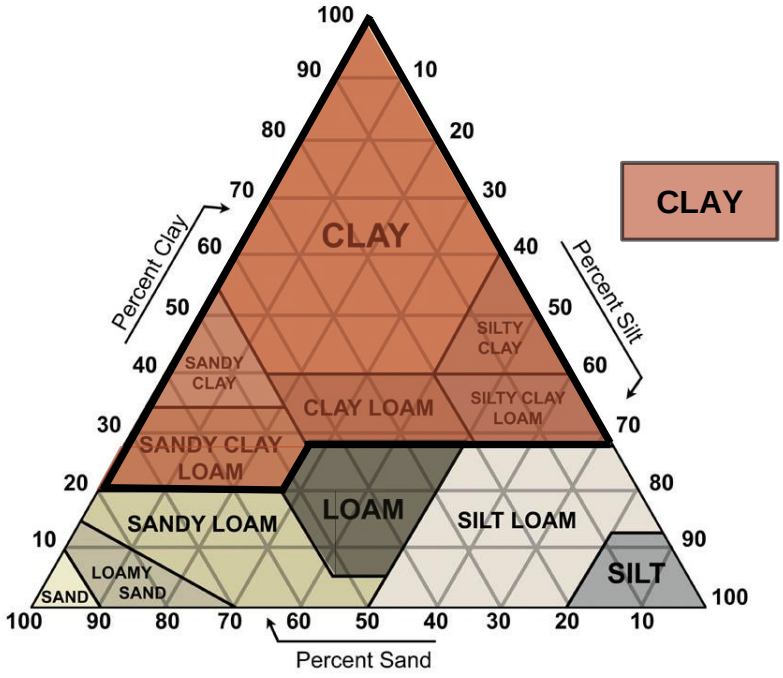


Table 2: CLAY Soil Textures by Weight %

GA USTMP SOIL CLASS: CLAY			
	CLAY Soil Class Area = # of ▲'s summed for all soil textures included in the soil class.		
CLAY Soil Textures:	**# of ▲'s per Soil Texture**	**Total # of ▲'s in Class**	**Soil Texture Weight %**
Clay	29.75	56.56	0.53
Clay Loam	6.19	56.56	0.11
Silty Clay Loam	5.00	56.56	0.09
Silty Clay	4.00	56.56	0.07
Sandy Clay Loam	7.63	56.56	0.13
Sandy Clay	4.00	56.56	0.07
Total #CLAY▲'s:	56.56	**Weight % Total:**	1.00

Table 3A: USTMP GRBCA CLAY Soil Properties (Volumetric Water and Air Porosities)

Table 3A: GA USTMP Soil Class: CLAY		Volumetric Water Content Cap. Fringe Soils (soil text. wt. %) (w_{cap}) (cm3/cm3)	Volumetric Air Content Cap. Fringe Soils (soil text. wt.%) (θ_{acap}) (cm3/cm3)	Volumetric Water Content Vadose Soils (soil text. wt. %) (θ_{ws}) (cm3/cm3)	Volumetric Air Content Vadose Soils (soil text. wt. %) (θ_{as}) (cm3/cm3)	Volumetric Water Content Fndn/wall Cracks (soil text. wt. %) (θ_{wcrack}) (cm3/cm3)	Volumetric Air Content Fndn/wall Cracks (soil text. wt. %) (θ_{acrack}) (cm3/cm3)
CLAY Soil Textures:	**Soil Texture** (Weight %)						
Clay	0.53	0.217	0.076	0.113	0.128	0.113	0.128
Clay Loam	0.11	0.041	0.007	0.018	0.030	0.018	0.030
Silty Clay Loam	0.09	0.035	0.004	0.018	0.021	0.018	0.021
Silty Clay	0.07	0.030	0.004	0.015	0.019	0.015	0.019
Sandy Clay Loam	0.13	0.045	0.007	0.020	0.032	0.020	0.032
Sandy Clay	0.07	0.025	0.002	0.014	0.013	0.014	0.013
Weight % Total:	1.00						
	Total Value:	**0.393**	**0.100**	**0.198**	**0.244**	**0.198**	**0.244**

Table 3B: USTMP GRBCA CLAY Soil Properties (Physical Properties)

Table 3B: GA USTMP Soil Class: CLAY		Capillary Fringe Thickness (soil text. wt. %) (h_{cap}) (cm)	Total Porosity (soil text. wt. %) (θ_t) (cm3/cm3)	Dry Bulk Density (soil text. wt. %) (ρ_s) (g/cm3)	Saturated Hydraulic Conductivity (soil text. wt. %) (K) (cm3/day)
CLAY Soil Textures:	**Soil Texture** (Weight %)				
Clay	0.53	42.88	0.241	0.75	7.68
Clay Loam	0.11	5.13	0.048	0.16	0.89
Silty Clay Loam	0.09	11.84	0.039	0.12	0.98
Silty Clay	0.07	13.59	0.034	0.10	0.68
Sandy Clay Loam	0.13	3.49	0.052	0.22	1.78
Sandy Clay	0.07	2.12	0.027	0.12	0.80
Weight % Total:	1.00				
	Total Value:	**79.04**	**0.44**	**1.47**	**12.80**

Soil Class: SILT

Soil Class - **SILT**: Soil textures within this brownish gray shaded zone below define SILT. The resulting soil property values listed in Table 4 and 5A and 5b (below), apply to Item #1 of the AOC SSTL Report in the GRBCA Workbook. Each soil texture within the defined soil class, contributes individual properties by property weight percent. For each soil property, the sum of all the weight percent values determines the total value for each soil property within the class.

Figure 3: Soil Class SILT Soil Textures

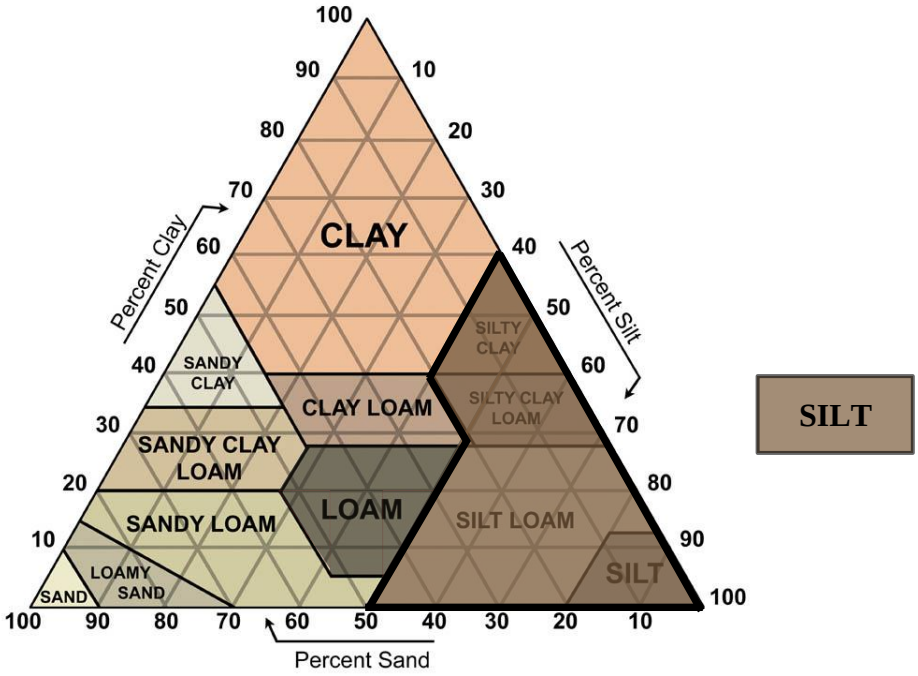


Table 4: SILT Soil Textures by Weight %

GA USTMP SOIL CLASS: SILT			
SILT Soil Textures Include:	**SILT Soil Class Area** = # of ▲'s summed for all soil textures included in the soil class.		
	# of ▲'s per Soil Texture	**Total # of ▲'s in Class**	**Soil Texture Weight %**
Silt	3.44	28.94	0.12
Silt Loam	16.50	28.94	0.57
Silt Clay Loam	5.00	28.94	0.17
Silty Clay	4.00	28.94	0.14
Total #SILT▲'s:	**28.94**	**Weight % Total:**	**1.00**

Table 5A: USTMP GRBCA SILT Soil Properties (Volumetric Water and Air Porosities)

Table 6A: GA USTMP Soil Class: SILT		**Volumetric Water Content Cap. Fringe Soils** (soil text. wt. %) **(w_{cap})** (cm3/cm3)	**Volumetric Air Content Cap. Fringe Soils** (soil text. wt.%) **(θ_{acap})** (cm3/cm3)	**Volumetric Water Content Vadose Soils** (soil text. wt. %) **(θ_{ws})** (cm3/cm3)	**Volumetric Air Content Vadose Soils** (soil text. wt. %) **(θ_{as})** (cm3/cm3)	**Volumetric Water Content Fndn/wall Cracks** (soil text. wt. %) **(θ_{wcrack})** (cm3/cm3)	**Volumetric Air Content Fndn/wall Cracks** (soil text. wt. %) **(θ_{acrack})** (cm3/cm3)
SILT Soil Textures:	**Soil Texture** (Weight %)						
Silt	0.12	0.045	0.018	0.020	0.038	0.020	0.038
Silt Loam	0.57	0.199	0.051	0.103	0.148	0.103	0.148
Silt Clay Loam	0.17	0.069	0.007	0.034	0.042	0.034	0.042
Silty Clay	0.14	0.059	0.008	0.030	0.037	0.030	0.037
Weight % Total:	1.00						
	Total Value:	**0.372**	**0.084**	**0.187**	**0.264**	**0.187**	**0.264**

Table 5B: USTMP GRBCA SILT Soil Properties (Physical Properties)

Table 6B: GA USTMP Soil Class: SILT		**Capillary Fringe Thickness** (soil text. wt. %) **(h_{cap})** (cm)	**Total Porosity** (soil text. wt. %) **(θ_t)** (cm3/cm3)	**Dry Bulk Density** (soil text. wt. %) **(ρ_s)** (g/cm3)	**Saturated Hydraulic Conductivity** (soil text. wt. %) **(K)** (cm3/day)
SILT Soil Textures:	**Soil Texture** (Weight %)				
Silt	0.12	19.37	0.058	0.16	5.19
Silt Loam	0.57	38.88	0.250	0.85	10.40
Silt Clay Loam	0.17	23.14	0.076	0.24	1.91
Silty Clay	0.14	26.56	0.066	0.19	1.33
Weight % Total:	1.00				
	Total Value:	**107.94**	**0.45**	**1.44**	**18.82**

Soil Class: SAND

Soil Class- **SAND**: Soil textures within this than shaded zone below define SAND. The resulting soil property values listed in Table 6 and 7A and 7B (below), apply to Item #1 of the AOC SSTL Report in the GRBCA Workbook. Each soil texture within the defined soil class, contributes individual properties by property weight percent. For each soil property, the sum of all the weight percent values determines the total value for each soil property within the class.

Figure 4: Soil Class SAND Soil Textures

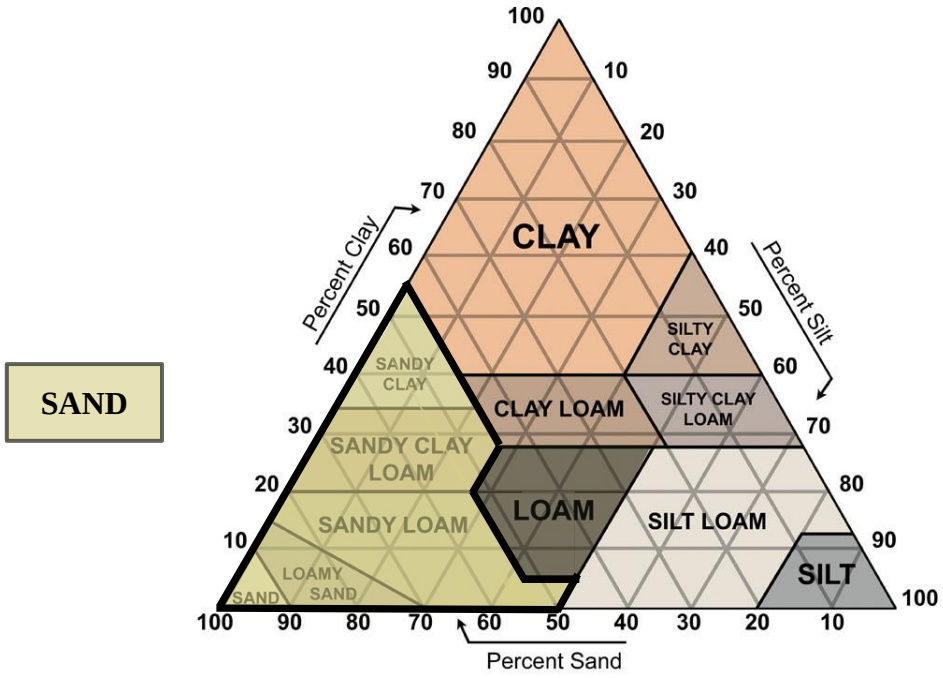


Table 6: SAND Soil Textures by Weight %

GA USTMP Soil Texture Class: SAND			
	SAND Soil Class Area = # of ▲'s summed for all soil textures included in the soil class.		
SAND Soil Textures:	**# of ▲'s per Soil Texture**	**Total # of ▲'s in Class**	**Soil Texture Weight %**
Sand	1.00	26.88	0.04
Loamy Sand	3.50	26.88	0.13
Sandy Loam	10.75	26.88	0.40
Sandy Clay Loam	7.63	26.88	0.28
Sandy Clay	4.00	26.88	0.15
Total #CLAY▲'s:	**26.88**	**Weight % Total:**	**1.00**

Table 7A: USTMP GRBCA SAND Soil Properties (Volumetric Water and Air Porosities)

Table 3A: GA USTMP Soil Class: SAND		Volumetric Water Content Cap. Fringe Soils (soil text. wt. %) (w_{cap}) (cm3/cm3)	Volumetric Air Content Cap. Fringe Soils (soil text. wt.%) (θ_{acap}) (cm3/cm3)	Volumetric Water Content Vadose Soils (soil text. wt. %) (θ_{ws}) (cm3/cm3)	Volumetric Air Content Vadose Soils (soil text. wt. %) (θ_{as}) (cm3/cm3)	Volumetric Water Content Fndn/wall Cracks (soil text. wt. %) (θ_{wcrack}) (cm3/cm3)	Volumetric Air Content Fndn/wall Cracks (soil text. wt. %) (θ_{acrack}) (cm3/cm3)
SAND Soil Textures:	**Soil Texture** (Weight %)						
Sand	0.04	0.009	0.004	0.002	0.012	0.002	0.012
Loamy Sand	0.13	0.039	0.011	0.010	0.041	0.010	0.041
Sandy Loam	0.40	0.128	0.027	0.041	0.114	0.041	0.114
Sandy Clay Loam	0.28	0.094	0.014	0.041	0.068	0.041	0.068
Sandy Clay	0.15	0.053	0.004	0.029	0.028	0.029	0.028
Weight % Total:	1.00	**0.324**	**0.061**	**0.124**	**0.262**	**0.124**	**0.262**
	Total Value:						

Table 7B: USTMP GRBCA SAND Soil Properties (Physical Properties)

Table 3B: GA USTMP Soil Class: SAND		Capillary Fringe Thickness (soil text. wt. %) (h_{cap}) (cm)	Total Porosity (soil text. wt. %) (θ_t) (cm3/cm3)	Dry Bulk Density (soil text. wt. %) (ρ_s) (g/cm3)	Saturated Hydraulic Conductivity (soil text. wt. %) (K) (cm3/day)
SAND Soil Textures:	**Soil Texture** (Weight %)				
Sand	0.04	0.63	0.014	0.06	23.92
Loamy Sand	0.13	2.44	0.051	0.21	13.69
Sandy Loam	0.40	10.00	0.155	0.65	15.36
Sandy Clay Loam	0.28	7.34	0.109	0.46	3.75
Sandy Clay	0.15	4.47	0.057	0.24	1.68
Weight % Total:	1.00	**24.88**	**0.39**	**1.63**	**58.39**
	Total Value:				

Appendix G – Soil Dependent Properties and Hydrogeological Parameters [+]

Symbol	Definition	Units	How Value Determined	Predominant Soil Class: *A & C, unless otherwise noted*				
				CLAY	SILT	SAND	Bedrock	Default
h_{cap}	thickness of capillary fringe	cm	literature value	79.04	107.94	24.88	5.0[B]	5.0[B]
h_v	thickness of vadose zone	cm	$= L_{gw}^{*} - h_{cap}$[B]	*Site Specific*	*Site Specific*	*Site Specific*	*Site Specific*	*Site Specific*
U_{gw}	GW Darcy velocity	cm/yr	$= (K \times i^{**})365$[B]	*Site Specific*	*Site Specific*	*Site Specific*	*Site Specific*	*Site Specific*
u	specific discharge	cm/day	$= (K \times i)/\eta_{eff}$[B]	*Site Specific*	*Site Specific*	*Site Specific*	*Site Specific*	*Site Specific*
q_{acap}	volumetric air content in capillary fringe soils	cm^3_{air}/cm^3_{soil}	$\theta_{wcap} = \theta_t(0.1)$[B]	0.044	0.045	0.039	0.030	0.030
q_{as}	volumetric air content in vadose zone soils	cm^3_{air}/cm^3_{soil}	$= (\theta_t)(0.26/0.38)$[B]	0.244	0.264	0.262	0.205	0.205
q_T	total soil porosity	cm^3/cm^3_{soil}	literature value	0.44	0.45	0.39	0.30[C]	0.30[C]
η_{eff}	effective porosity	cm^3/cm^3_{soil}	literature value	0.06[C]	0.20[C]	0.31[C]	0.17[C]	0.17
q_{wcap}	volumetric water content in capillary fringe soils	cm^3_{H2O}/cm^3_{soil}	$\theta_{wcap} = \theta_t(0.9)$[B]	0.397	0.406	0.347	0.270	0.270
q_{ws}	volumetric water content in vadose zone soils	cm^3_{H2O}/cm^3_{soil}	$= (\theta_t)(0.12/0.3)$[B]	0.198	0.187	0.124	0.095	0.095
K	hydraulic conductivity (saturated)	cm/day	literature value	12.80	18.82	58.39	86.40[E]	86.40[E]
f_{oc}	fraction of organic carbon	g_c/g_{soil}	literature value	0.01[B]	0.01[B]	0.01[B]	0.01[B]	0.01[B]
ρ_s	soil bulk density	g_{soil}/cm^3_{soil}	literature value	1.47	1.44	1.63	1.70[B]	1.70[B]

*where L_{gw} = Depth to groundwater [cm] (default depth = 300 cm)
**where i = Groundwater gradient [cm/cm]
A - EPA - Documentation for EPA's Implementation of the J & E Model to Evaluate Site Specific Vapor Intrusion into Buildings, Version 6.0 (September 2017). Appendix F,
B - ASTM E 1739 - 95 (Reapproved 2015).
C - Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil and Building Structures (September 2015)
- http://web.ead.anl.gov/resrad/datacoll/porosity.html (Arithmetic Mean) (Argonne National Lab).
E - ADEM - Alabama Risk-based Corrective Action Guidance Manual (April 2008, Revision 2)

Appendix H –Building Characteristics and Meteorological Parameters

(Not included in Appendix G)

SOIL PARAMETERS NOT INCLUDED IN APPENDIX G						
Symbol	**Definitions**	**Units**	**Residential**	**Nonresidential**	**Excavation**	**Default**
i	Infiltration Rate					0.005
W	Width of soil source area parallel to GW flow direction	cm	1500	1500		1500
L_s	Depth to subsurface soil sources	cm				30.48
d	Lower depth to surficial soil sources	cm				30.48
L_{crack}	Enclosed space foundation or wall thickness	cm	15	15		15
GROUNDWATER PARAMATERS NOT INCLUDED IN APPENDIX G						
Symbol	**Definitions**	**Units**	**Residential**	**Nonresidential**	**Excavation**	**Default**
L_{GW}	Depth to groundwater = $h_{cap} + h_v$	cm				300
S_d	Width of groundwater source area perpendicular to GW flow direction	cm	1500	1500		1500
δ_{gw}	Groundwater mixing zone thickness	cm				200
I	Infiltration rate of H_2O through soil	cm/yr	30	30		30
AMBIENT AIR						
δ_{gw}	Breathing Zone Height	cm				200
U_a	Wind Speed with Breathing Zone	cm/s				225

Appendix H – Building Characteristics and Meteorological Parameters (Not included in Appendix G) (continued)

GROUNDWATER PARAMATERS NOT INCLUDED IN APPENDIX G						
ENCLOSED SPACE						
ER	Enclosed space air exchange rate	s^{-1}	0.00014	0.00023		0.00023
L_B	Enclosed space volume/infiltration area ratio	cm	200	300		300
L_{crack}	Enclosed Space Foundation or Wall thickness	cm	15	15		15
η	Areal fraction of cracks in foundation/walls	cm^2/cm^2	0.01	0.01		0.01

* L_{gw} = Depth to groundwater [cm]

† i = Groundwater gradient [cm/cm]

A - https://archive.epa.gov/epawaste/hazard/web/pdf/appg-i.pdf (Table G-4) (Fetter94).

B - ASTM E 1739 - 95 (Reapproved 2015).

C - Fetter, C. W., Applied Hydrogeology - 3rd ed., 1994. (Average of the range).

D - http://web.ead.anl.gov/resrad/datacoll/porosity.html (Arithmetic Mean) (Argonne National Laboratory).

E - http://web.ead.anl.gov/resrad/datacoll/porosity.html (Average of the range) (Argonne National Laboratory).

F - Fetter, C. W., Applied Hydrogeology - 3rd ed., 1994.

Appendix I – Process to Determine the Applicable COC Selections in GRBCA workbook

This appendix provides the evaluation and decision matrix used to define the COCs included on each set of data entry and comparison tables imported by the RBTL Worksheet within the GRBCA workbook. The table defines the COCs for the SSTLS and Site Summary Report Tables. The COC selection is driven by REFERENCE 1 (below), which has been modified to add a color code key. The color code captures the various combinations of groundwater and surface water usages that are possible at a UST release site.

Table 1, (the REFERENCE 1 COLOR KEY CODE), presents a legend of acronyms used in Table 2 (raw data set) and Table 3 (final data set). Table 3 (below Table 2) defines the final COC data set that determines the applicable fuel type and receptor combinations for each COC suite. Table 2 and 3 are color coded to match REFERNCE 1 COLOR KEY CODE.

REFERENCE 1 COLOR KEY CODE (Used for Raw Data Analysis)

Each Fuel Type and GW or Surface Water resource combination was assigned a unique color code in boxes (1 – 16).

GA USTMP: Groundwater and Surface Water Chemicals of Concern COCs)

Product Released	COCs to Sample			
	Groundwater		Surface Water†††	
	Drinking Water (Ingestion)	**Non-Drinking Water** (Vapor Inhalation)	**Water Supply Withdrawal Point*** (Ingestion)	**Perennial Water Body**** (Direct Exposure)
Gasoline	1 Benzene, Ethyl benzene, Toluene, Total Xylenes, MTBE, Naphthalene	2 Benzene, Ethyl benzene, Toluene, Total Xylenes, MTBE, Naphthalene	3 Benzene, Ethyl benzene, Toluene, Total Xylenes	4 Benzene, Ethyl benzene, Toluene
Diesel/ Jet Fuel/ Kerosene	5 Benzene, Ethyl benzene, Toluene, Total Xylenes, MTBE, Naphthalene, 1-Methylnaphthalene, 1,2,4-TMB, Benzo(a)pyrene TEQ†	6 Benzene, Ethyl benzene, Toluene, Total Xylenes, MTBE, Naphthalene	7 Benzene, Ethyl benzene, Toluene, Total Xylenes, Benzo(a)pyrene TEQ†	8 Benzene, Ethyl benzene, Toluene, Naphthalene, 1-Methylnaphthalene, 1,2,4-TMB, Benzo(a)pyrene TEQ†
Used Oil	9 Diesel/Jet Fuel/Kerosene (above), Lead, Total	10 Diesel/Jet Fuel/Kerosene (above)	11 Diesel/Jet Fuel/Kerosene (above), Lead, Total	12 Diesel/Jet Fuel/Kerosene (above), Lead, Total
Aviation Fuel/ Leaded Gasoline/ Unknown††	13 Benzene, Ethyl benzene, Toluene, Total Xylenes, MTBE, Naphthalene, EDB***†, EDC†, 1-Methylnaphthalene, 1,2,4-TMB, Benzo(a)pyrene TEQ†, Lead, Total	14 Benzene, Ethyl benzene, Toluene, Total Xylenes, MTBE, Naphthalene, EDB†, EDC†	15 Benzene, Ethyl benzene, Toluene, Total Xylenes, Naphthalene, EDB***†, EDC†, Benzo(a)pyrene TEQ†, Lead, Total	16 Benzene, Ethyl benzene, Toluene, Naphthalene, EDC, Benzo(a)pyrene TEQ†, 1-Methylnaphthalene, 1,2,4-TMB, Lead, Total

2-4

14-16

1,2,4-TMB = 1,2,4 Trimethylbenzene

†Benzo(a)pyrene Toxic Equivalent Quotient (TEQ). See Appendix B, Section 2.9 for TEQ determination details.
††COCs to sample for all leaded aviation fuels, all leaded racing fuels and sites with historical leaded gasoline storage.
†††COCs to be sampled **only** at surface water receptor.
*GA EPD MCLs (Rule 391-3-5-.18).
**GA EPD In Stream Water Quality Standards (Rule 391-3-6-.03). See REFERENCE 4C for additional clarification of this category
***EDB drinking water samples to be analyzed by EPA Method 8011.
BTEX, MTBE, Naphthalene, 1,2,4-TMB, EDB (non-drinking water) and EDC to be analyzed by EPA method 5030C/8260C.
1 Methylnaphthalene to be analyzed by EPA Method 8270C.
Lead, Total to be analyzed by EPA Method 200.7

Rule: The maximum number of COCs for the fuel type released or combination of fuel types released, accounting for groundwater and surface water usage determines the COC table to import:

Table 1 – Fuel, Water Usage, COC and Receptor Acronym Legend

Fuel, Water Usage, COC and Receptor Descriptions	Acronym
Gasoline	G
Diesel(D)/ Jet Fuel(JF)/Kerosene(K)	D/JF/K
Used Oil	UO
Aviation Fuel (AF)/Leaded Gas (LG)/Unknown(U)	AF/LG/U
Drinking Water	DW
Groundwater	GW
Nondrinking Water	NDW
Surface Water	SW
Water Supply Withdrawal Point	WSWP
Perennial Water Body	PWB
Benzo(a)Pyrene Toxic Equivalent Quotient	BaP TEQ

Table 2 – Applicable COCs by Fuel Type and Receptor (raw data set)

Fuel Combinations	Water Usage/Receptors		Applicable Reference 1 Table Cell COCs (see table below)	Comments
	GW: DW/ NDW	SW: WSWP/ PWB		
G	DW	Any or None	1	
D/JF/K			5	
G/D/JF/K			5	
G/UO			9	
G/D/JF/K/UO			9	
D/JF/K/UO			9	
UO			9	
AF/LG/U			13	
AF/LG/U/G			13	
AF/LG/U/D/JF/K			13	
AF/LG/U/UO			13	
AF/LG/U/G/D/JF/K/UO			13	

Fuel Combinations	Water Usage/Receptors		Applicable Reference 1 Table Cell COCs (see table below)	Comments
	GW DW/ NDW	SW WSWP/ PWB		
G	NDW	None	1	
D/JF/K			1	
G/D/JF/K			1	
G/UO			1	
G/D/JF/K/UO			1	
D/JF/K/UO			1	
UO			1	
AF/LG/U			14	
AF/LG/U/G			14	
AF/LG/U/D/JF/K			14	
AF/LG/U/UO			14	
AF/LG/U/G/D/JF/K/UO			14	
G	NDW	WSWP	1	
D/JF/K			2a	Add BaP TEQ
G/D/JF/K			2a	Add BaP TEQ
G/UO			2b	Add BaP TEQ & Lead
G/D/JF/K/UO			2b	Add BaP TEQ & Lead
D/JF/K/UO			2b	Add BaP TEQ & Lead
UO			2b	Add BaP TEQ & Lead
AF/LG/U			14a	Add BaP TEQ & Lead
AF/LG/U/G			14a	Add BaP TEQ & Lead
AF/LG/U/D/JF/K			14a	Add BaP TEQ & Lead
AF/LG/U/UO			14a	Add BaP TEQ & Lead
AF/LG/U/G/D/JF/K/UO			14a	Add BaP TEQ & Lead
G	NDW	PWB	1	
D/JF/K			5	
G/D/JF/K			5	
G/UO			9	
G/D/JF/K/UO			9	
D/JF/K/UO			9	
UO			9	
AF/LG/U			13	
AF/LG/U/G			13	
AF/LG/U/D/JF/K			13	
AF/LG/U/UO			13	
AF/LG/U/G/D/JF/K/UO			13	

Table 2 – Applicable COCs by Fuel Type and Receptor (raw data set) (continued)

Fuel Combinations	Water Usage/Receptors		Applicable Reference 1 Table Cell COCs (see table below)	Comments
	GW DW/NDW	SW WSWP/O		
G	NDW	WSWP & PWB	1	***Note:*** *This COC data set was observed to be the same as the first COC data set in this Table.*
D/JF/K			5	
G/D/JF/K			5	
G/UO			9	
G/D/JF/K/UO			9	
D/JF/K/UO			9	
UO			9	
AF/LG/U			13	
AF/LG/U/G			13	
AF/LG/U/D/JF/K			13	
AF/LG/U/UO			13	
AF/LG/U/G/D/JF/K/UO			13	

Table 3- Applicable Fuel Type and Receptor by COCs (final data set for workbook)

Reference 1 GW COCs Key: Applicable COCs Included in the Data Entry Import and Comparison Tables within the GRBCA workbook, RBTL Worksheet:				
Fuel Combinations	**Water Usage/Receptors**		**Applicable Reference 1 Table Cell COCs Imported by Wrkbk** (see Ref 1 table below)	**Comments**
	GW: DW/NDW	**SW: WSWP/PWB**		
G – GW DW & no SW receptor or any combination SW receptor ***OR***				
G/D/K/JF/UO – GW NDW & no SW receptor or any combination SW receptor				
G	DW	Any or None	1	
G	NDW	None	1	
D/JF/K	NDW	None	1	
G/D/JF/K	NDW	None	1	
G/UO	NDW	None	1	
G/D/JF/K/UO	NDW	None	1	
D/JF/K/UO	NDW	None	1	
UO	NDW	None	1	
G	NDW	WSWP	1	
G	NDW	PWB	1	
G	NDW	WSWP/PWB	1	
D, G/D - GW NDW & SW WSWP				
D/JF/K	NDW	WSWP	2a	Add BaP TEQ
G/D/JF/K	NDW	WSWP	2a	Add BaP TEQ
UO, G/UO, D/UO or G/D/UO - GW NDW & SW WSWP				
G/UO	NDW	WSWP	2b	Add BaP TEQ & Lead
G/D/JF/K/UO	NDW	WSWP	2b	Add BaP TEQ & Lead
D/JF/K/UO	NDW	WSWP	2b	Add BaP TEQ & Lead
UO	NDW	WSWP	2b	Add BaP TEQ & Lead

Table 3- Applicable Fuel Type and Receptor by COCs (final data set for workbook) (continued)

Reference 1 GW COCs Key: Applicable COCs Included in the Data Entry Import and Comparison Tables within the GRBCA workbook, RBTL Worksheet:				
Fuel Combinations	**Water Usage/Receptors**		**Applicable Reference 1 Table Cell COCs Imported by Wrkbk** (see Ref 1 table below)	**Comments**
	GW: DW/NDW	**SW: WSWP/PWB**		
D, G/D – GW DW & no SW receptor or any combination SW receptor ***OR***				
D, G/D – GW NDW & SW PWB or SW SWI & PWB				
D/JF/K	DW	Any or None	5	
G/D/JF/K	DW	Any or None	5	
D/JF/K	NDW	PWB	5	
G/D/JF/K	NDW	PWB	5	
D/JF/K	NDW	WSWP/PWB	5	
G/D/JF/K	NDW	WSWP/PWB	5	
UO, G/UO, D/UO or G/D/UO - GW DW & no SW receptor or any combination SW receptor ***OR***				
UO, G/UO, D/UO or G/D/UO - GW NDW SW PWB or SW SWI & PWB				
G/UO	DW	Any or None	9	
G/D/JF/K/UO	DW	Any or None	9	
D/JF/K/UO	DW	Any or None	9	
UO	DW	Any or None	9	
G/UO	NDW	PWB	9	
G/D/JF/K/UO	NDW	PWB	9	
D/JF/K/UO	NDW	PWB	9	
UO	NDW	PWB	9	
G/UO	NDW	WSWP/PWB	9	
G/D/JF/K/UO	NDW	WSWP/PWB	9	
D/JF/K/UO	NDW	WSWP/PWB	9	
UO	NDW	WSWP/PWB	9	

Table 3- Applicable Fuel Type and Receptor by COCs (final data set for workbook) (continued)

Reference 1 GW COCs Key: Applicable COCs Included in the Data Entry Import and Comparison Tables within the GRBCA workbook, RBTL Worksheet:				
Fuel Combinations	**Water Usage/Receptors**		**Applicable Reference 1 Table Cell COCs Imported by RAR** (see Ref 1 table below)	**Comments**
	GW: DW/NDW	**SW: WSWP/PWB**		
AF/LG/U, AF/LG/U & any combo G/D/UO – GW DW & no SW receptor or any combo SW receptor ***OR***				
AFLG/U, AF/LGU &any combination G/D/UO – GW NDW & SW PWB or SW WSWP & PWB				
AF/LG/U	DW	Any or None	13	
AF/LG/U/G	DW	Any or None	13	
AF/LG/UD/JF/K	DW	Any or None	13	
AF/LG/U/UO	DW	Any or None	13	
AF/LG/U/G/D/JF/K/UO	DW	Any or None	13	
AF/LG/U	NDW	PWB	13	
AF/LG/U/G	NDW	PWB	13	
AF/LG/U/D/JF/K	NDW	PWB	13	
AF/LG/U/UO	NDW	PWB	13	
AF/LG/U/G/D/JF/K/UO	NDW	PWB	13	
AF/LG/U	NDW	WSWP/PWB	13	
AF/LG/U/G	NDW	WSWP/PWB	13	
AF/LG/U/D/JF/K	NDW	WSWP/PWB	13	
AF/LG/U/UO	NDW	WSWP/PWB	13	
AF/LG/U/G/D/JF/K/UO	NDW	WSWP/PWB	13	
AFLG/U, AF/LGU &any combination G/D/UO – GW DW & no SW receptor				
AF/LG/U	NDW	None	14	
AF/LG/U/G	NDW	None	14	
AF/LG/U/D/JF/K	NDW	None	14	
AF/LG/U/UO	NDW	None	14	
AF/LG/U/G/D/JF/K/UO	NDW	None	14	
AFLG/U, AF/LGU &any Combo G/D/UO – GW DW & SW WSWP				
AF/LG/U	NDW	WSWP	14a	Add BaP TEQ & Lead
AF/LG/U/G	NDW	WSWP	14a	Add BaP TEQ & Lead
AF/LG/U/D/JF/K	NDW	WSWP	14a	Add BaP TEQ & Lead
AF/LG/U/UO	NDW	WSWP	14a	Add BaP TEQ & Lead
AF/LG/U/G/D/JF/K/UO	NDW	WSWP	14a	Add BaP TEQ & Lead

Appendix J Key Public Works Cited

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