Chapter 4
Risk and Hazard Assessment

What's covered in Chapter 4:

◆ Individual Risk and Hazard Estimation

◆ Target Risk Levels

- Target Risk

- Target Hazard

- Delisting Levels

◆ Quantitative Estimation of Risk

◆ Quantitative Estimation of Potential Noncancer Effects

This chapter explains (1) back-calculation of pathway-specific delisting levels from target risk levels and subsequent selection of the final delisting level for each constituent in a petitioned waste and (2) aggregate risk analysis for one-time delisting petitions. Both determination of delisting levels and aggregate risk analysis involve risk assessment, but the calculations proceed in a different direction for the two cases. In determining delisting levels, the work begins by setting a target risk level, that reflects the maximum acceptable risk. Then, using waste volume and exposure parameters, the delisting level is back-calculated. This is done for each constituent and each potential exposure pathway (see Chapter 3), and the resulting constituent—and pathway-specific delisting levels are used to set the final delisting level for each constituent. It is important to note that even though the calculations proceed from the target risk to the delisting level (which is the reverse of the traditional risk assessment approach), the procedure is still based on standard risk assessment equations and methods — they are simply applied in reverse order.

The back-calculation procedure contrasts with the method used to compute the aggregate risk for a one-time delisting petition. To determine aggregate risk, the calculations proceed in a forward direction. Beginning with the leachate and total waste concentrations for each constituent in the waste (source concentrations), the waste volume and exposure parameters are used to estimate the upper-bound excess lifetime cancer risks

(risk) and noncarcinogenic hazards (hazard). The risk is said to be aggregate because risks and hazards are summed separately for receptors (resident adults and children) across all applicable waste constituents and exposure pathways to obtain an estimate of the total individual risk and hazard for each receptor.

Risk is the probability that a receptor will develop cancer. Risk is estimated based on a unique set of exposure, model, and toxicity assumptions. A risk of 1×10^{-6} means that one person out of 1 million persons assumed to be exposed under similar conditions could develop cancer as a result of lifetime exposure to one or more potential carcinogens. Hazard is defined as the potential for noncarcinogenic health effects as a result of exposure to constituents of concern, averaged over an exposure period of less than an entire lifetime. A hazard is not a probability but rather a measure (expressed as a ratio) of the magnitude of a receptor's potential exposure relative to a standard exposure level. The standard exposure level is calculated over an exposure period such that there is no likelihood of adverse health effects to potential receptors, including sensitive populations (U.S. EPA 1989e).

Risks and hazards typically are characterized for a single receptor and are referred to as individual risks and hazards (U.S. EPA 1989a; NC DEHNR 1997). "Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part A)" (U.S. EPA 1989a) states that human health risk assessments in the RCRA program have historically focused on high-end individual risk, and it has been recommended that risk assessors place their primary emphasis on characterizing high-end individual risks. All available guidance on target levels for risks and hazards is developed specifically for estimates of individual risk and hazard (see Sections 4.2 and 4.3). Therefore, the risk assessments performed for delisting using the DRAS will address only individual risks and hazards.

4.1   INDIVIDUAL RISK AND HAZARD ESTIMATION

Aggregate individual risk and hazard estimates are intended to convey information about the risks borne by individuals affected by releases from delisted wastes disposed of in Subtitle D nonhazardous waste management units. Aggregate risk assessments based on the equations described in this chapter provide quantitative risk and hazard estimates associated with potential exposure to constituents in wastes proposed for delisting. Both calculation of delisting levels and evaluation of aggregate risk involve use of risk equations described in the following sections. The cancer slope factors (CSF) for carcinogens and the oral and inhalation RfDs for noncarcinogens used in computing delisting levels and in the aggregate risk assessment are provided in Appendix A. Other chemical-specific variables (for example, bioaccumulation factors, Henry's Law constants, and so on) are also provided in Appendix A.

4.2   TARGET RISK LEVELS

Acceptable or target risk and hazard levels originated with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (U.S. EPA 1990e). More recently, U.S. EPA has modified the target levels established in the NCP to reflect the contribution of background levels of contamination (U.S. EPA 1994f). However, these modified target values are not discrete indicators of observed adverse effects. If a calculated risk falls within the target values, U.S. EPA may without further investigation conclude that a proposed action (such as delisting a petitioned waste) does not present an unacceptable risk. A calculated risk that exceeds these targets, however, would not in and of itself indicate that the proposed action is not safe or that it presents an unacceptable risk. Rather, a computed risk that exceeds a target value triggers further careful consideration of the underlying scientific basis for the calculation. Target risk and hazard levels are addressed in more detail in the following sections. Sections 4.2.1 through 4.2.5 describe target risk, target hazard, delisting levels, DRAS aggregate risk, and special limitations to the computation of each of these levels.

4.2.1   Target Risk

Risk estimates represent the incremental probability that an individual will develop cancer over a lifetime as a result of exposure to a carcinogenic chemical (U.S. EPA 1989a). As defined in the NCP, U.S. EPA has established the range of generally acceptable risks for known or suspected carcinogens as 1×10^{-6} to 1×10^{-4} (U.S. EPA 1990e). Risks less than 1×10^{-6} (one additional cancer in 1,000,000 individuals) generally are not of concern, whereas risk levels exceeding 1×10^{-4} (one additional cancer in 10,000 individuals) are usually considered unacceptable. A risk level of 1×10^{-6} is used as a point of departure; that is, U.S. EPA generally must determine whether a waste qualifies for delisting if the petitioned waste's risks are between 1×10^{-6} and 1×10^{-4}.

For calculation of delisting levels for multi year (multiple-batch) delistings, the default target risk in the DRAS is set to 1×10^{-5}. At this default target risk, delisting levels for waste constituents represent waste concentrations that pose a potential risk of one additional cancer in 100,000 individuals exposed. The delisting authority may change the target risk in DRAS to match their program requirements. For a one-time delisting, U.S. EPA performs a aggregate risk assessment for the petitioned waste. If the aggregate risk for the petitioned waste exceeds 1×10^{-4}, then the waste may not qualify for delisting. The delisting authority may also set the requirement for an aggregate risk more conservatively.

U. S. EPA Region 6 distinguished between three measures of risk: constituent— and exposure pathway- specific risk, total exposure pathway risk, and aggregate risk in developing the DRAS. Constituent — and pathway-specific risk is calculated as shown in Equation 4-1.

$$Risk_{c,p} = LADD_{c,p} \quad CSF_c \qquad \text{(4-1)}$$

where:

$Risk_{c,p}$ = risk for waste constituent c for specific exposure pathway p
$LADD_{c,p}$ = lifetime average daily dose for waste constituent c (mg/kg-day) via pathway p
CSF_c = cancer slope factor for waste constituent c (mg/kg-day)$^{-1}$

Equation 4-1 is re-arranged to compute $LADD_{c,p}$ from a given target risk level, when used in calculating delisting levels.

Within a specific exposure pathway, an individual may be exposed to more than one chemical. The total risk associated with exposure to all chemicals through a single exposure pathway, or the total exposure pathway risk, is estimated as shown in Equation 4-2 (U.S. EPA 1989a).

$$Risk_p = \Sigma_c Risk_{c,p} \qquad \text{(4-2)}$$

where:

$Risk_p$ = total risk from all constituents for a specific exposure pathway p
$Risk_{c,p}$ = risk for waste constituent c for specific exposure pathway p

At specific exposure points, individual receptors may be exposed via multiple exposure pathways (see Table 2-2 in Chapter 2). Two steps are required to determine whether risks from multiple exposure pathways should be summed for a given individual receptor (U.S. EPA 1989a). The first step is to identify "reasonable exposure pathway combinations." The second step is to determine whether it is likely that the "same individuals would consistently face the reasonable maximum exposure (RME) via more than one pathway." For the purposes of one-time delisting risk assessments, U. S. EPA conservatively assumes that one individual would consistently encounter the RME via more than one pathway. Therefore, risks are summed across the receptor-exposure pathway combinations identified in Table 2-2. Hence, the aggregate risk from multiple exposure pathways is the sum of the total risks for the individual exposure pathways, expressed as shown in Equation 4-3.

$$Risk_{cum} = \Sigma_p Risk_p \qquad \text{(4-3)}$$

where:

$Risk_{cum}$ = Aggregate risk from all constituents and all exposure pathways

$Risk_p$ = Total risk from all constituents for specific exposure pathway p

The equations used to calculate dose and risk levels are presented in Section 4.3. Appendix A presents the oral and inhalation CSFs used to compute risks for specific waste constituents. CSFs for constituents not identified in Appendix A-1 can be obtained from the following sources (listed in the preferred order):

1. U.S. EPA's IRIS (U. S. EPA 1996g); accessible online at "http://www.epa.gov/ngispgm3/iris/index.html")
2. U.S. EPA (HEAST) (U.S. EPA 1997f)

If relevant information is not available from these sources, the petitioner should, with the approval of the appropriate regulatory agency, contact the U.S. EPA National Center for Environmental Assessment (NCEA) office in Cincinnati, Ohio. NCEA personnel may be able to assist in developing the necessary toxicity values.

4.2.2   Target Hazard

Standard risk assessment models assume that noncarcinogenic effects, unlike carcinogenic effects, exhibit a threshold; that is, they assume that there is a level of exposure below which no adverse effects will be observed (U.S. EPA 1989a). The potential for noncarcinogenic health effects resulting from exposure to a chemical is assessed by comparing daily exposure estimates to RfDs. An RfD is a daily intake rate that is estimated to pose no appreciable risk of adverse health effects, even to sensitive populations, over a specific exposure duration. Chronic RfDs are used to characterize noncarcinogenic hazards in order to maintain a conservative approach consistent with the purposes of the risk assessment.

Appendix A-1 presents RfDs for a number of chemicals. RfDs for other chemicals can be obtained from the following sources (listed in the preferred order):

1. U.S. EPA's IRIS (U.S. EPA 1996g; accessible on-line at "http://www.epa.gov/ngispgm3/iris/index.html")
2. U.S. EPA (HEAST) (U.S. EPA 1997f)

If relevant information is not available from these sources, the applicant should, with the approval of the appropriate regulatory agency, contact the U.S. NCEA office in Cincinnati, Ohio. NCEA personnel may be able to assist in developing the necessary toxicity values.

The ratio between the daily exposure estimate for a constituent and that constituent's RfD is known as a hazard quotient (HQ). When simultaneous exposure occurs to more than one constituent or through more than one pathway, a hazard index (HI), a summation of HQs, is used to express the potential for harm. The NCP target hazard for systemic toxicants is an *HQ* of 1.0 for a single chemical or an *HI* of 1.0. for multiple chemicals or pathways. U.S. EPA typically considers the need for reducing hazards if an *HQ* or *HI* exceeds

1.0 for human receptors who may reasonably be expected to be exposed. U.S. EPA usually requires remedial action at locations where *HQ* or *HI* values significantly exceed 1.0.

For a one-time delisting, U.S. EPA Region 6 performs a aggregate risk assessment for the petitioned waste. As in risk calculation, a distinction is made between three measures of hazard: constituent— and exposure pathway-specific hazard, total exposure pathway hazard, and aggregate hazard. The ultimate result of a aggregate risk assessment is an *HI* rather than an *HQ* because the assessment includes multiple pathways and may include multiple constituents. Consistent with the NCP and U.S. EPA guidance documents, if the *HI* for a waste exceeds 1.0, U.S. EPA considers whether to allow the waste to qualify for delisting. However, where *HI* values significantly exceed 1.0, U. S. EPA usually reviews the target organ hazard contribution, establishes specific delisting conditions, or denies the delisting petition. Constituent— and pathway-specific hazard is computed as shown in Equation 4-4.

$$HQ_{c,p} = \frac{ADD_{c,p}}{RfD_c}$$

(4-4)

where:

$HQ_{c,p}$ = hazard quotient for waste constituent c for exposure pathway p (unitless)
$ADD_{c,p}$ = average daily dose for waste constituent c for pathway p (mg/kg-day)
RfD_c = reference dose for waste constituent c (mg/kg-day)

As with carcinogenic constituents in a specific exposure pathway, a receptor may be exposed to multiple constituents associated with noncarcinogenic health effects. The total noncarcinogenic hazard for each exposure pathway is calculated using the procedures outlined by U.S. EPA (1989a). As in the procedure for calculating risks, the constituent— and pathway-specific hazards are summed for each receptor. The sum represents the total hazard for a given exposure pathway and is calculated as shown in Equation 4-5.

$$HI_p = \Sigma_c \, HQ_{c,p}$$

(4-5)

where:

HI_p = total hazard index for all waste constituents for specific exposure pathway p

$HQ_{c,p}$ =   hazard quotient of waste constituent c for specific exposure pathway p

This summation methodology assumes that the health effects of the various chemicals to which a receptor is exposed are additive.

As discussed in Section 4.2.1 for risks, a receptor may be exposed to chemicals associated with noncarcinogenic health effects through more than one exposure pathway. For the purposes of a risk assessment, U.S. EPA assumes that it is reasonable to estimate a receptor's total hazard as the sum of the HIs for the exposure pathways identified in Table 2-2. Specifically, a receptor's aggregate HI is the sum of the hazards for the individual exposure pathways, expressed as shown in Equation 4-6.

$$HI_{cum} = \Sigma_p HI_p \qquad\qquad (4\text{-}6)$$

where:

HI_{cum} =   aggregate hazard index for all constituents and all exposure pathways
HI_p =   total hazard index for all constituents for specific exposure pathway p

Generally, when the aggregate HI is assessed, an HI_{cum} value less than or equal to 1.0 is considered to be protective of human health, whereas an HI_{cum} value exceeding 1.0 indicates a potential for noncarcinogenic health effects (U.S. EPA 1989a). The more the HI_{cum} value exceeds 1.0, the greater the level of concern. However, because RfDs do not have equal accuracy or precision, and because they are not based on the same severity of effects, the level of concern does not increase linearly as an Hi_{cum} value approaches and exceeds 1.0 (U.S. EPA 1989a).

The HI_{cum} for a receptor can exceed 1.0 as a result of (1) the presence of one or more chemicals with an HQ exceeding 1.0 ($HQ_{c,p} > 1.0$ in Equation 4-5) or (2) summation of several chemical-specific HQs (as in Equation 4-5) or pathway-specific HIs (as in Equation 4-6) that are each less than 1.0. In the first case, the presence of at least one chemical-specific hazard greater than 1.0 is interpreted as indicating the potential for noncarcinogenic health effects. In the second case, a detailed analysis is required to determine whether the potential for noncarcinogenic health effects is accurately estimated by HI_{cum} because the toxicological effects associated with exposure to multiple chemicals, often through different exposure pathways, may not be additive (U.S. EPA 1989a); therefore, HI_{cum} may overestimate the potential for noncarcinogenic health effects.

To address this issue, chemical-specific hazards may be summed according to major health effects and target organs or systems (U.S. EPA 1989a). Table A-4 in Appendix A identifies target organs and systems that are affected by listed waste constituents. It is especially important to consider any differences related to the exposure route; this process is referred to as segregation of the *HI*. If the highest segregated *HI* exceeds 1.0, there is a potential for noncarcinogenic health effects. However, if the highest segregated *HI* is less than 1.0, HI_{cum} (as calculated above) is overly conservative, and noncarcinogenic health effects are not likely to result from exposure to waste constituents, even if HI_{cum} is greater than 1.0. Therefore, when HI_{cum} for a specific volume of petitioned waste exceeds 1.0, it does not necessarily mean that the waste cannot be delisted; calculation of segregated *HI*s may show that HI_{cum} is too conservative. Calculation of segregated *HI*s is beyond the scope of this DTSD and should be performed by a qualified toxicologist or risk assessor. Segregated *HI*s are not used in calculating delisting levels or aggregate hazards in subsequent sections.

4.2.3   Delisting Levels

For all standard multi-year delisting petitions, the DRAS calculates delisting levels for each constituent of a petitioned waste at the default risk levels (a cancer risk of 1×10^{-5} and a noncancer hazard of 0.1) or the risk levels required by the delisting authority. The waste constituent concentrations of each batch of delisted waste should not exceed the established delisting levels. In determining the allowable concentrations for each constituent of a standard multi-year petitioned waste, U.S. EPA Region 6 sets two delisting levels for each constituent: (1) a total concentration delisting level and (2) a leachate concentration delisting level. The total concentration delisting level is the maximum allowable concentration of a constituent in the whole waste. The total concentration of each constituent in the waste should not exceed the total concentration delisting level. The leachate concentration delisting level is the maximum allowable concentration of a constituent in leachate derived from the waste. The TCLP concentration of each waste constituent should not exceed the leachate concentration delisting level. Note that leachate concentrations from leach tests other than the TCLP may also be considered.

The DRAS back-calculates a delisting level for each waste constituent and each exposure pathway that the program addresses. The DRAS generates leachate concentration delisting levels for all the groundwater exposure pathways (ingestion of groundwater, dermal absorption while bathing with groundwater, and inhalation of groundwater volatiles while showering) and for two of the air inhalation exposure pathways (inhalation of volatiles from a landfill and inhalation of volatiles from a surface impoundment). The DRAS generates total concentration delisting levels for the remaining air inhalation exposure pathway (inhalation

of particulates from a landfill), the surface water exposure pathways (ingestion of surface water and ingestion of fish), and the soil ingestion exposure pathway.

To develop the final leachate concentration delisting level for a waste constituent, the DRAS calculates the constituent's pathway-specific leachate concentration delisting levels for the groundwater pathways and the two relevant air exposure pathways and then selects the lowest of the pathway-specific values (including delisting levels derived from the SDWA MCL) as the final leachate concentration delisting level. Similarly, to develop the final total concentration delisting level for a waste constituent, the DRAS computes pathway- specific values for the relevant pathways and then chooses the lowest as the final total concentration delisting level.

The DRAS is a risk assessment tool that gives the user the flexibility to select alternative target risk levels. Delisting levels are determined according to the target risk level selected by the user. The selection of delisting levels is a risk management decision and, as such, should consider the selected risk level and other pertinent information.

The delisting levels for each waste constituent are the maximum concentrations (total and TCLP) allowed for the constituent in any batch of the petitioned waste, based on the most sensitive pathway associated with exposure dependent on the TCLP waste constituent concentration and the waste constituent total concentration. Although the DRAS calculates a delisting level (at the target risks) for each of the groundwater pathways, only the most sensitive pathway for each constituent is selected as that constituent's TCLP delisting level. The DRAS goes through the same procedure to determine the total delisting level for each waste constituent. These values are intended to be incorporated into the FR notice for a multi-year delisting and are not to be exceeded in any batch sample of the delisted waste. Sections 4.3 and 4.4 present the algorithms used in the DRAS to calculate the delisting level concentrations for multi-year delistings. If the concentration of each constituent in a petitioned waste is less than the total concentration delisting level, and if the waste TCLP concentration for each constituent is less than the leachate concentration delisting level, that waste may qualify to exit the hazardous waste management program. No single constituent concentration in the waste or TCLP concentration covered by a multi year delisting petition should exceed its delisting levels.

4.2.4   DRAS Aggregate Risk

In addition to calculating the delisting levels for standard multi-year delistings, the DRAS can perform an aggregate risk assessment for one-time disposal of waste in a landfill or surface impoundment waste management unit. The DRAS requires that the user input the total and TCLP concentrations for each constituent of a petitioned waste. The program then computes the aggregate risk and hazard ($Risk_{cum}$ and HI_{cum}) for the waste.

Computing the aggregate risk and hazard for a petitioned waste provides the user with a detailed analysis of the risks and hazards associated with the waste. The DRAS indicates which chemicals, pathways, and receptors are driving the risk and hazard for the waste. The DRAS computes the aggregate risk by summing the risks for all waste constituents for a given exposure pathway and then summing the risks for the pathways analyzed in the delisting risk assessment (see Equations 4-1 through 4-3). The DRAS computes the aggregate hazard by summing the HQs for all waste constituents for a given exposure pathway to obtain exposure pathway-specific HIs and then summing the HIs associated with the exposure pathways analyzed (see Equations 4-4 through 4-6). Sections 4.3 and 4.4 detail the equations and default parameters used in the DRAS to calculate the aggregate risk and hazard, respectively, for a petitioned waste.

If a delisting petition is for a one-time exclusion, the results of the aggregate risk assessment may be used in lieu of the delisting levels. A one-time delisting does not require U.S. EPA to establish monitoring concentrations that must be met by each batch of waste to be managed under a promulgated exclusion. Therefore, the user may bypass the delisting levels, which are set at more conservative risk levels, in favor of the aggregate risk process that is conducted using U.S. EPA's target risk range (1×10^{-4} to 1×10^{-6} for carcinogenic waste constituents and an HI of 1.0 to 0.1 for noncarcinogenic waste constituents). Use of the aggregate risk analysis allows the risk associated with an individual waste constituent to extend to a less conservative risk level as long as the aggregate risk for the entire petitioned waste lies below or within U.S. EPA's target risk range.

4.2.5   Special Limitations and Exceptions

This section summarizes special limitations and exceptions to the methods outlined for calculating delisting levels, and risk and hazard. Earlier regulatory work performed using methods similar to those discussed herein has shown that a waste concentration ceiling may be needed to ensure that risk from direct exposure on site does not achieve unsafe levels, as is discussed in Section 4.2.5.1. Also, as described in Section

4.2.5.2, a special, constituent-specific waste concentration ceiling based on soil saturation levels is needed to prevent delisting of waste that may give rise to nonaqueous-phase liquids (NAPL) in groundwater. Because toxicity factors are not available for lead, its delisting level must be established outside the usual methods of the DRAS (See Section 4.2.5.3). Section 4.2.5.4 describes how risk and hazard levels are computed for PCDDs and PCDFs, and PCBs are addressed in Section 4.2.5.5. Finally, other regulatory limits must be considered in the determination of delisting levels, including the Toxicity Characteristic regulatory levels (Section 4.2.5.6), maximum contaminant levels (MCLS) as described in Section 4.2.5.7. In addition, chemical detection limits are addressed in Section 4.2.5.8 and regulatory levels for aquatic biota are addressed in Section 4.2.5.9.

4.2.5.1   Waste Constituent Concentration Ceiling

Using standard chronic risk assessment algorithms, the DRAS generates upper-limit individual waste constituent source concentrations called delisting levels that are protective of the receptor for the defined exposure pathways. However, the delisting levels generated in this manner for certain constituents can be extremely high in their absolute concentrations (approaching those of pure compounds). Under certain circumstances, the generated delisting levels may not be the appropriate waste management concentration limits for the waste management unit. For example, a modeled chronic risk scenario (for example, volatile air emissions) cannot be relied upon if the source concentrations exceed certain limits (see Section 4.2.5.2 soil saturation). Above certain concentrations, the compounds may exist in free phase and exhibit behavior different from that assumed by the model (for example., dissolution and transport of immobile hazardous constituents). Moreover, were wastes allowed to be disposed of at very high concentrations, acute exposures could occur at the waste management unit itself. Some of these high constituent concentrations could interact with and damage liner systems. Finally, the proposed HWIR Media Rule states that "EPA believes it is reasonable to classify media as highly contaminated if 1 percent of the volume of the media is contaminated with a particular constituent" (U.S. EPA 1996b).

For these reasons, there is a need to assess the reasonableness of high concentration limits developed from the chronic risk models, particularly for liquid and volatile organics. The issue is a general policy concern for all chronic risk analyses, and its resolution is beyond the scope of the DRAS or this DTSD. However, the DRAS has been programmed to identify total waste constituents predicted at nominally high concentration levels (10,000 mg/kg or 1 percent by weight or greater). Delisting levels in excess of 10,000 mg/kg are highlighted in red on the Results Screen of the DRAS. When the DRAS computes a delisting level that exceeds 10,000 mg/kg, the petitioned waste containing constituents concentrations above this value will be

reviewed on a case-by-case basis. In the DRAS, the delisting levels (exit values) are not altered to reflect this ceiling review. The DRAS provides the user with the calculated delisting level based on the waste constituent concentrations, the waste volume, and the risk level selected by the user.

The HWIR Waste Exemption Rule was proposed (in 60 FR 66344, December 21, 1995) with more than 80 compounds in the non-wastewater leachate (NWT) category, which had criterion limits that exceeded 10,000 mg/kg total waste concentration. As the DTSD methodologies are similar to those of the proposed HWIR, U.S. EPA Region 6 is aware that the chronic risk algorithms in the DRAS will generate delisting levels that exceed 10,000 mg/kg or 1 percent pure compound by weight when the constituent is not particularly toxic or does not readily migrate through the environment due to its physical and chemical properties. U.S. EPA Region 6 believes that delisting levels greater than 10,000 mg/kg, although they are predicted to be protective of chronically exposed resident receptors because they are back-calculated using acceptable risk assessment methodology, may pose a risk involving direct exposure on site. It is conceivable that some waste constituents for which high delisting levels are generated may exhibit another hazardous waste characteristic (such as ignitability) and that the petitioned waste may not be delisted as a result. However, not all waste constituents with elevated delisting levels will exhibit another hazardous waste characteristic and be excluded from delisting. Therefore, U.S. EPA will closely review any petition that includes a waste constituent concentration that exceeds 10,000 mg/kg or 1 percent pure chemical by weight.

4.2.5.2   Soil Saturation Evaluation

A soil saturation value represents the contaminant concentration in soil at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above this concentration, pure or free-phase compound is expected in the soil. Three of the input parameters used to calculate soil saturation concentrations are constituent-specific: solubility (Sol), organic carbon partition coefficient (K_{oc}) and Henry's Law constant (H'). A chemical-specific soil saturation concentration is therefore dependent on the reference value used for each of these parameters and can vary significantly depending on the values selected for these three input parameters. Delisting decisions based on the soil saturation concentrations reported in Appendix A-3 should be made with caution.

The derivation of the soil saturation concentration (C_{sat}) is shown in Equation 4-7.

$$ C_{sat} \ = \ \frac{Sol}{\rho_b} \ (K_d \cdot \rho_b \ + \ \Theta_w \ + \ H'\Theta_a) \qquad (4\text{-}7) $$

where:

			<u>Default</u>
C_{sat}	=	soil saturation concentration (mg/kg)	calculated
Sol	=	solubility in water (mg/L-water)	chem-specific (Appendix A-1)
$\tilde{n}_b$	=	dry soil bulk density (kg/L)	1.5 (U.S. EPA 1996f)
K_d	=	soil-water partition coefficient (L/kg)	$K_{oc} \cdot f_{oc}$ (chem-specific)
K_{oc}	=	normalized distribution coefficient (L/kg)	chem-specific (Appendix A-1)
f_{oc}	=	fraction organic carbon content of soil (g/g)	0.006 or site-specific
$\dot{E}_w$	=	water-filled soil porosity (L_{water}/L_{soil})	0.15 (U.S. EPA 1996f)
$\dot{E}_a$	=	air filled soil porosity (L_{air}/L_{soil})	0.28 or $n\text{-}\dot{E}_w$ (U.S. EPA 1996f)
n	=	total soil porosity (L_{ore}/L_{soil})	0.43 or 1 - ($\tilde{n}_b/\tilde{n}_s$)
$\tilde{n}_s$	=	soil particle density (kg/L)	2.65
H	=	Henry's Law constant (atm-m³/mol)	chem-specific (Appendix A-1)
H'	=	Henry's Law constant (dimensionless)	H x 41, where 41 is a unit conversion factor

Equation 4-7 takes into account the amount of contaminant that is in the vapor phase in the pore spaces of the soil in addition to the amount dissolved in the soil's pore water and sorbed to soil particles. If the soil saturation limit is exceeded, formation of a NAPL plume is possible for the organic constituents. If NAPLs are present, significant contaminant migration may occur within this NAPL phase, which is not accounted for in the EPACMTP fate and transport model. Additionally, compound solubility assumptions for water may be inappropriate if another free-phase liquid or mixture is present. Therefore, EPACMTP modeling results may underestimate potential groundwater concentrations at downgradient receptor wells when waste constituent concentrations exceed soil saturation values.

The DRAS compares soil saturation values with calculated delisting levels and notifies the user when a waste constituent's total delisting level exceeds its soil saturation value. When the DRAS calculates a delisting level greater than the calculated soil saturation, the delisting manager should consider setting the delisting level equal to the soil saturation value in accordance with soil screening guidance (U.S. EPA 1996f).

4.2.5.3   Estimation of Potential Health Effects for Lead

Toxicity factors (for example, RfDs or CSFs) are not available for lead. Therefore, consistent with U.S. EPA (1994f), the U.S. EPA OSW recommends that the potential for adverse health effects associated with exposure to lead be characterized through a direct comparison with medium-specific health-based levels. Specifically, the target level for lead in drinking water is 0.015 mg/L. The drinking water target level is based on the lead action level established under the U.S. EPA primary drinking water regulations. The U.S. EPA OSW recommends target levels at the POE for lead in soil and air of 100 mg/kg and 0.2 (μg)/m³, respectively.

The soil target level of 100 mg/kg is based on U.S. EPA guidance (1994g) that indicates that soil lead levels less than 400 mg/kg (based on lead concentrations in blood, as discussed below) are not of concern for remediation purposes. The U.S. EPA OSW has incorporated a margin of safety into the risk assessment process by allowing only 25 percent of the remediation threshold lead level to be attributable to releases from a waste management unit. Similarly, the protective air standard of 0.2 µg/m ^{3} is based on 25 percent of the National Ambient Air Quality Standard (NAAQS) quarterly average air concentration of 1.5 µg/m^3 (40 CFR 50.12) converted to an annual basis value (0.9 µg/m^3).

Estimates of the potential for human health effects associated with potential exposure to lead are typically based on lead concentrations in blood. U.S. EPA guidance (1994g) recommends a maximum lead concentration in blood of 10 µg/deciliter (µg/dL), which is at the low end of the range of concern for adverse health effects in children. "Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes" (U.S. EPA 1994e) presents a mathematical model called the "Integrated Exposure U/BK [IEUBK] Model" for estimating lead levels in the blood of children on the basis of total lead uptake from exposures through diet, drinking water, air, and soil. When run with standard recommended default values (these generally represent national averages or "typical" values), U.S. EPA's IEUBK model predicts that no more than 5 percent of children exposed to a lead concentration in soil of 400 mg/kg will have lead concentrations in their blood exceeding 10 µg/dL (U.S. EPA 1994e).

4.2.5.4   Estimation of Potential Health Effects for PCDDs and PCDFs

PCDDs and PCDFs are toxic compounds that were first discovered as thermal decomposition products of polychlorinated compounds, including (1) the herbicide 2,4,5-T, (2) hexachlorophene, (3) PCBs,
(4) pentachlorophenol, and (5) intermediate chemicals used to manufacture these compounds. In recent years, as chemical analytical methods have become more sensitive, additional sources of PCDDs and PCDFs have been identified, including (1) effluent from paper mills that use chlorine bleaches and (2) combustion sources, including forest fires, municipal and medical waste incinerators, and hazardous waste combustion units. "Health Assessment Document for 2,3,7,8-TCDD and Related Compounds" (U.S. EPA 1994b) concludes that there is adequate evidence that exposure to PCDDs and PCDFs results in a broad spectrum of cancer and noncancer effects in animals, some of which may occur in humans. The procedures for estimating risks associated with PCDDs and PCDFs are discussed below.

There are 210 individual forms or "congeners" of PCDDs and PCDFs. U.S. EPA has developed procedures for assessing the cancer risks associated with exposure to the many PCDDs and PCDFs. These procedures

are used to assess risk on the basis of the relative toxicity of 2,3,7,8-TCDD, which is generally believed to be the most toxic form (U.S. EPA 1994c). Each congener is assigned a value referred to as a toxicity equivalency factor (TEF) that corresponds to its toxicity in relation to 2,3,7,8-TCDD. For example, 2,3,7,8-TCDD has a TEF of 1.0, and other PCDDs and PCDFs have TEFs of 0.0 to 1.0. The U.S. EPA OSW and U.S. EPA guidance (1993d) recommend that all risk assessments include any PCDD or PCDF congener with chlorine molecules in the 2, 3, 7, and 8 positions. There are a total of 17 possible compounds that generally display dioxin-like toxicity. The TEF values for these 17 compounds are listed below.

Dioxin Congener	TEF (unitless)	Furan Congener	TEF (unitless)
2,3,7,8-TCDD	1.000	2,3,7,8-Tetrachlorodibenzofuran	0.100
1,2,3,7,8-Pentachlorodibenzo(p)dioxin	0.500	1,2,3,7,8-Pentachlorodibenzofuran	0.050
1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin	0.100	2,3,4,7,8-Pentachlorodibenzofuran	0.500
1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin	0.100	1,2,3,4,7,8-Hexachlorodibenzofuran	0.100
1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin	0.100	1,2,3,6,7,8-Hexachlorodibenzofuran	0.100
1,2,3,4,6,7,8-Heptachlorodibenzo(p)dioxin	0.010	1,2,3,7,8,9-Hexachlorodibenzofuran	0.100
1,2,3,4,5,7,8,9-Octachlorodibenzo(p)dioxin	0.001	2,3,4,6,7,8-Hexachlorodibenzofuran	0.100
		1,2,3,4,6,7,8-Heptachlorodibenzofuran	0.010
		1,2,3,4,7,8,9-Heptachlorodibenzofuran	0.010
		1,2,3,4,6,7,8,9-Octachlorodibenzofuran	0.001

Source: U.S. EPA 1994c

Of the 2,3,7,8-substituted PCDD and PCDF congeners, a CSF has been developed for only 2,3,7,8-TCDD. The carcinogenic potential of the other sixteen 2,3,7,8-substituted congeners is derived by assigning TEF values that compare the toxicity of the 16 other toxic congeners to that of 2,3,7,8-TCDD; the CSF for 2,3,7,8- TCDD is based on evidence from experiments with rodents. The TEF values based on receptor binding studies or a sensitive measure of receptor binding, specifically, induction of aryl hydrocarbon hydroxylase enzyme activity. The TEFs are based on the activity of the compounds in short-term toxicity assays that are considered predictive of the compounds' ability to cause cancer in animals during long-term experimental carcinogenicity studies. Consequently, "CSFs" derived from the TEF values for these 16 toxic congeners are less certain than the CSF for 2,3,7,8-TCDD. Consistent with previous guidance (U.S. EPA 1994c), U.S. EPA Region 6 recommends that a risk assessment for PCDDs and PCDFs be completed by calculating the (TEQ) for 2,3,7,8-TCDD. The total TEQ is calculated by converting the dioxin congener concentrations to a 2,3,7,8-TCDD concentration using the TEFs for all 17 dioxin congeners.

To assess the risk association with a mixture of PCDDs and PCDFs reported in a delisting petition using the TEF procedure, the following steps should be performed:

1. Review the delisting petition for all PCDD and PCDF analytical determinations for the delisting sample.
2. Multiply the congener concentrations in the sample by the TEFs listed above to express the concentrations as 2,3,7,8-TCDD equivalents (TEQs).
3. Sum the products calculated in Step 2 to obtain the total TEQ for the delisting sample.
4. Use the delisting sample's total TEQ as the sample concentration of 2,3,7,8-TCDD to be entered in the DRAS under the chemical name "TCDDioxin 2,3,7,8" or(CAS) number 1746016.

All of the 17 PCDD or PCDF congeners with chlorine molecules in the 2, 3, 7, and 8 positions are highly bioaccummulative compounds. For highly bioaccummulative chemicals, the accumulation of these chemicals up the food chain is an exposure pathway of potential concern. The DRAS does not consider potential impacts from ingestion of production terrestrial food products (fruit/vegetables) or animal food products (beef, pork, chicken). Ingestion of contaminated food products may be a potential exposure pathway for bioaccumulating compounds encountered under continuous exposure conditions. Bioaccummulative compounds may cause adverse impacts via the production terrestrial food products pathway if these compounds continuous long-term releases from a landfill are expected to result in concentrations approaching some equilibrium at the point of exposure over a duration of years. Region 6 recommends analysis of the terrestrial food products pathway, in addition to the DRAS analysis, should the user have reason to expect that this compound's above ground releases from a landfill will occur continuously over a period of years to decades. Consult a risk assessor or toxicologist with questions regarding risk via the terrestrial food (fruit/vegetable and animal) products pathways.

4.2.5.5 Estimation of Potential Health Effects for PCBs

U.S. EPA guidance (1988c, 1994d, 1994e) recommends that all PCB congeners (209 different chemicals) be addressed as a mixture having a single carcinogenic potency in a risk assessment. This recommendation was based on the U.S. EPA drinking water criteria for PCBs (U.S. EPA 1988c), which in turn were based on available toxicological information with the following limitations:

· The only PCB for which a CSF had been developed was Aroclor 1260; there was no agreed-upon procedure for applying this CSF to similar mixtures with less chlorine content.

· Available physical, chemical, fate-and-transport, and toxicological information on individual congeners was limited, primarily because separation and synthesis of pure congeners can be technically difficult.

· The number of tests conducted with various PCB mixtures and specific PCB congeners to demonstrate similar toxicological effects was very limited.

4.2.5.5.1 Coplanar PCBs

Since the compilation of "Drinking Water Criteria Document for Polychlorinated Biphenyls (PCBs)" (U.S. EPA 1988c), additional research on PCBs has been reported. The most important result of this research is the finding that some of the moderately chlorinated PCB congeners can have dioxin-like effects (U.S. EPA 1992c; 1994d; ATSDR 1995). These dioxin-like congeners include are listed below.

PCB Congener	TEF (unitless)	PCB Congener	TEF (unitless)
3,3',4,4'-Tetrachlorobiphenyl	0.0005	2,3,3',4,4',5-Hexachlorobiphenyl	0.0005
2,3,3',4,4'-Pentachlorobiphenyl	0.0001	2,3,3',4,4',5'-Hexachlorobiphenyl	0.0005
2,3,4,4',5-Pentachlorobiphenyl	0.0005	2,3',4,4',5,5'-Hexachlorobiphenyl	0.00001
2,3',4,4',5-Pentachlorobiphenyl	0.0001	3,3',4,4',5,5'-Hexachlorobiphenyl	0.01
2',3,4,4',5-Pentachlorobiphenyl	0.0001	2,2',3,3',4,4',5-Hheptachlorobiphenyl	0.0001
3,3',4,4',5-Pentachlorobiphenyl	0.1	2,2',3,4,4',5,5'-Heptachlorobiphenyl	0.00001
		2,3,3',4,4',5,5'-Heptachlorobiphenyl	0.0001

Source: U.S. EPA 1996h

The listed congeners have four or more chlorine atoms with few substitutions in the ortho positions (positions designated as 2, 2', 6, and 6'). They are sometimes referred to as coplanar PCBs because the rings can rotate into the same plane if they are not blocked from rotation by ortho-substituted chlorine atoms; in this configuration, the shape of the PCB molecule is very similar to that of a PCDF molecule. Studies have shown that these dioxin-like congeners can then react with the aryl hydrocarbon receptor; this reaction is believed to initiate the adverse effects of PCDDs and PCDFs. As reported in "PCBs: Cancer Dose-Response

Assessment and Application to Environmental Mixtures" (U.S. EPA 1996h), the World Health Organization has used various test results to derive interim TEFs ranging from 0.1 to 0.00001 for the PCB congeners listed above. Additional congeners are suspected of producing similar reactions, but not enough data are available to derive TEF values for them. U.S. EPA Region 6 recommends that permitting authorities estimate risks associated with coplanar PCBs by computing a TEQ for PCBs and then applying a slope factor for dioxin on the chemical input screen of the DRAS.

4.2.5.5.2   Other PCBs

In addition to the coplanar (dioxin-like) PCB congeners, the remaining PCBs should be evaluated in a risk assessment. Based on consideration of the accumulated research on PCBs, (especially a recent carcinogenesis study of Aroclors 1016, 1242, 1254, and 1260 and a number of studies of the transport and bioaccumulation of various congeners) U.S. EPA derived three new CSFs to replace the former single CSF for PCBs (U. S. EPA 1996h). These new CSFs became effective in IRIS (U.S. EPA 1996g) on October 1, 1996. Additional studies are still being performed on PCBs. Therefore, the three CSFs are subject to revision as additional information becomes available. The three CSFs and the criteria for their use are listed below.

CSF $(mg/kg\text{-}day)^{-1}$	Criteria for Use
2	Food chain exposure; sediment or soil exposure Early-life (infant and child) exposure via all routes to all PCB mixtures
0.4 (less used)	Ingestion of water-soluble (less chlorinated) congeners Inhalation of evaporated (less chlorinated) congeners
0.07	Congeners with more than four chloride atoms per molecule less than 0.5 percent of the total PCBs

Source: U.S EPA 1996h

A CSF of 2 $mg/kg\text{-}day^{-1}$ will be used for a risk assessment. The DRAS will perform the PCB risk analysis using the PCB CSF of 2 $mg/kg\text{-}day^{-1}$ to generate a conservative estimate of the risk associated with PCB exposure. However, the CSF of 0.07 $mg/kg\text{-}day^{-1}$ can be used in risk assessments where the PCB mixture contains less than 0.5 percent PCB congeners with more than four chlorine atoms. This risk calculation would have to be made by the delisting manager.

All of the coplanar (dioxin-like) PCB congeners are highly bioaccummulative compounds. For highly bioaccummulative chemicals, the accumulation of these chemicals up the food chain is an exposure pathway

of potential concern. The DRAS does not consider potential impacts from ingestion of production terrestrial food products (fruit/vegetables) or animal food products (beef, pork, chicken). Ingestion of contaminated food products may be a potential exposure pathway for bioaccumulating compounds encountered under continuous exposure conditions. Bioaccummulative compounds may cause adverse impacts via the production terrestrial food products pathway if these compounds continuous long-term releases from a landfill are expected to result in concentrations approaching some equilibrium at the point of exposure over a duration of years. Region 6 recommends analysis of the terrestrial food products pathway, in addition to the DRAS analysis, should the user have reason to expect that this compound's above ground releases from a landfill will occur continuously over a period of years to decades. Consult a risk assessor or toxicologist with questions regarding risk via the terrestrial food (fruit/vegetable and animal) products pathways.

4.2.5.6   Toxicity Characteristic Rule Evaluation

The TC Rule was published on March 29, 1990, in 55 FR 11798. The TC Rule established regulatory levels for 40 nonhydrolyzing or minimally hydrolyzing constituents (see Table 4-1). A solid waste exhibits the characteristic of toxicity if, the (TCLP), extract from a representative sample of the waste contains a concentration equal to or greater than the concentration listed in 40 CFR 261.24(a) for any of the waste constituents listed. The regulatory levels were generated based on a health-based chronic toxicity limit and a DAF of 100. The health-based chronic toxicity reference levels for the toxicity characteristic constituents were generated using chronic RfDs, carcinogenic risk-specific doses, or MCLs.

The TC rule regulatory levels are not to be exceeded. Because the DRAS generates levels using different modeling and exposure scenarios, delisting levels for the 40 constituents may be below the regulatory levels. Therefore, the DRAS compares a waste constituent's leachate concentration delisting level concentration, called the maximum allowable TCLP concentration, with the waste constituent's TC Rule regulatory level. If the maximum allowable (see) TCLP concentration exceeds the TC Rule regulatory level, the DRAS notifies the user of the exceedance.

TABLE 4-1

TC RULE REGULATORY LEVELS

Chemical	Regulatory Level (mg/L)
Arsenic	5.0
Barium	100
Benzene	0.5
Cadmium	1.0
Carbon Tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100
Chloroform	6.0
Chromium	5.0
Cresol	200
m-Cresol	200
o-Cresol	200
p-Cresol	200
2,4-D	10.0
1,4-Dichlorobenzene	7.5
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
2,4-Dinitrotoluene	0.13
Endrin	0.02
Heptachlor and its epoxide	0.008
Hexachlorobenzene	0.13
Hexachloro-1,3-butadiene	0.5
Hexachloroethane	3.0
Lead	5.0
Lindane	0.4
Mercury	0.2
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitorbenzene	2.0
Pentachlorophenol	100.0
Pyridine	5.0
Selenium	1.0
Silver	5.0
Tetrachloroethylene	0.7
Toxaphene	0.5
Trichloroethylene	0.5
2,4,5-Trichlorophenol	400
2,4,6-Trichlorophenol	2.0
2,4,5-TP Acid (Silvex)	1.0
Vinyl chloride	0.2

Source: U.S. EPA 1990d

4.2.5.7   MCL Evaluation

In 1974, Congress passed the Safe Drinking Water Act. This law requires U. S. EPA to determine safe levels of chemicals in drinking water that do or may cause health problems. These non-enforceable levels, which are based solely on possible health risks and exposures, are called MCL goals (MCLGs). Based on MCLGs, U.S. EPA sets enforceable standards called MCLs (see Appendix A-2). MCLs are set as close to the MCLGs as possible, considering the ability of public water systems to detect contaminants and remove them using suitable treatment technologies.

In addition to calculating a waste constituent's delisting level the ingestion of groundwater based on the preselected target risk level, the DRAS calculates the waste constituent's delisting level for ingestion of groundwater where the groundwater concentration is set at the existing MCL. In some cases, the waste constituent's groundwater ingestion delisting level based on the MCL will be less conservative than that calculated based on the selected risk level.

When the DRAS indicates that groundwater ingestion is the limiting groundwater pathway, the user has the option of considering either of the groundwater ingestion pathway delisting levels: the risk-based maximum acceptable TCLP concentration or the MCL-based maximum allowable TCLP concentration. By default, however, the DRAS will select the more conservative of the two in summarizing delisting levels.

4.2.5.8   Detection Limit Evaluation

Often a delisting petition contains waste sample analytical results that for a number of the constituents analyzed for but not detected. A non-detect may be reported at the method detection limit (MDL), an estimated quantitation limit (EQL), or a reporting level (RL). A number of variables influence a detection limit including the instrumentation used, the waste matrix, and the analytical test method. In some instances, the reported detection limit for a given chemical may exceed an allowable delisting level at the target risk level. If the user suspects the analyte to be a potential waste constituent, the user can employ DRAS to determine whether the reported detection limit for a waste constituent exceeds a delisting level at the target risk level.

The user enters a detection level concentration as the concentration in DRAS and selects a check box identifying the concentration as a detection limit. The DRAS determines the risk and hazard associated with a fraction of the waste constituent value. The default fraction used in the risk assessment is 0.5 (50 percent of the detection limit). The program tracks waste constituent risks associated with actual measured concentrations and risks associated with 50 percent of the entered detection limit values. The risk assessment results for a value entered as a waste constituent's detection limit are presented in italics to distinguish them from risk assessment results for measured waste constituent concentrations.

4.2.5.9   Estimation of Ecological Effects

A simple framework was developed for ecological assessment of wastes petitioned for delisting based on EPA's Framework for Ecological Risk Assessment (U.S. EPA, 1992d). During the problem formulation phase, a suite of ecological exposure scenarios were reviewed to determine potential ecological exposure pathways. At best, one can only infer that an ecosystem is protected from chemical stressors. The toxicological data support the evaluation of individuals, populations, and occasionally communities, but are inadequate to address the complexities of an ecosystem in most cases. Thus, the approach taken in the assessment was to estimate protective levels for the populations and communities expected to be exposed to wastes disposed to a landfill or surface impoundment, the WMUs evaluated in the DRAS program.

Ecological Exposure

The ecological risk assessment is based upon an approach that evaluates the movement of waste constituents from their WMUs, through different pathways, to the points where ecological receptors are expected to be exposed to these constituents. In selecting the ecological exposure pathways, U.S. EPA Region 6 considered the evaluated WMUs, the landfill and surface impoundment, and the potential for ecological exposure at these managed non-Subtitle C units. Potential exposure to two generic ecosystems was reviewed: A freshwater-based ecosystem and a terrestrial-based ecosystem. Terrestrial-based exposure from wastes disposed to landfills is minimized by regulations. Under 40 CFR §258, minimum criteria are established for all municipal solid waste landfills. These criteria, including wetland and floodplain controls, disease vector control and cover material requirements minimize terrestrial exposure. In Region 6, state regulations impose these criteria on industrial solid waste landfills. Given the measures employed to control terrestrial exposure, Region 6 believes terrestrial exposures to be minimal. Other regions should consult their respective states for regulations imposing criteria on industrial landfills. Nevertheless, Region 6 considered the potential for exposure to the freshwater ecosystem from wastewater runoff from a landfill receiving delisted wastes.

Although most RCRA delistings involve solid materials, liquid wastes may on occasion be delisted to surface impoundments. There are no federal regulations establishing criteria for municipal or industrial surface

impoundments. The DRAS does not consider the potential for exposure to the freshwater ecosystem from wastewater runoff from a surface impoundment receiving delisted wastes. In the case of a delisting to a surface impoundment, Region 6 encourages the delisting manager to consider conducting a waste specific ecological risk assessment. The risk assessment should consider potential ecological pathways such as acute exposure to avian species.

Ecological Assessment Endpoint

The "Framework for Ecological Risk Assessment" defines assessment endpoints as explicit expressions of the environmental value that is to be protected (U.S. EPA 1992d). The Framework document goes on to define measurement endpoints as the measurable attributes related to the environmental value chosen as the assessment endpoint (U.S. EPA 1992d). Although it is conceptually useful to distinguish between the two types of endpoints, the practical implications in a predictive regulatory assessment require that both types be evaluated concurrently. In other words, assessment endpoints are not useful if they do not have measurable attributes, and measurement endpoints are not useful for assessment endpoints lacking ecological significance. For ecological receptors, an environmental value for the protection of populations or communities was selected as an assessment endpoint over a value to protect a given species.

Ecological Benchmarks

Ecological benchmarks were developed for the protection of the aquatic community. These ecological benchmarks are referred to as toxicity reference values (TRVs) and were developed from a variety of ecological receptors based on the availability of data for a given waste constituent. The TRV is developed to protect the entire community, not one particular species. In general, TRVs (the measurement endpoints) were selected for consistency with the Agency's "Framework for Ecological Risk Assessment" (U.S. EPA 1992d). Region 6 believes the ecological analysis is conservative with respect to the overall assessment endpoint (e.g., sustainability of the reproducing populations) because of the way the source, fate and transport parameters are set and how the TRVs are developed. However, the degree to which this conservativeness transfers to ecosystems is not known. See Appendix A-1 for the list of aquatic TRVs currently used in the DRAS analyses.

The ecological assessment focused on inferring the sustainability of populations and communities within the aquatic ecosystem. Therefore, TRVs were derived from measurement endpoints (i.e., reproductive, developmental, growth, survival, and mortality) from which such inferences could be made. Reproductive

studies (e.g., number of viable young per female) were preferred over other endpoints. The aquatic TRVs defaulted to a more conservative no effects level (or concentration) approach for ecological receptors. For populations of fish and aquatic invertebrates (represented by daphnids), a hierarchical approach was taken for use of data sources in deriving aquatic TRVs. The first choice was the final chronic values (FCVs) from the Ambient Water Quality Criteria (AWQC) effort by the EPA Office of Water (U.S. EPA 1998d). If these benchmarks were not available, then a freshwater aquatic TRV was selected from the draft *Protocol for Screening Level Ecological risk Assessment at Hazardous Waste Combustion Facilities* (U.S. EPA. 1998e). Finally, TRVs were selected from the *Toxicological Benchmarks for Screening Potential contaminants of Concern for Effects on Aquatic Biota* (Suter and Tsao, 1996).

Ecological Example Calculation

The following outlines an example calculation for determining whether the waste constituent concentration is predicted to exceed the protective concentration of the constituent in the aquatic community at the point of exposure. The aquatic toxicity reference value (TRV) is the constituent concentration in the ecosystem that should not be exceeded to protect the aquatic community. The allowable ecological delisting level concentration is the delisting waste constituent concentration that will not exceed the aquatic TRV and is specific to the waste volume/chemical/waste management unit/receptor.

Receptor: Aquatic ecosystem
Pathway: Waste Constituent Concentration — WMU — Runoff — Surface water — Aquatic TRV
WMU: Landfill

Equations 2-48 through 2-54 are used to calculate the predicted surface water concentration for a given waste constituent delisted to a landfill, based on the waste constituent's concentration and volume reported in the petition. The overland to surface water model used in this pathway encompasses both the WMU release and the fate and transport portions of the calculation. The DRAS compares the waste constituent's predicted surface water concentration to the constituent's aquatic TRV. If the predicted surface water concentration exceeds the aquatic TRV, the petitioned waste has exceeded the ecological assessment. The DRAS notifies the user of any waste constituent whose total concentration is predicted to exceed the aquatic TRV in the modeled aquatic ecosystem.

The DRAS compares the predicted ambient concentration with the TRV for protection of the ambient water community. For highly bioaccummulative waste constituents (log $K_{ow} > 4.0$ or BCF > 100), such as PCBs

or dioxin, the user should consider that bioaccumulation of the waste constituent through the food web may occur. Under these circumstances, the ambient TRV value may not be protective. The current version of the DRAS does not account for bioaccumulation of waste constituents in the aquatic community. When assessing ecological impacts from the runoff of waste constituents having a log $K_{ow} > 4.0$ or a BCF > 100, the user should consider the potential for bioaccummulative impacts within the food web or benthic community.

4.3   QUANTITATIVE ESTIMATION OF RISK

This section presents the equations used to calculate pathway delisting levels and risks associated with exposures to carcinogenic chemicals constituents via groundwater, surface water, air, and soil pathways. Calculation of delisting levels and hazards associated with exposures to noncarcinogenic chemicals is addressed in Section 4.4. The equations used are adapted from the Technical Support Document HWIR (U.S. EPA 1995b) and U.S. EPA OSW delisting dockets (U.S. EPA 1993a, and 1994a). The general risk equations presented in Section 4.2.1 are implemented for specific constituents and exposure pathways. $Risk_{c,p}$ is first computed for each constituent using an expanded form of Equation 4-1, and is summed across all constituents to calculate $Risk_p$ for each exposure pathway as shown in Equation 4-2. Risks for all groundwater exposure pathways and surface exposure pathways are summed separately by the DRAS to assist the user in understanding which pathways contribute most to risk. The DRAS finally sums groundwater exposure pathway risk and surface exposure pathway risk as shown in Equation 4-3 to provide the user with the aggregate risk, $Risk_{cum}$, for all exposure pathways. Constituent- and pathway-specific subscripts are omitted in subsequent equations for simplicity of presentation; the context indicates whether the value being calculated is constituent- or pathway-specific.

For groundwater exposures, the DRAS computes constituent-specific delisting levels and aggregate risks for the following groundwater pathways: ingestion of groundwater, dermal exposure to groundwater via bathing (adult and child), and inhalation of volatile constituents released from groundwater during showering. The equations used to compute the risks associated with groundwater exposures are discussed in Section 4.3.1. For surface water, the DRAS computes delisting levels and aggregate risks for the following exposure pathways: ingestion of drinking water and ingestion of fish, both from surface water bodies receiving runoff from landfills. The equations used to calculate risks from exposure to surface water are discussed in Section 4.3.2. For air, the DRAS computes delisting levels and aggregate risks associated with exposure via inhalation of particulates and volatiles from solid wastes disposed of in landfills and inhalation of volatiles from liquid wastes disposed of in surface impoundments. Finally, the DRAS computes delisting levels and aggregate risks associated with exposure via (child) ingestion of soil contaminated by particles eroded from

a landfill by wind and deposited on the soil from the air. The equations used to calculate risks associated with the inhalation exposure pathways and with soil ingestion are discussed in Sections 4.3.3 and 4.3.4, respectively.

4.3.1 Groundwater Exposure Pathways

Three groundwater exposure pathways are evaluated in the DRAS: ingestion of groundwater, dermal exposure to groundwater via bathing, and inhalation of volatile constituents released from groundwater during showering. The receptor is assumed to be an adult for the ingestion and showering pathways; both adult and child receptors are addressed for the bathing pathway. Each pathway is discussed below.

4.3.1.1 Ingestion of Groundwater

This section discusses computation of leachate concentration delisting levels and of risks associated with exposure of adults to carcinogenic waste constituents via the groundwater ingestion pathway. Section 4.3.1.1.1 presents the equations used to compute pathway delisting levels for standard multi-year delistings. Section 4.3.1.1.2 presents the equations and methods used to compute constituent-specific risk and pathway- specific risk.

4.3.1.1.1 Delisting Level Analysis

A pathway leachate concentration delisting level for groundwater ingestion ($C_{dl\text{-}ingest}$) is calculated for each carcinogenic constituent using the maximum allowable constituent concentration in groundwater for ingestion exposure ($C_{gw\text{-}ingest}$). $C_{gw\text{-}ingest}$ is computed at the target risk level using Equation 4-8.

$$C_{gw-ingest} = \frac{TR \cdot AT \cdot 365 \ days/yr}{EF \cdot IFW_{adj} \cdot CSF_{oral}}$$

(4-8)

where:

			Default
$C_{gw\text{-}ingest}$	=	maximum allowable constituent concentration in groundwater for ingestion (mg/L)	calculated
TR	=	individual target risk level (unitless)	User specified (default 1 x 10^{-5} See Section 4.2.3)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)

AT $\quad$ = $\quad$ averaging time (years) $\qquad$ 75 (U.S. EPA 1997b)

IFW_{adj} = water ingestion factor, age-adjusted $\qquad$ 1.07 (Equation 3-4)
$\qquad$ [L·year]/[kg·day]

CSF_{oral} = constituent oral cancer slope factor (mg/kg-day)$^{-1}$ $\qquad$ chem-specific (Appendix A-1)

The waste constituent's $C_{gw-ingest}$ is multiplied by its volume-adjusted DAF to generate the constituent's $C_{dl-ingest}$, as shown in Equation 4-9. Note that since some inorganic constituents now have DAFs that vary based on the landfill leachate concentration, DRAS now uses an iterative procedure to determine the leachate concentration-volume-adjusted DAF pairing that corresponds to the maximum allowable receptor well concentration. The DRAS may in some cases extrapolate between known leachate-DAF pairings in order to determine the appropriate delisting level. See discussion in Chapter 2 at the end of Section 2.2.2.2.

$$C_{dl-ingest} = DAF_{va} \quad C_{gw-ingest} \qquad (4-9)$$

where:

			Default
$C_{dl-ingest}$	=	pathway leachate concentration delisting level for groundwater ingestion (mg/L)	calculated
DAF_{va}	=	waste volume-adjusted dilution-attenuation factor (unitless)	Equation 2-5
$C_{gw-ingest}$	=	maximum allowable constituent concentration in groundwater for ingestion (mg/L)	Equation 4-8

If the TCLP concentration for a given waste constituent exceeds its pathway leachate concentration delisting level, $C_{dl-ingest}$, the waste may not qualify for a standard multi year delisting. The waste may qualify for a one- time delisting, depending on the results of risk analysis calculations presented Section 4.3.1.1. 2.

4.3.1.1.2 Risk Analysis

The basic risk equation used to develop Equations 4-8 and 4-9, in which the target risk is specified and the leachate concentration delisting level is back-calculated, is solved in the forward direction to compute the risk from groundwater ingestion for each carcinogenic constituent, given a concentration of that constituent in groundwater, as shown in Equation 4-10.

$$Risk \quad = \quad \frac{C_{gw} \cdot IFW_{adj} \cdot EF \cdot CSF_{oral}}{AT \cdot 365 \ days/year} \qquad (4-10)$$

where:

			Default
$Risk$	=	cancer risk for carcinogens (unitless)	calculated

C_{gw}	=	constituent concentration in groundwater (mg/L)	Equation 2-6
IFW_{adj}	=	water ingestion factor, age-adjusted $[L \cdot year]/[kg \cdot day]$	1.07 (Equation 3-4)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
CSF_{oral}	=	constituent oral cancer slope factor $(mg/kg\text{-}day)^{-1}$	chem-specific (Appendix A-1)
AT	=	averaging time (years)	75 (U.S. EPA 1997b)

To compute the individual constituent risks for groundwater ingestion, the user enters each waste constituent TCLP concentration into the DRAS at the specified prompt. The DRAS computes a waste constituent's C_{gw} by dividing the waste constituent TCLP concentration by the constituent's DAF_{va} (see Equation 2-6). Using Equation 4-10, the DRAS calculates the groundwater ingestion- specific risk for each constituent. Then the DRAS uses Equation 4-2 and sums the individual constituent risks to determine the total risk for the groundwater ingestion pathway.

4.3.1.2   Adult and Child Dermal Contact with Groundwater During Bathing

This section describes computation of leachate concentration delisting levels and risks associated with exposure of adults and children to carcinogenic waste constituents via dermal contact with groundwater during bathing. Section 4.3.1.2.1 presents the equations used to compute pathway delisting levels for standard multi year delisting. Section 4.3.1.2.2 presents the equations used to compute constituent-specific risk and pathway-specific risk for one-time delistings.

4.3.1.2.1   Delisting Level Analysis

Pathway leachate concentration delisting levels for dermal contact with groundwater used for bathing ($C_{dl\text{-}dermal}$) are calculated using the target risk level. The DRAS computes $C_{dl\text{-}dermal}$ for the adult and child receptors using appropriate exposure parameters for each and then sets the final $C_{dl\text{-}dermal}$ using the results for the more sensitive of the two receptors. $C_{dl\text{-}dermal}$ is calculated for each carcinogenic constituent and is a function of the maximum allowable constituent concentration in groundwater for dermal exposure, $C_{gw\text{-}dermal}$, which is computed so as not to exceed the acceptable risk level for dermal exposure during bathing. $C_{gw\text{-}dermal}$ is multiplied by the constituent's DAF_{va} to generate $C_{dl\text{-}dermal}$, as shown in Equation 4-11.

$$C_{dl\text{-}dermal} = DAF_{va} \quad C_{gw\text{-}dermal} \tag{4-11}$$

where: Default

$C_{dl\text{-}dermal}$ = pathway leachate concentration delisting level for   calculated

groundwater dermal contact (mg/L)

DAF_{va} = waste volume-adjusted dilution attenuation   Equation 2-5
factor (unitless)

$C_{gw\text{-}dermal}$ = maximum allowable constituent concentration   Equations 4-12 through 4-14
in groundwater for dermal exposure (mg/L)

$C_{gw\text{-}dermal}$ is computed differently for organic and inorganic constituents. For organic constituents, $C_{gw\text{-}dermal}$ is calculated using one of two methods, depending on whether the elapsed time from the beginning of bathing (called the event duration, t_{event}) is greater or less than the time required for the flux of chemical through the skin to reach steady state (a chemical-specific constant called t^*). For inorganic constituents, the method used is independent of t_{event}.

Equation 4-12 is used to compute $C_{gw\text{-}dermal}$ for an organic constituent when t_{event} is less than t^*.

$$C_{gw\text{-}dermal} = \frac{DA_{event} \cdot 10^3 cm^3/L}{2K_p^w \sqrt{\dfrac{6\tau t_{event}}{\pi}}} \qquad \textbf{(4- 12)}$$

where:

		Default
		calculated

$C_{gw\text{-}dermal}$ = maximum allowable constituent concentration   calculated
in groundwater for dermal exposure (mg/L)

DA_{event} = dose absorbed per unit area per event   Equation 4-15
$(mg/cm^2\text{-}event)$

K_p^w = skin permeability constant in water (cm/hr)   chem-specific (Appendix A-1)

$\hat{o}$ = lag time (hr)   chem-specific (Appendix A-1)
t_{event} = duration of event (hr/event)   0.25(adult) or
0.33 (child) (U.S. EPA 1997b)

$C_{gw\text{-}dermal}$ is computed for organic constituents using Equation 4-13 when t_{event} is greater than or equal to t^*.

$$C_{gw\text{-}dermal} = \frac{DA_{event} \cdot 10^3 cm^3/L}{K_p^w \left[\dfrac{t_{event}}{1+B} + 2\tau(\dfrac{1+3B+(3B)^2}{1+B^2}) \right]} \qquad \textbf{(4-13)}$$

where:

		Default
		calculated

$C_{gw\text{-}dermal}$ = maximum allowable constituent concentration   calculated
in groundwater for dermal exposure (mg/L)

DA_{event} = dose absorbed per unit area per event   Equation 4-15
$(mg/cm^2\text{-}event)$

K_p^w =   skin permeability constant in water (cm/hr)   chem-specific (Appendix A-1)

t_{event} =   duration of event (hr/event)   0.25 (adult) or
     0.33 (child) (U.S. EPA 1997b)

$\hat{o}$ =   lag time (hr)   chem-specific (Appendix A-1)

B =   Bunge constant (unitless)   chem-specific (Appendix A-1)

$C_{gw-dermal}$ is computed for inorganic constituents using Equation 4-14.

$$C_{gw-dermal} = \frac{DA_{event} \cdot 10^3 cm^3/L}{K_p^w \cdot t_{event}}$$ **(4-14)**

where:

                                                      <u>Default</u>

$C_{gw-dermal}$ = maximum allowable constituent concentration in groundwater for dermal exposure (mg/L)   calculated

DA_{event} = dose absorbed per unit area per event (mg/cm²-event)   Equation 4-15

K_p^w = skin permeability constant in water (cm/hr)   chem-specific (Appendix A-1)

t_{event} = duration of event (hr/event)   0.25(adult) or
     0.33 (child) (U.S. EPA 1997b)

To generate $C_{gw-dermal}$, one must first generate the dose absorbed per unit area per event (DA_{event}). DA_{event} is calculated separately for adults and children using Equation 4-15.

$$DA_{event} = \frac{AT \cdot DAD \cdot BW \cdot 365 \; days/year}{EV \cdot EF \cdot ED \cdot A_{skin}}$$ **(4-15)**

where:

                                                      <u>Default</u>

DA_{event} = dose absorbed per unit area per event (mg/cm²-event)   Calculated

AT = averaging time (years)   75 (U.S. EPA 1997b)

DAD = dermally absorbed dose (mg/kg-day)   Equation 4-16

BW = body weight (kg)
     - adult   72 (U.S. EPA 1997b)
     - child   15 (U.S. EPA 1997b)

EV = event frequency (events/day)   1 (U.S. EPA 1997b)

EF = exposure frequency (days/year)   350 (U.S. EPA 1997b)

ED = exposure duration (years)
     - adult   30 (U.S. EPA 1997b)
     - child   6 (U.S. EPA 1997b)

A_{skin} = exposed skin surface area (cm^2)
- adult   20,000 (U.S. EPA 1997b)
- child   7,900 (U.S. EPA 1997b)

The *DAD*, or dermally absorbed dose for contact with water during bathing, is computed for carcinogens using Equation 4-16.

$$DAD = \frac{TR}{CSF_{oral}}$$ **(4-16)**

where:

			Default
DAD	=	dermally absorbed dose (mg/kg-day)	calculated
TR	=	individual target risk level (unitless)	user specified (1 x 10^{-5} default)
CSF_{oral}	=	constituent oral cancer slope factor $(mg/kg\text{-}day)^{-1}$	chem-specific (Appendix A-1)

If the TCLP concentration for a given waste constituent exceeds its pathway leachate concentration delisting level, $C_{dl\text{-}dermal}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of risk steps calculations presented Section 4.3.1.2.2..

4.3.1.2.2 Risk Analysis

In the risk analysis, the DRAS uses the equations used in computation of the delisting levels, but instead of back-calculating from the target risk level to a maximum allowable constituent concentration in leachate, the equations are used to calculate the risk given some constituent concentration expected in the groundwater. The risk for a given carcinogenic constituent associated with dermal contact during bathing is computed for the adult and child receptors using Equation 4-17.

$$R = DAD \quad CSF_{oral}$$ **(4-17)**

where:

			Default
R	=	risk from dermal contact during bathing for constituent (unitless)	calculated
DAD	=	dermally absorbed dose (mg/kg-day)	Equation 4-18
CSF_{oral}	=	constituent oral cancer slope factor $(mg/kg\text{-}day)^{-1}$	chem-specific (Appendix A-1)

The dermally absorbed dose (*DAD*), needed in Equation 4-17, is calculated as shown in Equation 4-18 (U.S. EPA 1992b).

$$DAD = \frac{DA_{event} \cdot EV \cdot EF \cdot ED \cdot A_{skin}}{AT \cdot 365days/year \cdot BW} \qquad \textbf{(4-18)}$$

where:

			Default
DAD	=	dermally absorbed dose (mg/kg-day)	calculated
DA_{event}	=	dose absorbed per unit area per event (mg/cm^2-event)	Equations 4-19 through 4-21
EV	=	event frequency (events/day)	1 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	
		- adult	30 (U.S. EPA 1997b)
		- child	6 (U.S. EPA 1997b)
A_{skin}	=	exposed skin surface area (cm^2)	
		- adult	20,000 (U.S. EPA 1997b)
		- child	7,900 (U.S. EPA 1997b)
AT	=	averaging time (years)	75 (U.S. EPA 1997b)
BW	=	body weight (kg)	
		- adult	72 (U.S. EPA 1997b)
		- child	15 (U.S. EPA 1997b)

The dose absorbed per unit area per event (DA_{event}) must be calculated using Equation 4-19, 4-20, or 4-21, depending on the type of waste constituent in question and the relationship between the duration of the bath (t_{event}) and the time constituents required for the flux of chemical through the skin to reach steady state (t^*, a chemical- specific constant). For organic, when t_{event} is less than t^*, DA_{event} is computed using Equation 4-19 (U.S. EPA 1992b).

$$DA_{event} = \frac{C_{gw} \cdot 2K_p^{\ w} \sqrt{\dfrac{6\tau t_{event}}{\pi}}}{10^3 cm^3/L} \qquad \textbf{(4-19)}$$

where:

			Default
DA_{event}	=	dose absorbed per unit area per event (mg/cm^2-event)	calculated
C_{gw}	=	constituent concentration in groundwater (mg/L)	Equation 2-6
$K_p^{\ w}$	=	skin permeability constant in water (cm/hr)	chem-specific (Appendix A-1)
$\hat{o}$	=	lag time (hr)	chem-specific (Appendix A-1)
t_{event}	=	duration of event (hr/event)	0.25(adult) or 0.33 (child) (U.S. EPA 1997b)

For organic constituents, when t_{event} is greater than or equal to t^*, Equation 4-20 is used (U.S. EPA 1992b).

$$DA_{event} = \frac{C_{gw} \cdot K_p^{w} \left[\dfrac{t_{event}}{1 + B} + 2\tau \left(\dfrac{1 + 3B + (3B)^2}{1 + B^2} \right) \right]}{10^3 cm^3/L} \tag{4-20}$$

where:

			Default
DA_{event}	=	dose absorbed per unit area per event (mg/cm^2-event)	calculated
C_{gw}	=	constituent concentration in groundwater (mg/L)	Equation 2-6
K_p^{w}	=	skin permeability constant in water (cm/hr)	chem-specific (Appendix A-1)
t_{event}	=	duration of event (hr/event)	0.25 (adult) 0.33 (child) (U.S. EPA 1997b)
B	=	Bunge constant (unitless)	chem-specific (Appendix A-1)
$\hat{o}$	=	lag time (hr)	chem-specific (Appendix A-1)

For inorganic constituents, DA_{event} is calculated using Equation 4-21.

$$DA_{event} = \frac{C_{gw} \cdot K_p^{w} \cdot t_{event}}{10^3 cm^3/L} \tag{4-21}$$

where:

			Default
DA_{event}	=	dose absorbed per unit area per event (mg/cm^2-event)	calculated
C_{gw}	=	waste constituent conc. in groundwater (mg/L)	Equation 2-6
K_p^{w}	=	skin permeability constant in water (cm/hr)	chem-specific (Appendix A-1)
t_{event}	=	duration of event (hr/event)	0.25 (adult) 0.33 (child) (U.S. EPA 1997b)

Using Equation 4-17, the DRAS calculates the risk associated with groundwater exposure via dermal absorption during bathing for each waste constituent. Subsequently, the DRAS uses Equation 4-2 and sums the constituent-specific risks to determine the total risk for the groundwater dermal absorption pathway.

4.3.1.3 Adult Inhalation of Volatiles from Groundwater During Showering

This section describes computation of pathway leachate concentration delisting levels and risks associated with exposure to carcinogenic constituents in groundwater via inhalation of volatiles by adults while showering. Section 4.3.1.3.1 presents the equations used to calculate the delisting levels for standard multi-

year delistings. Section 4.3.1.3.2 presents the equations used to calculate constituent-specific and pathway- specific risk for one-time delistings.

The method used to determine waste constituent-specific exposures resulting from inhalation of constituents in tap water is based on information used to support the "Petroleum Refinery Listing Determination" (U.S. EPA 1997a). This project used a method developed by McKone (1987) to estimate a time-varying constituent concentration in three compartments: the shower, the bathroom, and the house. Therefore, U.S. EPA Region 6 uses simplified versions of the equations that compute a conservative constant concentration for each of the three compartments. The simplified equations are based on the steady-state model developed by McKone and Bogen (1992), which calculates a chemical concentration in air for each of the three compartments.

4.3.1.3.1 Delisting Level Analysis

The pathway total waste constituent concentration delisting levels for carcinogenic constituents inhaled when groundwater is used for showering ($C_{dl\text{-}inhale}$) are calculated for each constituent using the maximum allowable concentration in groundwater for inhalation ($C_{gw\text{-}inhale}$) at the specified target risk level. To generate $C_{dl\text{-}inhale}$, $C_{gw\text{-}inhale}$ is multiplied by the constituent's DAF_{va} as shown in Equation 4-22.

$$C_{dl-inhale} = DAF_{va} \quad C_{gw-inhale}$$
(4-22)

where:

			Default
$C_{dl\text{-}inhale}$	=	pathway leachate concentration delisting level for shower inhalation (mg/L)	calculated
DAF_{va}	=	waste volume-adjusted dilution attenuation factor (unitless)	Equation 2-5
$C_{gw\text{-}inhale}$	=	maximum allowable constituent concentration in groundwater used for showering (mg/L)	Equation 4-24

To generate $C_{gw\text{-}inhale}$, one must first generate the sum of products of the maximum allowable air concentration and corresponding exposure time in three compartments during showering (CET_{max}) using Equation 4-23.

$$CET_{max} = \frac{TR \cdot AT \cdot 365 \ days/year}{EV \cdot EF \cdot IFA_{adj} \cdot CSF_{inhal}}$$
(4-23)

where:

			Default
CET_{max}	=	sum of products of maximum allowable constituent air concentration in specific compartment and corresponding exposure time (mg-days/m^3)	calculated (Equation 4-23)
TR	=	individual target risk level (unitless)	1×10^{-5} (U.S. EPA 1997b) or user-specified
AT	=	averaging time (years)	75 (U.S. EPA 1997b)
EV	=	event frequency (events/day)	1 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
IFA_{adj}	=	inhalation factor, age-adjusted ([m^3-year]/[kg-day])	10.7 (Equation 3-3)
ET_{comp}	=	exposure time in each compartment (days/shower) - shower - bathroom - house	(McKone and Bogen 1992) 0.00792 0.0338 0.625
CSF_{inhal}	=	constituent inhalation cancer slope factor (mg/kg-day)$^{-1}$	chem-specific (Appendix A-1)

Once CET_{max} for a given waste constituent is known, $C_{gw-inhale}$ is back-calculated based on the linear relationship of the transient shower concentration equations as described in Equations 4-31 through 4-33. In other words, the linearity of these equations allows us to simply calculate the fractions of the average compartment concentrations to the groundwater concentration in the forward calculations and then divide CET_{max} by the sum of products of concentration fraction and corresponding exposure time to get $C_{gw-inhale}$. This requires that one forward calculation be performed at an arbitrary TCLP concentration before the backward calculations begin. The allowable groundwater concentration can then be computed using Equation 4-24.

$$C_{gw-inhale} = \frac{CET_{max}}{\sum_{comp} F_{GW,\,comp} \cdot ET_{comp}} \qquad \textbf{(4-24)}$$

where:

			Default
$C_{gw-inhale}$	=	maximum allowable constituent concentration in groundwater used for showering (mg/L)	calculated
CET_{max}	=	sum of products of maximum allowable constituent air concentration in specific compartment and corresponding exposure time (mg-days/m^3)	calculated (Eq. 4-23)
$F_{GW,\,comp}$	=	fraction of average waste constituent concentration in the compartment over the groundwater waste constituent concentration based on a forward calculation	Equation 4-25
ET_{comp}	=	exposure time in each compartment (days/shower)	(McKone and Bogen 1992)

- shower	0.00792
- bathroom	0.0338
- house	0.625

The relationship between the average waste constituent concentration in a given compartment (determined using Equations 4-28 to 4-33) divided by an established waste concentration in the groundwater is calculated in Equation 4-25. This relationship is unique to each chemical since it is based on the volatilization of the chemical in the compartment. However, the relationship between this calculated fraction and the allowable delisting concentration is linear.

$$F_{GW,\ comp} = \frac{C_{F\text{-}avg,\ comp}}{C_{F\text{-}gw\text{-}inhale}} \qquad (4\text{-}25)$$

where:

$F_{GW,\ comp}$ = fraction of average waste constituent concentration in the compartment over the groundwater waste constituent concentration based on a forward calculation — Equation 4-25

$C_{F\text{-}avg,\ comp}$ = average compartment concentration from a forward calculation (mg/m^3) — Equations 4-28 - 4-30

$C_{F\text{-}gw\text{-}inhale}$ = groundwater concentration that C_{Favg} is based on (mg/L)

Once $C_{gw\text{-}inhale}$ is determined from Equation 4-24, the DRAS performs the back-calculation described in Equation 4-22 to generate the pathway delisting level ($C_{dl\text{-}inhale}$). If the TCLP concentration of a given waste constituent exceeds its pathway leachate concentration delisting level, $C_{dl\text{-}inhale}$, the waste may not qualify for a standard multi-year delisting. However, the waste may qualify for a one-time delisting, depending on the results of risk analysis calculations presented Section 4.3.1.3.2.

4.3.1.3.2 Risk Analysis

In the risk analysis, the DRAS computes the risk for an adult receptor exposed to carcinogenic waste constituents through inhalation of air concentrations contaminated during showering with the groundwater and subsequent exposure. The shower model used in this analysis is based on the equations presented in McKone (1987). The shower model estimates the change in the shower air concentration based on the mass of waste constituent lost by the contaminated groundwater and the air exchange rate between the various model compartments (shower, bathroom, and house). The constituent-specific risk is calculated for each inhalation compartment using Equation 4-26.

$$R = \frac{CET \cdot 1000L/m^3 \quad CSF_{inhal} \cdot IFA_{adj} \cdot EF \cdot EV \cdot}{AT \cdot 365 \, days/year} \qquad \text{(4-26)}$$

where:

			Default
R	=	risk from inhalation during showering for constituent (unitless)	calculated
CET	=	sum of products of maximum allowable constituent air concentration in specific compartment and corresponding exposure time (mg-days/m³)	calculated (Equation 4-27)
1000L/m³	=	conversion from cubic meters to liters	
CSF_{inhal}	=	constituent inhalation cancer slope factor (mg/kg-day)$^{-1}$	chem-specific (Appendix A-1)
IFA_{adj}	=	inhalation factor, age-adjusted ([m³-year]/[kg-day])	10.67 (Equation 3-3)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
EV	=	event frequency (events/day)	1 (U.S. EPA 1997b)
AT	=	averaging time (years)	75 (U.S. EPA 1997b)

$C_{air,i}$ is the sum of the exposure concentrations in the shower, bathroom, and house compartments computed using Equation 4-27.

$$CET = \sum_{comp} C_{avg, \, comp} \cdot ET_{comp} = C_{avg, \, s} \, ET_s + C_{avg, \, b} \, ET_b + C_{avg, \, h} \, ET_h \qquad \text{(4-27)}$$

where:

			Default
CET	=	sum of products of maximum allowable constituent air concentration in specific compartment and corresponding exposure time (mg-days/m³)	calculated (Equation 4-27)
$C_{avg,s}$	=	average constituent air conc. in shower (mg/L)	Equation 4-28
$C_{avg,b}$	=	average constituent air conc. in bathroom (mg/L)	Equation 4-29
$C_{avg,h}$	=	average constituent air conc. in house (mg/L) exposure	Equation 4-30
ET_{comp}	=	time in each compartment (days/shower)	U.S EPA 1997b
		- shower	0.00792
		- bathroom	0.0338
		- house	0.625

To calculate the total constituent air concentration inhaled, the average constituent-specific air concentration ($C_{avg,i}$) that the individual is exposed to in each inhalation compartment (shower, bathroom, and house) is calculated using Equations 4-28 through 4-30, respectively.

$$C_{avg,s} = \frac{\sum_{t=1}^{N} y_{s,t}}{N}$$

(4-28)

where:

			Default
$C_{avg,s}$	=	average air concentration in shower (mg/L)	calculated
t	=	calculational time step index	
N	=	total number of time steps for the time in the shower	57 (n/ Ät)
$Ät$	=	time step (min)	0.2 (McKone 1987)
n	=	time in shower (min)	11.4 (U.S. EPA 1997b)
$y_{s,t}$	=	air concentration in shower at time t (mg/L)	Equation 4-31

and:

$$C_{avg,b} = \frac{\sum_{t=1}^{N} y_{b,t}}{N}$$

(4-29)

where:

			Default
$C_{avg,b}$	=	average air concentration in bathroom (mg/L)	calculated
t	=	calculational time step index	
N	=	total number of time steps for the time in the bathroom excluding time in shower	243 (n/Ät)
$Ät$	=	time step (min)	0.2 (McKone 1987)
n	=	time in bathroom excluding time in shower (min)	48.6 (U.S. EPA 1997b)
$y_{b,t}$	=	air concentration in bathroom at time t (mg/L)	Equation 4-32

and:

$$C_{avg,h} = \frac{\sum_{t=1}^{N} y_{h,t}}{N}$$

(4-30)

where:

			Default
$C_{avg,h}$	=	average air concentration in house (mg/L)	calculated

t	=	calculational time step index	
N	=	total number of time steps for the time in the house excluding time in the bathroom and shower	4500 (n/Ät)
n	=	time in house excluding shower and bathroom time (min)	900 (U.S. EPA 1997b)
Ät	=	time step (min)	0.2 (McKone 1987)
$y_{h,t}$	=	air concentration in house at time t (mg/L)	Equation 4-33

For each of the compartments, the average concentration of the waste constituent in the air is dependent on calculation of the gas phase of the waste constituent in that compartment. For example, calculation of the average air concentration in the shower, $C_{avg,s}$, is dependent on calculation of the gas phase constituent concentration in the shower at time t $(y_{s,t+1})$ as derived using Equation 4-31. The air exchange rate between the shower and the bathroom is included in the estimation of the gas phase concentration of the constituents in the shower (McKone 1987).

$$y_{s,t+1} = y_{s,t} + \left[(Q_{gs} \cdot (y_{b,t} - y_{s,t})) + (I_s \cdot C_{gw} \cdot f_{em,s}) \right] \cdot \left(\frac{t_{t+1} - t_t}{V_s} \right) \tag{4-31}$$

where:

			Default
$y_{s,t+1}$	=	gas phase constituent concentration in the shower at end of time step (mg/L)	calculated
$y_{s,t}$	=	gas phase constituent concentration in the shower at beginning of time step (mg/L)	calculated (0.0 for 1st time step)
Q_{gs}	=	volumetric gas exchange rate between shower and bathroom (L/min)	100 (McKone 1987)
$y_{b,t}$	=	gas phase constituent concentration in bathroom at beginning of time step (mg/L)	calculated (0.0 for 1st time step)
$(t_{t=1} - t_t) =$		calculational time step (min)	0.2 (McKone 1987)
I_s	=	shower water use (L/min)	5.5 (McKone 1987)
C_{gw}	=	waste constituent concentration in the receptor well (mg/L)	Equation 2-6
$f_{em,s}$	=	fraction of constituent emitted from shower water use (unitless)	(Equation 4-34)
V_s	=	volume of shower stall (L)	2,300 (U.S. EPA 1997b)

To calculate the average concentration of the waste constituent in the air of the bathroom, $C_{avg,b}$, the gas phase constituent concentration in the bathroom at time t $(y_{b,t+1})$ is calculated using Equation 4-32. Equation 4-32 is calculated based on total bathroom water use of 125 L/day and exposure duration in bathroom of 1 hr/day (U.S. EPA 1997b).

$$y_{b,t+1} = y_{b,t} + \left[(Q_{gs} \cdot (y_{s,t} - y_{b,t})) - (Q_{gb} \cdot (y_{b,t} - y_{h,t})) + (I_b \cdot C_{gw} \cdot f_{em,b}) \right] \cdot \left(\frac{t_{t+1} - t_t}{V_b} \right) \quad (4\text{-}32)$$

where:

			Default
$y_{b,t+1}$	=	gas phase constituent concentration in the bathroom at end of time step (mg/L)	calculated
$y_{b,t}$	=	gas phase constituent concentration in the bathroom at for previous time step (mg/L)	calculated (0.0 for 1st time step)
Q_{gs}	=	volumetric gas exchange rate between shower and bathroom (L/min)	100 (McKone 1987)
$y_{s,t}$	=	gas phase constituent concentration in the shower for previous time step (mg/L)	calculated (0.0 for 1st time step)
Q_{gb}	=	volumetric gas exchange rate between bathroom and house (L/min)	300 (McKone 1987)
$y_{h,t}$	=	gas phase constituent concentration in bathroom at for previous time step (mg/L)	calculated (0.0 for 1st time step)
$(t_{t+1} - t_t)$	=	calculational time step (min)	0.2 (McKone 1987)
I_b	=	bathroom water use (L/min)	2.08 (McKone 1987)
C_{gw}	=	waste constituent concentration in the receptor well (mg/L)	Equation 2-6
$f_{em,b}$	=	fraction of constituent emitted from bathroom water use (unitless)	(Equation 4-34)
V_b	=	volume of bathroom (L)	13,600 (U.S. EPA 1997b)

To calculate the average air concentration of a waste constituent in the house, $C_{avg,h}$, the gas phase constituent concentration in the house at time t ($y_{h,t+1}$) is calculated using Equation 4-33. Equation 4-33 is calculated based on total bathroom water use of 201 L/day and 16 hours of household exposure (U.S. EPA 1997b).

$$y_{h,t+1} = y_{h,t} + \left[(Q_{gb} \cdot (y_{b,t} - y_{h,t})) - (Q_{gh} \cdot (y_{h,t} - y_{a,t})) + (I_h \cdot C_{gw} \cdot f_{em,h}) \right] \cdot \left(\frac{t_{t+1} - t_t}{V_h} \right) \quad (4\text{-}33)$$

where:

			Default
$y_{h,t+1}$	=	gas phase constituent concentration in the house at end of time step (mg/L)	calculated
$y_{h,t}$	=	gas phase constituent concentration in the house for previous time step (mg/L)	calculated (0.0 for 1st time step)
Q_{gb}	=	volumetric gas exchange rate between the bathroom and house (L/min)	300 (McKone 1987)
$y_{b,t}$	=	gas phase constituent concentration in the bathroom for previous time step (mg/L)	calculated (0.0 for 1st time step)
Q_{gh}	=	volumetric gas exchange rate between house and atmosphere (L/min)	2,325 (McKone 1987)
$y_{a,t}$	=	gas phase constituent concentration in the atmosphere (mg/L)	assumed 0.00
$(t_{t+1} - t_t)$	=	calculational time step (min)	0.2 (McKone 1987)

I_h	=	water use in house - other than bathroom (L/min)	0.21 (McKone 1987)
C_{gw}	=	waste constituent concentration in the receptor well (mg/L)	Equation 2-6
$f_{em,h}$	=	fraction of constituent emitted from household	(Equation 4-34)

water use - other than bathroom (unitless)

V_h = volume of house (L)   310,000 (U.S. EPA 1997b)

In order to calculate the gas phase constituent concentration in the three compartments (shower, bathroom and house) at time t, the fraction of the waste constituent emitted from the contaminated groundwater (f_{em}) must be calculated for each compartment. The fraction emitted for the shower compartment ($f_{em, s}$) is calculated using the formula in Equation 4-34. The fraction emitted for the bathroom compartment and the house compartment are calculated using the general formula in Equation 4-38. The fraction of the gas phase saturation (f_{sat}) is unique to each compartment, thereby determining a unique fraction emitted (f_{em}) for each compartment.

$$f_{em,i} = (1 - f_{sat,i})\ (1 - e^{-N}) \qquad (4\text{-}34)$$

where:

Default

$f_{em, i}$ = fraction of constituent emitted from contaminated   calculated
groundwater for each compartment i (unitless)

N = Dimensionless mass transfer coefficient (unitless)   Equation 4-36

f_{sat} = Fraction of gas phase saturation for each   Equation 4-35
compartment i (unitless)

The fraction of the gas phase saturation (f_{sat}) for each compartment is calculated using Equation 4-35.

$$f_{sat,s} = \frac{y_{i,t}}{H' \cdot C_{gw}} \qquad (4\text{-}35)$$

where:

Default

f_{sat} = fraction of gas phase saturation for each   calculated
compartment i (unitless)

$y_{i,t}$ = gas phase constituent concentration in each
compartment i (mg/L)

$y_{s,t}$ = for shower compartment   Equation 4-31
$y_{b,t}$ = for bathroom compartment   Equation 4-32
$y_{h,t}$ = for house compartment   Equation 4-33

H' = dimensionless Henry's law constant (H × 41)   chem-specific (Appendix A)

C_{gw} = waste constituent concentration in the receptor   Equation 2-6
well (mg/L)

To calculate the fraction of waste constituent emitted from the contaminated groundwater (f_{em}), the dimensionless overall mass transfer coefficient (N) is determined using Equation 4-36.

$$N = K_{ol} \left(\frac{6}{d_p} \right) \left(\frac{h}{v_t} \right) \qquad \textbf{(4-36)}$$

where:

			Default
N	=	dimensionless mass transfer coefficient (unitless)	calculated
K_{ol}	=	overall mass transfer coefficient (cm/sec)	Equation 4-37
d_p	=	droplet diameter (cm)	0.098 (McKone 1987)
h	=	nozzle height (cm)	180 (McKone 1987)
v_t	=	terminal velocity (cm/sec)	400 (McKone 1987)

To calculate the dimensionless overall mass transfer coefficient (N), the overall mass transfer coefficient (K_{ol}) is computed using Equation 4-37.

$$K_{ol} = \beta \left(\frac{2.5}{D_w^{2/3}} + \frac{1}{D_a^{2/3} \acute{H}} \right)^{-1} \qquad \textbf{(4-37)}$$

where:

			Default
K_{ol}	=	Overall mass transfer coefficient (cm/sec)	Calculated
$\hat{a}$	=	Proportionality constant (cm/sec)$^{-1/3}$	216 (McKone 1987)
D_w	=	Diffusion coefficient in water (cm^2/sec)	Chem-specific (Appendix A)
D_a	=	Diffusion coefficient in air (cm^2/sec)	Chem-specific (Appendix A)
$\grave{H}$	=	Dimensionless Henry's law constant (H × 41)	Chem-specific (Appendix A)

The fraction of the gas phase saturation (f_{sat}) is unique to each compartment, thereby determining a unique fraction emitted (f_{em}) for each compartment. The fraction emitted from the bathroom or household water use is a function of the input transfer efficiency (or maximum fraction emitted) and the driving force for mass transfer. For the bathroom, the fraction emitted is calculated as follows:

$$f_{em,b} = \left(1 - \frac{y_b}{H' \cdot C_{gw}} \right) (\varepsilon_{transfer} \quad f_{max,b}) \qquad \textbf{(4-38)}$$

where

			Default
$f_{em,b}$	=	fraction of constituent emitted from bathroom water use (unitless)	Calculated
y_b	=	gas phase constituent concentration in the bathroom (mg/L)	Equation 4-32

H'	=	Dimensionless Henry's law constant	Chem-specific (Appendix A)
C_{gw}	=	waste constituent concentration in the receptor well (mg/L)	Equation 2-6
$å_{transfer}$	=	transfer efficiency for non-shower water use (unitless)	Equation 4-40
$f_{max,b}$	=	maximum transfer efficiency for bathroom water use (unitless)	0.5 (McKone, 1987)

The fraction emitted from the household water use is calculated as follows:

$$f_{em,h} = \left(1 - \frac{y_h}{H' \cdot C_{gw}} \right) (\varepsilon_{transfer} \quad f_{max,h}) \tag{4-39}$$

where

			Default
$f_{em, h}$	=	fraction of constituent emitted from bathroom water use (unitless)	Calculated
y_h	=	gas phase constituent concentration in the house (mg/L)	Equation 4-33
H'	=	Dimensionless Henry's law constant	41 × Henry's Law Constant
C_{gw}	=	waste constituent concentration in the receptor well (mg/L)	Equation 2-6
$å_{transfer}$	=	transfer efficiency for non-shower water use	Equation 4-40
$f_{max, h}$	=	maximum transfer efficiency for household water use (unitless)	0.66 (McKone, 1987)

The transfer efficiency is calculated using the following equation based on Little (1992).

$$\varepsilon_{transfer} = 2.76E{+}6 \left(\frac{2.5}{(D_l \times 10^{-4})^{0.667}} + \frac{70}{(D_a \times 10^{-4})^{0.667} \times H'} \right)^{-1} \tag{4-40}$$

where

			Default
$å_{transfer}$	=	transfer efficiency for non-shower water use	Calculated
D_l	=	diffusion coefficient in water (cm²/s)	chem-specific (Appendix A-1)
D_a	=	diffusion coefficient in air (cm²/s)	chem-specific (Appendix A-1)
H'	=	Dimensionless Henry's law constant (H' = 41 × Henry's Law Constant)	chem-specific (Appendix A-1)

There is a theoretical maximum air concentration that can occur in a compartment. The DRAS calculates that theoretical maximum concentration, $C_{air\text{-}max}$, for each compartment using the Ideal Gas Law. The DRAS calculates $C_{air\text{-}i}$ for all three compartments and compares the compartment concentration to the theoretical maximum. If $C_{air\text{-}i}$ for a compartment is larger than $C_{air\text{-}max}$, $C_{air\text{-}i}$ for the compartment is set equal to $C_{air\text{-}max}$.

The C_{air-i} or $C_{air-max}$ for each compartment are totaled in Equation 4-27 and the sum is used in Equation 4-26 to calculate the inhalation risk for each constituent. Then the risk for each waste constituent is summed using Equation 4-2 to obtain the total pathway-specific risk associated with shower inhalation of volatiles from groundwater during showering.

4.3.2   Surface Water Exposure Pathways

The surface water exposure pathways addressed by the DRAS include ingestion of surface water and ingestion of fish. An adult receptor is assured for both pathways. The pathway delisting levels and risks for these pathways are calculated using a method described in EPA Headquarters delisting docket materials (U.S. EPA 1993a, 1993b).   The method uses the USLE to calculate the rate of erosion of a petitioned waste from a landfill to a surface water body. The receiving water body is assumed to be a stream. The amount of eroded waste delivered in runoff to the stream is calculated using a sediment delivery ratio, and the volume of surface water into which runoff occurs is determined by estimating the size of the stream into which the eroded waste is likely to be transported.

For the purposes of delisting, the stream is assumed to be a second-order or fifth-order stream (U.S. EPA 1993a). A second-order stream is assumed to be the smallest stream capable of supporting fish, whereas a fifth-order stream is assumed to be the smallest stream capable of serving as a community water supply. For the surface water ingestion pathway, drinking of unfiltered, untreated water is assumed. Clean Water Act regulations restrict the potential for such exposure, making this a very conservative exposure pathway. Delisting decisions based on this exposure pathway should reviewed carefully. The surface water ingestion analyses are based on the assumption that a chemical is transported to a fifth-order stream; the fish ingestion analyses are based on the assumption that the chemical is transported to a second-order stream.

Sections 4.3.2.1 and 4.3.2.2 describe the equations and default parameters used to calculate the pathway delisting levels and risks associated with the ingestion of surface water and ingestion of fish exposure pathways.

4.3.2.1   Ingestion of Surface Water

This section describes the computation of the total concentration delisting levels and risks associated with exposure of adults to carcinogenic waste constituents via ingestion of surface water. Section 4.3.2.1.1 presents the equations used to compute pathway delisting levels for carcinogenic waste constituents for

standard multi year delisting petitions. Section 4.3.2.1.2 presents the equations and methods used to compute constituent-specific and pathway-specific risks for one-time delistings.

4.3.2.1.1 Delisting Level Analysis

Pathway total concentration delisting levels for carcinogens associated with ingestion of surface water ($C_{dl\text{-}water}$) are calculated using the user specified target risk level (default 1 x 10^{-5}). To calculate $C_{dl\text{-}water}$, the maximum allowable concentration of a waste constituent in surface water (C_{sw}) must first be calculated. The DRAS then back-calculates $C_{dl\text{-}water}$ using C_{sw}. Equation 4-41 is used to calculate C_{sw}.

$$C_{sw} = \frac{TR \cdot AT \cdot 365 \text{ days/year}}{EF \cdot IFW_{adj} \cdot CSF_{oral}}$$

(4-41)

where:

			Default
C_{sw}	=	maximum allowable concentration of constituent in surface water (mg/L)	calculated
TR	=	individual target risk level (unitless)	User specified (default 1 x 10^{-5})
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1998b)
AT	=	averaging time (years)	75 (U.S. EPA 1997b)
IFW_{adj}	=	water ingestion factor, age-adjusted ([L-yr]/[kg-day])	1.07 (Equation 3-4)
CSF_{oral}	=	oral cancer slope factor (mg/kg-day)$^{-1}$	chem-specific (Appendix A-1)

After is calculated, C_{sw}, the waste constituent's pathway total concentration delisting level, $C_{dl\text{-}water}$, for the surface water ingestion pathway is computed as shown in Equation 4-42.

$$C_{dl\text{-}water} = \frac{C_{sw}}{C_{5th\text{-}stream}}$$

(4-42)

where:

			Default
$C_{dl\text{-}water}$	=	pathway total concentration delisting level for ingestion of surface water (mg/kg)	calculated
C_{sw}	=	maximum allowable concentration of constituent in surface water (mg/L)	Equation 4-41
$C_{5th\text{-}stream}$	=	concentration of eroded waste and soil in fifth-order stream (kg/L)	Equation 4-43

$C_{5th\text{-}stream}$ is calculated as shown in Equation 4-43.

$$C_{5th-stream} = \frac{A_w}{Q_{5th}} A \qquad \text{(4-43)}$$

where:

			Default
$C_{5th-stream}$	=	concentration of eroded waste and soil in fifth-order stream (kg/L)	calculated
A_w	=	rate of soil and waste erosion from landfill (kg/[acre-year])	Equation 2-51
Q_{5th}	=	volumetric flow in fifth-order stream (L/year)	3.4×10^{11} (U.S. EPA, 1993a)
A	=	area of waste management unit (acres)	Equation 2-12 or 2-13

If the total concentration of a given constituent in the waste exceeds its pathway total concentration delisting level, $C_{dl-water}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of risk analysis calculations presented in Section 4.3.2.1.2.

4.3.2.1.2 Risk Analysis

This section describes how the DRAS computes risks associated with the surface water ingestion exposure pathway. The DRAS computes each carcinogenic waste constituent's risk for surface water ingestion pathway as shown in Equation 4-44.

$$Risk = \frac{C_{sw} \cdot IFW_{adj} \cdot EF \cdot CSF_{oral}}{AT \cdot 365days/year} \qquad \text{(4-44)}$$

where:

			Default
$Risk$	=	risk for surface water ingestion for waste constituent (unitless)	calculated
C_{sw}	=	concentration of constituent in surface water (mg/L)	Equation 4-45
IFW_{adj}	=	water ingestion factor, age-adjusted ([L-year]/[kg-day])	1.07 (Equation 3-4)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
CSF_{oral}	=	constituent oral cancer slope factor $(mg/kg-day)^{-1}$	chem-specific (Appendix A-1)
AT	=	averaging time (years)	75 (U.S. EPA 1997b)

The concentration of a constituent in surface water, C_{sw}, is computed using Equation 4-45.

$$C_{sw} = C_{total\ waste} \cdot \frac{A_w}{Q_{stream}} \cdot A \tag{4-45}$$

where:

			Default
C_{sw}	=	concentration of waste constituent in surface water (mg/L)	calculated
$C_{total\ waste}$	=	total concentration of constituent in waste (mg/kg)	waste-specific
A_w	=	rate of waste erosion from landfill (kg/[acre-year])	Equation 2-49
Q_{stream}	=	volumetric flow of stream (L/year)	(U.S. EPA 1994a)
		- for fifth-order stream	3.4×10^{11}
		- for second-order stream	3.3×10^{9}
A	=	area of waste management unit (acres)	Equation 2-12 or 2-13

Using Equation 4-44, the DRAS calculates the risks from ingestion of surface water for each constituent and then, using Equation 4-2, sums the individual constituent risks to determine the total risk for the surface water ingestion pathway.

4.3.2.2 Ingestion of Fish

This section describes computation of total concentration delisting levels and of risks associated with adult ingestion of fish that are exposed to petitioned carcinogenic waste constituents that erode from a waste disposal unit and are transported to surface water. The bioaccumulation factor (BAF) values used are for a trophic level 4 (carnivorous) fish (U.S. EPA 1995e).

Section 4.3.2.2.1 presents the equations used to compute carcinogenic waste constituent pathway delisting levels for standard multi-year delistings. Section 4.3.2.2.2 presents the equations and methods used to compute constituent-and pathway-specific risks for one-time delistings.

4.3.2.2.1 Delisting Level Analysis

This section describes the equations used to calculate the pathway total concentration delisting levels for fish ingestion ($C_{dl\text{-}fish}$) for carcinogens. To perform these calculations, the DRAS must first calculate the maximum allowable fish tissue concentration such that the target risk level is not exceeded (C_{fish}). Knowing the allowable fish tissue concentration (C_{fish}), we can backcalculate to determine the maximum allowable total surface water concentration (C_{sw}). Using C_{sw}, the maximum allowable concentration of the dissolved phase

of the constituent in the waste (C_{dw}) is then calculated. Finally, C_{dw} is used to calculate $C_{dl\text{-}fish}$. The first step, then, is to calculate C_{fish} for the carcinogenic constituent using Equation 4-46.

$$C_{fish} = \frac{TR \cdot AT \cdot 365\,days/year \cdot BW}{EF \cdot ED \cdot CR_{fish} \cdot CSF_{oral}}$$

(4-46)

where:

			Default
C_{fish}	=	maximum allowable concentration of constituent in fish tissue (mg/kg)	calculated
TR	=	target risk level (unitless)	user specified (1 x 10^{-5} default)
AT	=	averaging time (years)	75 (U.S. EPA 1997b)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)
CR_{fish}	=	fish consumption rate (kg/day)	0.02 (U.S. EPA 1997b)
CSF_{oral}	=	constituent oral cancer slope factor (mg/kg-day)$^{-1}$	chem-specific (Appendix A-1)

Now, the maximum allowable concentration of the constituent in the total waste is determined, C_{sw}, using Equation 4-47 and the appropriate factor, either the BCF or the BAF, as discussed in Section 2.3.4.2, Concentration of Waste Constituent in Fish (C_{fish}).

$$C_{dw} = \frac{C_{fish}}{BAF \lor BCF}$$

(4-47)

where:

			Default
C_{dw}	=	maximum allowable dissolved phase water concentration (mg/L)	calculated
C_{fish}	=	maximum allowable concentration of constituent in fish tissue (mg/kg)	Equation 4-43
BAF	=	fish bioaccumulation factor (L/kg) or	chem-specific (Appendix A-1)
BCF	=	fish concentration factor (L/kg)	chem-specific (Appendix A-1)

Using Equation 4-48, the maximum allowable concentration of the waste concentration in water column in the second order stream (C_{sw}) is calculated:

$$C_{sw} = C_{dw} [1 + Kd_{sw} \cdot TSS \cdot 1 \times 10^{-6}]$$

(4-48)

where:

			Default
C_{dw}	=	Dissolved phase water concentration (mg/L)	Calculated
C_{sw}	=	Waste concentration in water column (mg/L)	Equation 4-47
Kd_{sw}	=	Suspended sediments/surface water partition coefficient (L water/kg suspended sediment)	chem-specific (Appendix A-1)
TSS	=	Total suspended solids concentration (mg/L)	Equation 2-54
1×10^{-6}		Units conversion factor (kg/mg)	

Finally, C_{sw} is used in Equation 4-49 to back calculate the delisting level ($C_{dl\text{-}fish}$) for the fish ingestion pathway.

$$C_{dl\text{-}fish} = \frac{C_{sw} \cdot Q_{2ndstream}}{A \cdot A_w} \tag{4-49}$$

where:

			Default
$C_{dl\text{-}fish}$	=	pathway total concentration delisting level for fish ingestion (mg/kg)	calculated
C_{sw}	=	Waste concentration in water column (mg/L)	Equation 4-48
A_w	=	rate of waste erosion from landfill (kg/[acre-year])	Equation 2-51
$Q_{2ndstream}$	=	volumetric flow of second-order stream (L/year)	3.3×10^9 (U.S.EPA 1994a)
A	=	area of waste management unit (acres)	Equation 2-12 or 2-13

If the total concentration of a given waste constituent exceeds its total concentration delisting level, $C_{dl\text{-}fish}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of risk analysis calculations presented in Section 4.3.2.2.2.

4.3.2.2.2 Risk Analysis

In the risk analysis, the DRAS program computes the risk associated with the fish ingestion exposure pathway. Each carcinogenic waste constituent's risk for the fish is computed using Equation 4-50.

$$Risk = \frac{C_{fish} \cdot F_c \cdot CR_{fish} \cdot ED \cdot EF \cdot CSF_{oral}}{BW \cdot AT \cdot 365 \ days/year} \tag{4-50}$$

where:

Default

Risk	=	risk from fish ingestion for constituent (unitless)		calculated
C_{fish}	=	concentration of constituent in fish tissue (mg/kg)		Equation 4-51
F_c	=	fraction contaminated (unitless)		1.0 (U.S. EPA 1997b)
CR_{fish}	=	fish consumption rate (kg/day)		0.02 (U.S. EPA 1997b)
ED	=	exposure duration (years)		30 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)		350 (U.S. EPA 1997b)
CSF_{oral}	=	constituent oral cancer slope factor $(mg/kg\text{-}day)^{-1}$		chem-specific (Appendix A-1)
BW	=	body weight (kg)		72 (U.S. EPA 1997b)
AT	=	averaging time (years)		75 (U.S. EPA 1997b)

C_{fish} is calculated as shown in Equation 4-48.

$$C_{fish} \;=\; C_{dw} \;\; BAF \;\lor\; BCF \tag{4-51}$$

where:

Default

C_{fish}	=	concentration of constituent in fish tissue (mg/kg)	calculated
C_{dw}	=	concentration of dissolved phase of constituent in waste water (mg/L)	Equation 4-48
BAF	=	fish bioaccumulation factor (L/kg) or	chem-specific (Appendix A-1)
BCF	=	fish bioconcentration factor (L/kg)	chem-specific (Appendix A-1)

First the DRAS calculates the constituent-specific risk for fish ingestion using the total waste constituent concentration. Then the program sums all the constituent-specific risks for the fish ingestion pathway using Equation 4-2 to determine the total risk for the fish ingestion pathway.

4.3.3   Air Exposure Pathways

The DRAS includes an analysis of the human health risks associated with exposure of adults to carcinogens via three air exposure pathways: (1) inhalation of particulates from solid wastes disposed of in landfills, (2) inhalation of volatiles from solid wastes disposed of in landfills, and (3) inhalation of volatiles from liquid wastes disposed of in surface impoundments. The DRAS also includes analysis of the human health risks associated with exposure of children to carcinogens via air exposure by ingestion of soil contaminated by deposition of particulate matter from solid wastes disposed of in landfills. The delisting level for the air exposure pathways is expressed in terms of the total constituent concentration in the waste.

The risks associated with inhalation exposure to particulate and volatile matter can typically be determined only when inhalation HBNs are available. Inhalation cancer slopes derived from oral potency values are only

used when specifically recommended by IRIS or when target organ endpoints are far from the respiratory system (U.S. EPA 2006).

Releases and transport of contaminated particulates from landfills and releases of volatiles from landfills and surface impoundments are evaluated using methods described in U.S. EPA Headquarters delisting dockets (U.S. EPA 1993b,1994a). Particulate emissions are determined by estimating respirable contaminated particulate emissions from wind erosion of landfill surfaces (U.S. EPA 1985a). The DRAS uses the AP-42 methodologies for calculating dust emissions resulting from on-site vehicular traffic and waste loading and unloading operations (U.S. EPA 1985b).

Emission of volatiles from landfills is evaluated with Shen's modification of Farmer's equation, which was developed by U.S. EPA's OAQPS (U.S. EPA 1984). The modified Farmer's equation (Equation 2-33), which was developed to estimate atmospheric emissions from covered landfills. Estimates of emissions of volatile organics from liquid wastes in surface impoundments use a methodology developed by the U.S. EPA OAQPS and known as SIMS (U.S. EPA 1990a, 1990b). The approach used by SIMS estimates (1) individual liquid- and gas-phase mass transfer coefficients for each pollutant, (2) equilibrium constants for each pollutant based on Henry's Law constants, (3) overall mass transfer coefficients for each pollutant, and (4) emissions based on the pollutant mass balance in the vicinity of the surface impoundment.

The DRAS calculates emission rates for particulates and volatiles and uses a Gaussian dispersion model to predict worst-case average chemical concentrations 1,000 feet downwind of a hypothetical land disposal facility, as documented in U.S. EPA's "Ambient Air Dispersion Model" (U.S. EPA 1985c). The equations and default parameters used to calculate the concentrations of respirable particulates and volatiles at the POE are presented in Sections 2.3.1 and 2.3.2, respectively.

The following sections describe the equations and default parameters used to calculate pathway delisting levels and assess risks associated with exposure to waste constituents via the air exposure pathways. Section **4.3.3.1** presents the equations used to compute pathway delisting levels for standard multi year delistings. Section 4.3.3.2 presents the equations used to compute constituent-and pathway-specific risks for one-time delistings.

4.3.3.1 Delisting Level Analysis

Before pathway delisting levels for carcinogens associated with the air inhalation exposure pathways can be computed, the constituent's maximum allowable respirable air concentration at the POE (C_{air}) must be calculated. C_{air} is calculated at the target risk level using Equation 4-52.

$$C_{air} = \frac{TR \cdot AT \cdot 365 \ days/year}{EF \cdot IFA_{adj} \cdot CSF} \tag{4-52}$$

where:

			Default
C_{air}	=	constituent's maximum allowable respirable air concentration at POE (mg/m^3)	calculated
TR	=	target risk (unitless)	user specified (default 1 x 10^{-5})
AT	=	averaging time (years)	75 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
IFA_{adj}	=	inhalation factor, age-adjusted ($[m^3$-year]/[kg-day])	10.67 (Equation 3-3)
CSF	=	inhalation cancer slope factor $(mg/kg$-day$)^{-1}$	chem-specific (Appendix A-1)

C_{air} is used with the air transport equation (Equation 2-25) and the air emission equations (Equation 2-33 for volatiles and Equation 2-24 for particulates) to back-calculate the pathway total concentration delisting levels. The following sections describe the methods used to calculate delisting levels for the landfill particulates inhalation pathway ($C_{dl-air-p}$), the landfill volatiles inhalation pathway ($C_{dl-air-v}$), and the surface impoundment volatiles inhalation pathway (C_o). If the total concentration of a given carcinogenic waste constituent exceeds $C_{dl-air-p}$, or if the TCLP concentration of a constituent exceeds either $C_{dl-air-v}$ or C_o, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of risk analysis calculations presented in Section 4.3.3.2.

Landfill Particulate Delisting Levels

First the maximum allowable emission rate of the constituent, Q_p, is back-calculated from C_{air} (see equation 4-52) using Equation 4-53.

$$Q_p = \frac{C_{air} \cdot \Sigma_z \cdot U \cdot L_v}{2.03 \cdot F} \tag{4-53}$$

where:

			Default
Q_p	=	maximum allowable emission rate of waste constituent particulates (mg/s)	calculated
C_{air}	=	constituent's maximum allowable air concentration at POE (mg/m^3)	Equation 4-52

z	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1994a)
L_v	=	distance from the virtual point to the compliance point located 1,000 feet (304.8 m) downwind (m)	Equation 2-27
F	=	frequency that wind blows across waste unit 0.15 toward the receptor (unitless)	(U.S. EPA 1994a)

Then the pathway waste concentration delisting level for respirable landfill particulates in air ($C_{dl-air-p}$) is calculated by setting the maximum allowable total emission rate for respirable particulates, Q_{p10}, as equal to Q_p and using Equation 4-54.

$$C_{dl-air-p} = \frac{Q_{p10}}{(E_{w10} + E_{v10} + E_{l10}) \cdot \frac{10^3 \ mg}{1 \ g} \cdot \frac{1 \ hr}{3,600} \cdot \frac{10^{-6} \ kg}{1 \ mg}} \qquad (4\text{-}54)$$

where: Default

$C_{dl-air-p}$	=	pathway total concentration delisting level for respirable landfill air particulates (mg/kg)	calculated
Q_{p10}	=	emission rate of waste constituent particulates up to 10 µm (mg/s)	set equal to Q_p (Equation 4-53)
E_{w10}	=	wind erosion emissions rate of particulates up to 10 µm (g/hr)	Equation 2-9
E_{v10}	=	vehicle travel emissions rate of particulates up to 10 µm (g/hr)	Equation 2-19
E_{l10}	=	waste loading and unloading emissions rate of particulates up to 10 µm (g/hr)	Equations 2-21 and 2-22

Landfill Volatile Delisting Levels

First the maximum allowable volatile emission flux of the constituent, E_i, from the landfill is calculated by setting the maximum allowable total emission rate of volatiles, Q_v, as equal to Q_p (calculated in Equation 4-53) and using Equation 4-55.

$$E_i = \frac{Q_v}{1000 \ mg \ / \ g} \qquad (4\text{-}55)$$

where:

Default

E_i	=	maximum allowable volatile emission flux of	calculated

constituent (g/s)

Q_v = maximum allowable constituent volatile emission rate (mg/s)   equal to Q_p (Equation 4-53)

1000 mg/1g conversion factor

Then E_i is used to calculate the pathway waste constituent concentration delisting level for volatiles from a landfill ($C_{dl\text{-}air\text{-}v}$) using Shen's modification of Farmer's Landfill Volatilization Equation as presented in Equation 4-56 (adopted from EPA-450/3-84-020; *Evaluation and Selection of Models for Estimating Air Emissions from Hazardous Waste Treatment, Storage, and Disposal Facilities*).

$$C_{dl\text{-}air\text{-}v} = \frac{E_i \cdot d \cdot P_T^2 \cdot 1x10^6 \cdot 1x10^4}{D_a \cdot P_a^{10/3} \cdot A_{exposed} \cdot C_{si}} \tag{4-56}$$

where:

			Default
$C_{dl\text{-}air\text{-}v}$	=	pathway waste constituent concentration delisting level for volatiles from landfill (mg/kg)	calculated
E_i	=	maximum allowable volatile emission flux of constituent (g/s)	Equation 4-55
d	=	depth of soil cover (m)	0.1524 (U.S. EPA 1994a)
P_T	=	total sand porosity (unitless)	0.4 (U.S. EPA 1994a)
D_a	=	diffusivity of constituent in air (cm²/s)	chem-specific (Appendix A-1)
P_a	=	air-filled sand porosity (unitless)	0.4 (U.S. EPA 1994a)
$A_{exposed}$	=	surface area (m²)	Equation 2-15
C_{si}	=	saturation vapor concentration of i in landfill	Equation 4-57
$1x10^6$	=	conversion from kilograms to milligrams	
$1x10^4$	=	conversion from m² to cm²	

Finally, the saturation vapor concentration (C_{si}) of waste constituent i in the landfill is calculated using Equation 4-57.

$$C_{si} = \frac{V_p \cdot MW_i}{R \cdot T} \tag{4-57}$$

where:

			Default
C_{si}	=	saturation vapor concentration of i in landfill (g/m³)	Calculated
MW	=	molecular weight of waste constituent i	chem-specific (Appendix A-1)
R	=	universal gas constant (atm-m³/mole- K)	8.21 x 10⁻⁵
T	=	standard temperature (K)	298
V_p	=	Vapor Pressure (atm)	chem-specific (Appendix A-1)

Surface Impoundment Volatile Delisting Levels

The pathway leachate concentration delisting level for volatiles from waste disposed of in a surface impoundment is calculated by setting the maximum allowable total emission rate of volatiles, Q_v, as equal to Q_p (calculated in Equation 4-53) and using Equation 4-58.

$$C_{dl-air-si} = \frac{Q_v \cdot tp \cdot 86,400 \; s/1 \; day}{V \cdot \frac{1000L}{m^3} \cdot e^{\left(1 - \left(\frac{K \cdot A_{si} \cdot 4,046.8 \; m^2/1 \; acre \cdot tp \cdot 86,400 \; s/1 \; day}{V}\right)\right)}} \qquad (4-58)$$

where: Default

$C_{di-air-si}$ = pathway leachate concentration delisting level for   calculated
            volatiles from surface impoundment (mg/L)

Q_v = maximum allowable constituent volatile emission   set equal to Q_p (Equation 4-53)
        rate (mg/s)

tp = time period for mass emission (days)   minimum of tr and tf

t_f = time for constituent concentration to reach 1 %   Equation 4-59
        of $C_{dl-air-si}$ (days)

V = volume of liquid in surface impoundment (m³)   unit-specific (user-provided)

K = overall mass transfer coefficient (m/s)   Equation 4-60
A = area of waste management unit (acres)   Equation 2-12 or 2-13
t_r = retention time of liquid in surface impoundment   Equation 2-40
        (days)

The time for the constituent concentration to reach one percent of $C_{di-air-si}$, t_f, is computed using Equation 4-59.

$$tf = \frac{Ln(0.01) \cdot V}{-(K \cdot A_{si})} \cdot \frac{1 \; day}{86,400 \; s} \qquad (4-59)$$

where:

                                                                                        Default

t_f = time for constituent concentration to reach   calculated
        1 percent of $C_{dl-air-si}$ (days)

V = volume of liquid in surface impoundment (m³)   unit-specific (user provided)

K = overall mass transfer coefficient (m/s)   Equation 4-60
A_{si} = area of surface impoundment (m²)   Equation 2-12 or 2-13

The overall mass transfer coefficient, K, is calculated using Equation 4-60.

$$K = \frac{1}{\left(\dfrac{1}{K_l} + \dfrac{1}{K_g \cdot K_{eq}}\right)} \tag{4-60}$$

where:

			Default
K	=	overall water to air mass transfer coefficient (m/s)	calculated
K_l	=	liquid-phase mass transfer coefficient (m/s)	Equation 4-61
K_g	=	gas-phase mass transfer coefficient (m/s)	Equation 4-62
K_{eq}	=	equilibrium constant (unitless)	Equation 4-63

K_l is calculated using Equation(4-61).

$$K_l = 2.611 \times 10^{-7} \cdot U_{10}{}^2 \cdot \left[\frac{D_w}{D_{ether}}\right]^{2/3} \tag{4-61}$$

where:

			Default
K_l	=	liquid-phase mass transfer coefficient (m/s)	calculated
U_{10}	=	wind speed (m/s)	5.73 (U.S. EPA 1994a)
D_w	=	diffusion coefficient in water (cm^2/s)	chem-specific (Appendix A-1)
D_{ether}	=	diffusion coefficient of ether (cm^2/s)	8.56 x 10^{-6} (U.S. EPA 1994a)

K_g is calculated using Equation (4-62).

$$K_g = 4.82 \times 10^{-3} \cdot U_{10}{}^{0.78} \cdot S_{cg}{}^{-0.67} \cdot d_e{}^{-0.11} \tag{4-62}$$

where:

			Default
K_g	=	gas phase mass transfer coefficient (m/s)	calculated
U_{10}	=	wind speed (m/s)	5.73 (U.S. EPA 1994a)
S_{cg}	=	Schmidt number on gas side (unitless)	Equation 4-64
d_e	=	effective diameter of surface impoundment (m)	unit-specific (user-provided)

K_{eq} is calculated using Equation 4-63.

$$K_{eq} = \frac{H}{R \cdot T} \tag{4-63}$$

where:

				Default
K_{eq}	=	equilibrium constant (unitless)		calculated
H	=	Henry's Law constant (atm-m^3/mol)		chem-specific (Appendix A-1)
R	=	universal gas law constant (atm-m^3/mol-K)		8.21×10^{-5}
T	=	standard temperature (K)		298

S_{cg} is calculated using Equation 4-64.

$$S_{cg} = \frac{\mu_a}{\rho_a \cdot D_a} \tag{4-64}$$

where:

			Default
S_{cg}	=	Schmidt number on gas side (unitless)	calculated
μ_a	=	viscosity of air (g/[cm-sec])	0.000181 (U.S. EPA 1990a)
$\tilde{n}_a$	=	density of air (g/cm^3)	1.2×10^{-3} (U.S. EPA 1990a)
D_a	=	diffusivity of constituent in air (cm^2/s)	chem-specific (Appendix A-1)

4.3.3.2 Risk Analysis

Risk as a function of the effective air concentration of a particulate or volatile carcinogenic constituent (C_{air}) is calculated for each of the three air exposure pathways as shown in Equation 4-65.

$$Risk = \frac{C_{avg} \cdot IFA_{adj} \cdot EF \cdot CSF}{AT \cdot 365 days/year} \tag{4-65}$$

where:

			Default
$Risk$	=	risk for waste constituent (unitless)	calculated
C_{avg}	=	constituent's air concentration at POE (mg/m^3)	
		Particulates	Equation 4-66
		Landfill volatiles	Equation 4-67
		Surface Impoundment volatiles	Equation 4-71
IFA_{adj}	=	inhalation factor, age-adjusted ([m^3-year]/[kg-day])	10.67 (Equation 3-3)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
CSF	=	constituent inhalation cancer slope factor	chem-specific (Appendix A-1)

$(mg/kg\text{-}day)^{-1}$

AT =   averaging time (years)   75 (U.S. EPA 1997b)

C_{avg} at the POE is determined separately for each of the three air exposure pathways using the air emission and transport equations derived in Section 2.3 and presented below for each pathway. Using Equation 4-65, the DRAS calculates the risks for receptors at the POE for the three air exposure pathways. The program then sums the individual constituent risks using Equation 4-2 to determine the total risk for each of the air inhalation pathways.

Landfill Particulates

The average air concentration of a waste constituent at the POE (C_{avg}) derived from the particulate released from the landfill is calculated using Equation 4-66.

$$C_{avg} = \frac{2.03 \cdot Q_{p10}}{\Sigma_z \cdot U \cdot L_v} \cdot F \qquad (4\text{-}66)$$

where:

			Default
C_{avg}	=	downwind concentration of waste constituent at POE (mg/m³)	calculated
Q_{p10}	=	emission rate of waste constituent particulates up to 10 μm (mg/s)	Equation 2-24
Σ_z	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1994a)
L_v	=	distance from virtual point to compliance point located 1,000 ft (304.8 m) downwind (m)	Equation 2-27
F	=	frequency that wind blows across waste unit 0.15 toward receptor (unitless)	(U.S. EPA 1994a)

Landfill Volatiles

For the to landfill volatiles inhalation pathway, C_{avg} for landfill volatile emissions is calculated using Equation 4-67.

$$C_{avg} = \frac{2.03 \cdot Q_v}{\Sigma_z \cdot U \cdot L_v} \cdot F \qquad (4\text{-}67)$$

where:

			Default
C_{avg}	=	downwind concentration of waste constituent at	calculated

		POE (mg/m³)	
Q_v	=	constituent volatile emission rate (mg/s)	Equation 4-68
$_z$	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1994a)
L_v	=	distance from virtual point to compliance point located 1,000 feet (304.8 m) downwind (m)	Equation 2-27
F	=	frequency that wind blows across waste unit 0.15 toward receptor (unitless)	(U.S. EPA 1994a)

For volatile emissions from a covered landfill, the emission rate, Q_v, is calculated using Equation 4-68.

$$Q_v = E_i \frac{1,000\ mg}{1\ g}$$ (4-68)

where: Default

Q_v	=	constituent volatile emission rate (mg/s)	calculated
E_i	=	emission flux of constituent (g/s)	Equation 4-69
1000mg/1g conversion factor to mg			

The emission flux of a volatile waste constituent released from the landfill, E_i, is calculated using Equation 4-69. Equation 4-69 is essentially Shen's modification of Farmer's landfill volatilization equation (U.S. EPA 1984). Farmer's equation was developed by U.S. EPA's Office of Air Quality Planning and Standards (OAQPS) to estimate the rate of emission of volatiles from a covered landfill (U.S. EPA 1984).

$$E_i = \frac{C_{waste} \cdot D_a \cdot P_a^{10/3} \cdot A_{exposed} \cdot C_{si}}{d \ P_T^2 \cdot 1x10^6 \cdot 1x10^4}$$ (4-69)

where:

                                                                                           Default

E_i	=	maximum allowable volatile emission flux of constituent (g/s)	calculated
C_{waste}	=	waste concentration of constituent (mg/kg)	waste-specific (user-provided)
d	=	depth of soil cover (m)	0.1524 (U.S. EPA 1994a)
P_T	=	total sand porosity (unitless)	0.4 (U.S. EPA 1994a)
D_a	=	diffusivity of constituent in air (cm²/s)	chem-specific (Appendix A-1)
P_a	=	air-filled sand porosity (unitless)	0.4 (U.S. EPA 1994a)
$A_{exposed}$	=	surface area (m²)	Equation 2-15
C_{si}	=	saturation vapor concentration of i in landfill	Equation 4-70
$1x10^6$	=	conversion from kilograms to milligrams	
$1x10^4$	=	conversion from m² to cm²	

And the saturation vapor concentration (C_{si}) of waste constituent i in the landfill is calculated using Equation 4-70.

$$C_{si} = \frac{p_i \cdot MW_i}{R \cdot T} \tag{4-70}$$

where:

			Default
C_{si}	=	saturation vapor concentration of i in landfill (g/m^3)	Calculated
p_i	=	vapor pressure of waste constituent i (atm)	chem-specific (Appendix A-1)
MW_i	=	molecular weight of waste constituent i	chem-specific (Appendix A-1)
R	=	universal gas constant (atm-m^3/mol-K)	8.21 x 10^{-5}
T	=	standard temperature (K)	298

Surface Impoundment Volatiles

For the surface impoundment volatiles inhalation pathway, C_{avg} for use in Equation 4-65 is calculated using Equation 4-71.

$$C_{avg} = \frac{2.03 \cdot Q_v}{\Sigma_z \cdot U \cdot L_v} F \tag{4-71}$$

where:

			Default
C_{avg}	=	downwind concentration of waste constituent at POE (mg/m^3)	calculated
Q_v	=	constituent volatile emission rate (mg/s)	Equation 4-72
F	=	frequency wind blows from sector of interest	0.15 (U.S. EPA 1994a)
Σ_z	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1994a)
L_v	=	distance from virtual point to compliance point located 1,000 feet (304.8 m) downwind (m)	Equation 2-27

Q_v for volatile emissions from a surface impoundment is computed using Equation 4-72.

$$Q_V = \left(\frac{V \cdot C_L \cdot 1000\,L/m^3}{t_p \cdot 86{,}400\,sec/day}\right) \cdot \left(1 - e^{\left(\frac{K \cdot A_{si} \cdot 4{,}046.8 m^2/acre \cdot t_p \cdot 86{,}400 sec/day}{V}\right)}\right) \tag{4-72}$$

Default

where:

Q_v	=	volatile emission rate of constituent i from the surface impoundment (mg/s)	calculated
C_L	=	liquid waste concentration of constituent (mg/L)	waste-specific (user-provided)
tp	=	time period for mass emission (days)	minimum of tf and tr
V	=	lifetime volume of liquid in surface impoundment (m³)	unit-specific (user-provided)
K	=	overall mass transfer coefficient (m/s)	Equation 4-60
A_{si}	=	area of surface impoundment (acres)	Equation 2-12 or 2-13
t_r	=	retention time for liquid in surface impoundment (days)	Equation 2-40
tf	=	time for constituent concentration to reach 1 percent of C_L (days)	Equation 4-59

4.3.4   Soil Exposure Pathway

This section presents equations used to calculate pathway total concentration delisting levels and risks associated with exposure of children to soils contaminated with carcinogenic waste constituents at a POE 1,000 feet from a waste disposal unit. The soil contamination is assumed to be the result of deposition of waste particulates from the air. The equations used to compute the delisting levels and risks are based on a method described in U.S. EPA Headquarters delisting docket materials (U.S. EPA 1993a, 1993b).

Section 4.3.4.1 presents the equations used to compute pathway total concentration delisting levels for standard multi-year delistings. Section 4.3.4.2 presents the equations and methods used to compute constituent-and pathway-specific risks for one-time delistings.

4.3.4.1   Delisting Level Analysis

To calculate the pathway total concentration delisting levels for exposure to carcinogenic waste constituents via ingestion of soil ,$C_{dl\text{-}soil}$, the maximum allowable concentration of each constituent in soil at the POE, C_{soil}, must first be computed. C_{soil} is the maximum concentration of the waste constituent in soil that does not cause the risk from soil ingestion to exceed the target level. C_{soil} is calculated using Equation 4-73.

$$C_{soil} = \frac{TR \cdot AT \cdot 365 days/year}{EF \cdot IFS_{adj} \cdot CSF_{oral}} \cdot 1x10^6 mg/kg \qquad (4\text{-}73)$$

where:

Default

C_{soil}	=	maximum allowable concentration of constituent in soil at POE (mg/kg)	calculated
TR	=	target risk level (unitless)	user-specified (default 1 x 10⁻⁵)

AT	$=$	averaging time (years)	75 (U.S. EPA 1997b)
EF	$=$	exposure frequency (days/year)	350 (U.S. EPA 1997b)
IFS_{adj}	$=$	soil ingestion factor ([mg/year]/[kg/day])	113 (Equation 3-2)
CSF_{oral}	$=$	constituent oral cancer slope factor (mg/kg-day)$^{-1}$	chem-specific (Appendix A-1)

Using C_{soil}, the DRAS back-calculates the maximum allowable constituent concentration in air at the POE, C_{avg}. Assumptions include a constituent accumulation period in the soil of 1 year and a depth of mixing of 1 cm C_{avg} is calculated as shown in Equation 4-74.

$$C_{avg} = \frac{\rho_b \quad t \quad C_{soil} \quad \frac{10^3 \ mg}{1 \ g} \cdot \frac{10^6 \ cm^3}{1 \ m^3} \cdot \frac{1 \ kg}{10^6 \ mg} \cdot 1/yr}{v_d \quad \frac{31{,}536{,}000 \ s}{1 \ year}} \tag{4-74}$$

where:

			Default
C_{avg}	$=$	maximum allowable concentration of constituent in air at POE (mg/m^3)	calculated
C_{soil}	$=$	maximum allowable concentration of constituent in soil at POE (mg/kg)	Equation 4-73
$ñ_b$	$=$	soil bulk density (g/cm^3)	1.45 (Brady 1984)
t	$=$	soil thickness from which particles can be ingested (m)	0.01 (U.S. EPA 1994a)
v_d	$=$	deposition velocity (m/s)	0.03 (U.S. DOE, 1984)

Before the pathway delisting level can be calculated, it is necessary to compute the annual average emission rate of particles up to 30 μm in size from the disposal unit as shown in Equation 4-75.

$$E_{T30} = E_{w30} + E_{v30} + E_{l30} \tag{4-75}$$

where:

			Default
E_{T30}	$=$	annual average emission rate of particles up to 30 μm (g/hr)	calculated
E_{w30}	$=$	wind erosion emission rate of particulates up to 30 μm (g/hr)	Equation 2-16
E_{v30}	$=$	vehicle travel emissions rate of particulates up to 30 μm (g/hr)	Equation 2-20
E_{l30}	$=$	loading and unloading emission rate of particles up to 30 μm (g/hr)	Equation 2-23

Finally, once C_{air} and E_{T30} are known, the total concentration delisting level is computed using Equation 4-76.

$$C_{dl-soil} = \frac{C_{avg} \cdot \Sigma_z \cdot U \cdot L_v \cdot \dfrac{1{,}000\ g}{1\ kg}}{2.03 \cdot E_{T30} \cdot F \cdot \dfrac{1\ hr}{3{,}600\ s}} \qquad \text{(4-76)}$$

where:

			Default
$C_{dl-soil}$	=	pathway total concentration delisting level for soil ingestion (mg/kg)	calculated
C_{avg}	=	maximum allowable concentration of constituent in air at POE (mg/m³)	Equation 4-74
Σ_z	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1986a)
L_v	=	distance virtual point to compliance point located 1,000 feet (0.3048 km) downwind (m)	Equation 2-27
E_{T30}	=	annual average emission rate of particles up to 30 μm (g/hr)	Equation 4-75 (also, see Section 2.3.1.3)
F	=	frequency that wind blows across waste unit 0.15 toward receptor (unitless)	(U.S. EPA 1994a)

If the total concentration for a given carcinogenic waste constituent exceeds its pathway total concentration delisting level, $C_{dl-soil}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of risk analysis calculations presented Section 4.3.4.2.

4.3.4.2   Risk Analysis

In the risk analysis, the DRAS computes the risk associated with the soil ingestion exposure pathway. The risk for each carcinogenic waste constituent associated with soil ingestion at the POE is calculated. Children have higher daily soil intake rates when comparing their contact rates and lower body weights to those of adults (U. S. EPA 1997b). However, the child's exposure duration is considerably shorter than the adult's. For carcinogens, exposure is averaged over a lifetime (75 years; U. S. EPA 1997b). Exposure to contaminants via soil ingestion is calculated as a weighted average of exposures for 6 years as a child and as an adult. The total exposure is still averaged over a lifetime. For the soil ingestion exposure scenario, the constituent-specific cancer risk from ingestion of soil is calculated using Equation 4-77.

$$Risk = \frac{C_{soil} \cdot IFS_{adj} \cdot EF \cdot CSF_{oral}}{AT \quad 365 days/year \quad 1x10^6 mg/kg} \tag{4-77}$$

where:

			Default
$Risk$	=	risk for waste constituent (unitless)	Calculated
C_{soil}	=	conc. of constituent in soil at POE (mg/kg)	Equation 4-78
IFS_{adj}	=	soil ingestion factor ([mg/year]/[kg/day])	113 (Equation 3-2)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
CSF_{oral}	=	oral cancer slope factor (mg/kg-day)$^{-1}$	chem-specific (Appendix A-1)
AT	=	averaging time (years)	75 (U.S. EPA 1997b)

C_{soil} is calculated based on the constituent's rate of deposition onto the soil. Assuming that at any given time the soil is burdened with 1 year's accumulation of constituent from air deposition and that the mixing depth of the constituent into the soil is 1 cm, Equation 4-78 is used to calculate C_{soil}.

$$C_{soil} = \frac{q_d \cdot \dfrac{31,536,000\ s}{1\ year}}{\rho_b \cdot t \cdot \dfrac{10^6\ cm^3}{1\ m^3} \cdot \dfrac{1\ kg}{10^3\ g}} \tag{4-78}$$

where:

			Default
C_{soil}	=	conc. of constituent in soil at the POE (mg/kg)	calculated
q_d	=	constituent deposition rate (mg/m^2-s)	Equation 4-79
$ñ_b$	=	soil bulk density (g/cm^3)	1.45 (Brady 1984)
t	=	soil thickness of particles that can be ingested (m)	0.01 (U.S. EPA 1994a)

The constituent deposition rate is determined using the deposition velocity and the constituent concentration in air, as shown in Equation 4-79.

$$q_d = v_d \quad C_{avg} \tag{4-79}$$

where:

			Default
q_d	=	constituent deposition rate (mg/m^2-s)	calculated
v_d	=	deposition velocity (m/s)	0.03 (U.S. DOE, 1984)
C_{avg}	=	downwind concentration of waste constituent at	Equation 4-80

POE (mg/m³)

C_{avg} is calculated using Equation 4-80.

$$C_{avg} = \frac{2.03 \cdot Q_{p30}}{\Sigma_z \cdot U \cdot L_v} \quad F \qquad (4\text{-}80)$$

where:

Default

C_{avg}	=	downwind concentration of waste constituent at POE (mg/m³)	calculated
Q_{p30}	=	emission rate of waste constituent particulates up to 30 μm (mg/s)	Equation 2-30
Σ_z	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1994a)
L_v	=	distance from virtual point to compliance point located 1,000 feet (304.8 m) downwind (m)	Equation 2-27
F	=	frequency that wind blows across waste unit 0.15 toward receptor (unitless)	(U.S. EPA 1994a)

Using Equation 4-77, the DRAS calculates the risk associated with ingestion of soil for each constituent. Then the program sums the constituent-specific risks using Equation 4-2 to determine the total risk for the soil ingestion pathway.

4.4   QUANTITATIVE ESTIMATION OF POTENTIAL NONCANCER EFFECTS

This section presents the equations used to calculate pathway delisting levels and aggregate hazards associated with exposures to noncarcinogenic chemicals via the groundwater, surface water, air, and soil exposure pathways. Calculation of delisting levels and risks associated with exposures to carcinogenic chemicals is described in Section 4.3. The equations used below to compute pathway delisting levels and aggregate hazards are adapted from the "HWIR Technical Support Document" (U.S. EPA 1995b) and U.S. EPA OSW delisting dockets (U.S. EPA 1993a, 1993c, 1994a). The general hazard equations presented in Section 4.2.2 are implemented for specific constituents-and exposure pathways. The constituent and pathway-specific $HQ_{c,p}$, is computed for each constituent using an expanded form of Equation 4-4. Then the $HQ_{c,p}$ is summed across all constituents to calculate the HI_p, for each exposure pathway, as shown in Equation 4-5. The DRAS sums all the HI_p values for the groundwater exposure pathways and the surface exposure pathways separately to assist the user in identifying the most important exposure pathways. Finally, the aggregate HI_{cum} is calculated by summing the HI_p across all the groundwater and surface exposure pathways, as shown in Equation 4-6. Constituent-and pathway-specific subscripts are omitted in subsequent

equations for simplicity of presentation; the context indicates whether the value being calculated is constituent-or pathway-specific.

For exposures to noncarcinogens, the DRAS evaluates the following groundwater pathways: ingestion of groundwater, dermal exposure to groundwater during bathing (adult and child), and inhalation exposure to volatile groundwater components during showering. The equations used to compute the associated with groundwater exposures are discussed in Section 4.4.1. For surface water, the DRAS evaluates hazards associated with the following exposure pathways: ingestion of drinking water and ingestion of fish from surface water bodies contaminated by runoff from landfills; the relevant equations are discussed in Section 4.4.2. For air exposure pathways, the DRAS evaluates hazards associated with inhalation of particulates and volatiles from solid wastes disposed of in landfills and inhalation of volatiles from liquid wastes disposed of in surface impoundments; the relevant equations are discussed in Section 4.4.3. Finally, the DRAS evaluates hazards associated with a child receptor's ingestion of soil contaminated by air deposition of particulates eroded from a landfill. The relevant equations are discussed in Section 4.4.4.

4.4.1   Groundwater Exposure Pathways

For noncarcinogens, the DRAS evaluates exposure to groundwater using the same pathways that it uses for carcinogens: ingestion of groundwater, dermal exposure to groundwater during bathing, and inhalation of volatiles during showering with groundwater. The receptor is assumed to be an adult for the ingestion and showering pathways; both adult and child receptors are considered for bathing pathway. The following sections address calculation of constituent-and pathway-specific *HQ*s for each constituent and groundwater pathway.

4.4.1.1   Adult Ingestion of Groundwater

The DRAS computes leachate concentration delisting levels and hazards associated with exposure of adults to noncarcinogenic waste constituents via the groundwater ingestion pathway. Section 4.4.1.1.1 presents the equations used to compute pathway delisting levels for standard multi-year delistings. Section 4.4.1.1.2 presents the equations and methods used to compute the constituent-specific HQ and the pathway-specific HI for one-time delistings.

4.4.1.1.1   Delisting Level Analysis

Pathway leachate concentration delisting levels for noncarcinogens associated with ingestion of groundwater, $C_{dl\text{-}ingest}$, are determined based on a default target hazard quotient (*THQ*) of 0.1 in order to account for HQ from other pathways and/or chemicals. To calculate $C_{dl\text{-}ingest}$, the DRAS first computes the maximum allowable groundwater concentration for the ingestion pathway for the waste constituent $C_{gw\text{-}ingest}$ using Equation 4-81.

$$C_{gw\text{-}ingest} = \frac{THQ \cdot RfD \cdot BW \cdot AT \cdot 365 days/year}{CR \cdot EF \cdot ED} \qquad \textbf{(4-81)}$$

where:

			Default
$C_{gw\text{-}ingest}$	=	maximum allowable constituent concentration in groundwater for ingestion (mg/L)	calculated
THQ	=	target hazard quotient (unitless)	user specified (0.1 default)
RfD	=	constituent reference dose (mg/kg-day)	chem-specific (Appendix A-1)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)
CR	=	water consumption rate (L/day)	2 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)

Once $C_{gw\text{-}ingest}$ is calculated, $C_{dl\text{-}ingest}$ can be computed. $C_{gw\text{-}ingest}$ is multiplied by the waste constituent's DAF_{va} to generate $C_{dl\text{-}ingest}$ as shown in Equation 4-82.

$$C_{dl\text{-}ingest} = DAF_{va} \quad C_{gw\text{-}ingest} \qquad \textbf{(4-82)}$$

where:

			Default
$C_{dl\text{-}ingest}$	=	pathway leachate concentration delisting level for groundwater ingestion (mg/L)	calculated
DAF_{va}	=	waste volume-adjusted dilution attenuation factor (unitless)	equation 2-5
$C_{gw\text{-}ingest}$	=	maximum allowable constituent concentration in groundwater for ingestion (mg/L)	equation 4-81

If the TCLP concentration for a given waste constituent exceeds its $C_{dl\text{-}ingest}$, the waste may not qualify for a standard multi-year delisting. However, the waste may qualify for a one-time delisting, depending on the results of hazard analysis calculations presented in Section 4.4.1.1.2.

4.4.1.1.2   Hazard Analysis

In the hazard analysis, the DRAS computes the hazard associated with the groundwater ingestion exposure pathway. The DRAS calculates the noncarcinogenic waste constituent-specific *HQ* for ingestion of groundwater using Equation 4-83.

$$HQ = \frac{CR \cdot C_{gw} \cdot EF \cdot ED}{BW \cdot RfD \cdot AT \cdot 365 days/year} \quad\quad (4\text{-}83)$$

where:

			Default
HQ	=	constituent-specific hazard quotient for ingestion of groundwater (unitless)	calculated
CR	=	water consumption rate (L/day)	2 (U.S. EPA 1997b)
C_{gw}	=	waste constituent concentration in groundwater (mg/L)	Equation 2-6
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
RfD	=	constituent reference dose (mg/kg-day)	chem-specific (Appendix A-1)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)

The *HQ*s for all noncarcinogenic constituents in the petitioned waste are summed using Equation 4-5 to determine the HI_p for the groundwater ingestion pathway.

4.4.1.2   Adult and Child Dermal Contact with Groundwater During Bathing

The DRAS computes of leachate concentration delisting levels and hazards associated with adult and child exposures during bathing through dermal absorption of noncarcinogenic constituents in groundwater. Section **4.4.1.2.1** presents the equations used to compute pathway delisting levels for standard multi year delistings. Section 4.4.1.2.2 presents the equations and methods used to compute constituent-specific *HQs* and pathway-specific *HIs* for one-time delistings.

4.4.1.2.1   Delisting Level Analysis

Pathway leachate concentration delisting levels for noncarcinogens associated with adult and child dermal exposures to groundwater during bathing, $C_{dl\text{-}dermal,}$ are based on the target hazard quotient. The DRAS computes delisting levels for the adult and child receptors after separately determining their respective

exposures. The DRAS then selects the delisting level that corresponds to the more sensitive receptor. $C_{dl\text{-}dermal}$ is calculated as the product of the waste constituent's maximum allowable groundwater concentration for dermal exposure during bathing, $C_{gw\text{-}dermal}$, and the waste constituent DAF_{va} generated by the EPACMTP model (see Section 2.2). Equation 4-84 shows this calculation.

$$C_{dl\text{-}dermal} = DAF_{va} \quad C_{gw\text{-}dermal} \qquad (4\text{-}84)$$

where:

			Default
$C_{dl\text{-}dermal}$	=	pathway leachate concentration delisting level for groundwater dermal contact (mg/L)	calculated
DAF_{va}	=	waste volume-adjusted dilution attenuation factor (unitless)	Equation 2-6
$C_{gw\text{-}dermal}$	=	maximum allowable constituent concentration in groundwater for dermal exposure (mg/L)	Equation 4-12, 4-13, or 4-14

For organic waste constituents, $C_{gw\text{-}dermal}$ is computed using one of two methods, depending on whether the duration of the bath t_{event} is greater or less than the time required for the flux of the chemical through the skin to reach steady-state (t^*, a chemical-specific constant). For inorganic waste constituents, only one method is used. The maximum allowable constituent concentration in groundwater is computed using Equation 4-12 for organic constituents when t_{event} is less than t^*, Equation 4-13 for organic constituents when t_{event} is greater than or equal to t^*, and Equation 4-14 for inorganic constituents.

The dose of the waste constituent absorbed during bathing per unit area per event (DA_{event}) is used in each equation to calculate $C_{gw\text{-}dermal}$. DA_{event} is calculated separately for adults and children using Equation 4-85; the appropriate default parameters are used for the adult and child receptors.

$$DA_{event} = \frac{AT \cdot DAD \cdot BW \cdot 365 days/year}{EV \cdot EF \cdot ED \cdot A_{skin}} \qquad (4\text{-}85)$$

where:

			Default
DA_{event}	=	dose absorbed per event (mg/cm^2-event)	calculated
AT	=	averaging time (years)	
		-adult	30 (U.S. EPA 1997b)
		-child	6 (U.S. EPA 1997b)
DAD	=	dermally absorbed dose (mg/kg-day)	Equation 4-86
BW	=	body weight (kg)	

		- adult	72 (U.S. EPA 1997b)
		- child	15 (U.S. EPA 1997b)
EV	=	event frequency (events/day)	1 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	
		-adult	30 (U.S. EPA 1997b)
		-child	6 (U.S. EPA 1997b)
A_{skin}	=	exposed skin surface area (cm^2)	
		- adult	20,000 (U.S. EPA 1997b)
		- child	7,900 (U.S. EPA 1997b)

The *DAD* for dermal contact with groundwater needed in Equation 4-85 is calculated using Equation 4-86.

DAD is the product of the *THQ* and the *RfD* for a given noncarcinogenic waste constituent.

$$DAD = THQ \cdot RfD \qquad \text{(4-86)}$$

where:

			Default
DAD	=	dermally absorbed dose (mg/kg-day)	calculated
THQ	=	target hazard quotient (unitless)	user specified (0.1 default U.S. EPA 1997b)
RfD	=	constituent reference dose (mg/kg-day)	chem-specific (Appendix A-1)

$C_{dl\text{-}dermal}$ is calculated using Equation 4-84 for each noncarcinogenic waste constituent in the petitioned waste. If the TCLP concentration of a given waste constituent exceeds $C_{dl\text{-}dermal}$, the waste may not qualify for a standard multi-year delisting. However, the waste may qualify for a one-time delisting, depending on the results of hazard analysis calculations presented in Section 4.4.1.2.2.

4.4.1.2.2 Hazard Analysis

In the hazard analysis, the DRAS computes the hazard associated with the dermal contact with groundwater during bathing exposure pathway. The DAD for exposure to a noncarcinogenic waste constituent during bathing is computed using Equation 4-87.

$$DAD = \frac{DA_{event} \cdot EV \cdot EF \cdot ED \cdot A_{skin}}{AT \cdot 365 days/year \cdot BW} \qquad \text{(4-87)}$$

where:

			Default
DAD	=	dermally absorbed dose (mg/kg-day)	calculated
DA_{event}	=	dose absorbed per event (mg/cm^2-event)	Equation 4-19, 4-20, or 4-21

EV	=	event frequency (events/day)	1 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	
		- adult	30 (U.S. EPA 1997b)
		- child	6 (U.S. EPA 1997b)
A_{skin}	=	exposed skin surface area (cm^2)	
		- adult	20,000 (U.S. EPA 1997b)
		- child	7,900 (U.S. EPA 1997b)
AT	=	averaging time (years)	
		- adult	30 (U.S. EPA 1997b)
		- child	6 (U.S. EPA 1997b)
BW	=	body weight (kg)	
		- adult	72 (U.S. EPA 1997b)
		- child	15 (U.S. EPA 1997b)

DA_{event} is computed using Equation 4-19 for organic constituents when t_{event} is less than t^*, Equation 4-20 for organic constituents when t_{event} is greater than or equal to t^*, and Equation 4-21 for inorganic constituents. All three equations use the groundwater well concentration, C_{gw}, which is equal to the TCLP concentration of the constituent divided by the DAF_{va} (see Equation 2-6).

The constituent-specific HQ for the dermal contact with groundwater during bathing exposure pathway is computed as shown in Equation 4-88 (U.S. EPA 1992b).

$$HQ = \frac{DAD}{RfD} \qquad \text{(4-88)}$$

where:

			Default
HQ	=	constituent-specific hazard quotient for dermal contact with groundwater during bathing (unitless)	calculated
DAD	=	dermally absorbed dose (mg/kg-day)	Equation 4-87
RfD	=	constituent reference dose (mg/kg-day)	chem-specific (Appendix A-1)

Using Equation 4-88, the DRAS calculates the constituent-specific HQs for groundwater exposure via dermal absorption during bathing and, using Equation 4-5, sums the HQs to determine the total HI_p for the groundwater dermal absorption pathway.

4.4.1.3   Adult Inhalation of Volatiles from Groundwater During Showering

The DRAS computes leachate concentration delisting levels and hazards associated with exposure of adults to noncarcinogenic volatile constituents groundwater during showering. Exposure of children is not evaluated

for this pathway because the adult resident receptor scenario has been found to be protective of children (U.S. EPA 1997a).

The method used to determine waste constituent-specific exposures resulting from inhalation of constituents in tap water is based on information used to support the "Petroleum Refinery Listing Determination" (U.S. EPA 1997a). This project used a method developed by McKone (1987) to estimate a time-varying constituent concentration in three compartments: the shower, the bathroom, and the house.

The constraints associated with implementing the risk algorithms in a QuattroPro Version 6.0 spreadsheet precluded incorporating and solving time-varying shower equations because a complex system of macros and linked analyses would have been required. Therefore, U.S. EPA Region 6 uses simplified versions of the equations that compute a conservative constant concentration for each of the three compartments. The simplified equations are based on the steady-state model developed by McKone and Bogen (1992), which calculates a chemical concentration in air for each of the three compartments.

Section 4.4.1.3.1 presents the equations used to compute delisting levels for standard multi year delistings. Section 4.4.1.3.2 presents the equations used to compute the constituent-specific *HQ* and pathway-specific *HI* for one-time delistings.

4.4.1.3.1 Delisting Level Analysis

The pathway leachate concentration delisting levels for noncarcinogens associated with adult inhalation exposure to groundwater during showering, $C_{dl\text{-}inhale}$, are back-calculated from the maximum allowable groundwater concentration for the showering exposure pathway, $C_{gw\text{-}inhale}$. Specifically, $C_{dl\text{-}inhale}$ is calculated as the product of $C_{gw\text{-}inhale}$ and the constituent's DAF_{va} using Equation 4-89.

$$C_{dl\text{-}inhale} = DAF_{va} \quad C_{gw\text{-}inhale} \qquad (4\text{-}89)$$

where:

			Default
$C_{dl\text{-}inhale}$	=	pathway leachate concentration delisting level for shower inhalation (mg/L)	calculated
DAF_{va}	=	waste volume-adjusted dilution attenuation factor (unitless)	Equation 2-5
$C_{gw\text{-}inhale}$	=	maximum allowable constituent concentration in groundwater for inhalation (mg/L)	Equation 4-91

To calculate $C_{gw\text{-}inhale}$, one must first calculate the maximum allowable concentration volatilized into air, CET_{max}, during showering. For noncarcinogens, CET_{max}, is calculated by DRAS using the target hazard quotient and the constituent's inhalation RfD. Equation 4-90 shows how CET_{max}, is calculated.

$$CET_{max} = \frac{THQ \cdot RfD \cdot BW \cdot AT \cdot 365 days/year}{IR \cdot EV \cdot EF \cdot ED} \qquad \textbf{(4-90)}$$

where:

			Default
CET	=	sum of products of maximum allowable constituent air concentration in specific compartment and corresponding exposure time (mg-days/m^3)	calculated (Equation 4-27)
THQ	=	target hazard quotient (unitless)	user specified (0.1 default U.S. EPA 1997b)
RfD	=	constituent inhalation reference dose (mg/kg-day)	chem-specific (Appendix A-1)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)
IR	=	inhalation rate (m^3/day)	20 (U.S. EPA 1997b)
EV	=	event frequency (showers/day)	1 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)

CET_{max}, is the maximum allowable constituent concentration in air that will not allow the acceptable hazard level to be exceeded. Once CET_{max}, is calculated for a given waste constituent, the DRAS calculates $C_{gw\text{-}inhale}$ based on the inhalation exposure in the shower, bathroom, and house compartments combined. The DRAS calculates $C_{gw\text{-}inhale}$ using Equation 4-91.

$$C_{gw\text{-}inhale} = \frac{CET_{max}}{\sum_{comp} F_{GW,\,comp}\, ET_{comp}} \qquad \textbf{(4-91)}$$

where:

			Default
$C_{gw\text{-}inhale}$	=	maximum allowable constituent concentration in groundwater used for showering (mg/L)	calculated
CET_{max},	=	sum of products of maximum allowable constituent air concentration in specific compartment and corresponding exposure time (mg-days/m^3)	calculated (Equation 4-90)
$F_{GW,\,comp}$	=	fraction of average waste constituent concentration in the compartment over the groundwater waste constituent concentration based on a forward calculation	Equation 4-25
ET_{comp}	=	exposure time in compartment (days/shower) - shower	(U.S. EPA 1997b) 0.00792

- bathroom	0.0338
- house	0.625

If the TCLP concentration for a given waste constituent exceeds $C_{dl\text{-}inhale}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of hazard analysis calculations presented in Section 4.4.1.2.3.

4.4.1.3.2   Hazard Analysis

In the hazard analysis, the DRAS computes the hazard associated with adult inhalation exposure to a noncarcinogenic waste constituent during showering with groundwater. To determine total inhalation exposure to volatilized waste constituents in the house during and after showering, the DRAS computes the air concentration of waste constituents in three compartments of the house; the shower, the bathroom and the house. The DRAS computes each constituent's *HQ* for this exposure pathway using Equation 4-92.

$$HQ = \frac{CET \cdot EV \cdot EF \cdot ED \cdot IR \cdot 1000L/m^3}{AT \cdot 365days/year \cdot RfD \cdot BW} \qquad \textbf{(4-92)}$$

where:

			Default
HQ	=	hazard quotient for inhalation during showering for constituent (unitless)	calculated
CET	=	sum of products of maximum allowable constituent air concentration in specific compartment and corresponding exposure time (mg-days/m^3)	calculated (Equation 4-27)
EV	=	event frequency (showers/day)	1 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ET$_{comp}$	=	exposure time in compartment (days/shower)	(U.S. EPA 1997b)
		- shower	0.00792
		- bathroom	0.0338
		- house	0.625
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)
IR	=	inhalation rate (m^3/day)	20 (U.S. EPA 1997b)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)
RfD	=	constituent's inhalation reference dose (mg/kg-day)	chem-specific (Appendix A-1)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
1000L /m^3		conversion factor for cubic meters to liters	

CET is calculated by summing the waste constituent concentration for each of the three compartments in the house using Equation 4-27 and the appropriate default parameters. There is a theoretical maximum air concentration that can occur in a compartment. The DRAS calculates that theoretical maximum concentration, $C_{air-max}$, for each compartment using the Ideal Gas Law. The DRAS calculates C_{air-i} for all three compartments and compares the compartment concentration to the theoretical maximum. If C_{air-i} exceeds $C_{air-max}$ for a given waste constituent, C_{air-i} is reset to the value of $C_{air-max}$. Using Equation 4-92 the user calculates the constituent-specific *HQ*s for groundwater exposure via inhalation during showering. The DRAS then sums these *HQ*s using Equation 4-5 to determine the HI_p for the pathway.

4.4.2 Surface Water Exposure Pathways

The surface water exposure pathways addressed by the DRAS include ingestion of surface water and ingestion of fish. An adult receptor is assumed for both pathways. The pathway delisting levels and hazards for these pathways are calculated using a method described in EPA Headquarters delisting docket materials (U.S. EPA 1993a, 1993b). The method uses the USLE to calculate the rate of erosion of a petitioned waste from a landfill to a surface water body. The receiving water body is assumed to be a stream. The amount of eroded waste delivered in runoff to the stream is calculated using a sediment delivery ratio, and the volume of surface water into which runoff occurs is determined by estimating the size of the stream into which the eroded waste is likely to be transported.

For the purposes of delisting, the stream is assumed to be a second-order or fifth-order stream (U.S. EPA 1993a). A second-order stream is assumed to be the smallest stream capable of supporting fish, whereas a fifth-order stream is assumed to be the smallest stream capable of serving as a community water supply. The surface water ingestion analyses are based on the assumption that a noncarcinogenic waste constituent is transported to a fifth-order stream; the fish ingestion analyses are based on the assumption that the chemical is transported to a second-order stream.

Sections 4.4.2.1 and 4.4.2.2 describe the equations and default parameters used to calculate the pathway delisting levels and hazard associated with the ingestion of surface water and ingestion of fish exposure pathways.

4.4.2.1   Ingestion of Surface Water

The DRAS computes total concentration delisting levels and hazards associated with exposure of adults to noncarcinogenic waste constituents via the surface water ingestion pathway. Section 4.4.2.1.1 presents the equations used to compute pathway total concentration delisting levels for standard multi year delistings. Section 4.4.2.1.2 presents the equations and methods used to compute constituent- and pathway-specific hazards for one-time delistings.

4.4.2.1.1   Delisting Level Analysis

Pathway total concentration delisting levels for noncarcinogens associated with ingestion of surface water, $C_{dl\text{-}water}$, are computed for the target hazard quotient.. To calculate $C_{dl\text{-}water}$, it is necessary to first calculate the maximum allowable concentration of the waste constituent in surface water, C_{sw}, using Equation 4-93. The DRAS then calculates $C_{dl\text{-}water}$ using C_{sw}.

$$C_{sw} = \frac{THQ \cdot RfD \cdot BW \cdot AT \cdot 365 days/year}{CR \cdot EF \cdot ED} \tag{4-93}$$

where:

			Default
C_{sw}	=	maximum allowable concentration of constituent in surface water (mg/L)	calculated
THQ	=	target hazard quotient (unitless)	user specified (0.1 default U.S. EPA 1997b)
RfD	=	reference dose (mg/kg-day)	chem-specific (Appendix A-1)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)
CR	=	water consumption rate (L/day)	2.0 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)

Once C_{sw} is known, $C_{dl\text{-}water}$ is calculated using Equation 4-94.

$$C_{dl\text{-}water} = \frac{C_{sw}}{C_{5th\text{-}stream}} \tag{4-94}$$

where:

			Default
$C_{dl\text{-}water}$	=	pathway total waste concentration delisting	calculated

level for ingestion of surface water (mg/kg)

C_{sw} = maximum allowable concentration of   Equation 4-93
constituent in surface water (mg/L)

$C_{5th\text{-}stream}$ = concentration of constituents in fifth-order stream   Equation 4-43
(kg/L)

If the total concentration of a constituent in the waste exceeds its pathway total concentration delisting level, $C_{dl\text{-}water}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of hazard analysis calculations presented in Section 4.4.2.1.2.

4.4.2.1.2 Hazard Analysis

In the hazard analysis, the DRAS computes hazards associated with the surface water ingestion pathway. The DRAS calculates each noncarcinogenic waste constituent's *HQ* for this pathway using Equation 4-95.

$$HQ = \frac{CR \cdot C_{sw} \cdot EF \cdot ED}{BW \cdot RfD \cdot AT \cdot 365 days/year} \tag{4-95}$$

where:

			Default
HQ	=	constituent-specific hazard quotient for ingestion of surface water (unitless)	calculated
CR	=	water consumption rate (L/day)	2.0 (U.S. EPA 1997b)
C_{sw}	=	concentration of constituent in surface water (mg/L)	Equation 4-45
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
RfD	=	reference dose (mg/kg-day)	chem-specific (Appendix A-1)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)

Equation 4-45, which is used to compute C_{sw}, is based on the USLE and the sediment delivery ratio for overland transport of eroded waste to surface water as described in the delisting docket (U.S. EPA 1993a). Using Equation 4-95, the DRAS calculates the *HQ* associated with ingestion of surface water for each waste constituent. The program then sums the *HQ*s using Equation 4-5 to determine the total HI_p for the surface water ingestion pathway.

4.4.2.2   Ingestion of Fish

This section describes the computation of total pathway concentration pathway delisting levels and hazards associated with exposure of adults to noncarcinogenic waste constituents via ingestion of fish. Section 4.4.2.2.1 presents the equations used to compute constituent-specific total concentration delisting levels for standard multi year delistings.   Section 4.4.2.2.2 presents the equations used to compute constituent-and pathway-specific hazards for one-time delistings. The BAF values used are for a trophic level 4 (carnivorous) fish (U.S. EPA 1995e).

4.4.2.2.1   Delisting Level Analysis

This section describes the equations used to calculate the pathway total concentration delisting levels for exposure to noncarcinogenic constituents through fish ingestion, $C_{dl\text{-}fish}$. The DRAS first calculates the maximum allowable constituent concentration in surface water that will not result in a constituent concentration in fish tissue in excess of the maximum edible concentration. The maximum allowable fish tissue concentration for a waste constituent, C_{fish}, is calculated at the target hazard quotient using Equation 4-96.

$$C_{fish} = \frac{THQ \cdot RfD \cdot BW \cdot AT \cdot 365 days/year}{CR_{fish} \cdot EF \cdot ED} \qquad (4\text{-}96)$$

where:

			Default
C_{fish}	=	maximum allowable concentration of constituent in fish tissue (mg/kg)	calculated
THQ	=	target hazard quotient (unitless)	user specified (0.1 default U.S. EPA 1997b)
RfD	=	reference dose (mg/kg-day)	chem-specific (Appendix A-1)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)
CR_{fish}	=	fish consumption rate (kg/day)	0.02 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)

Once C_{fish} is calculated, the corresponding maximum allowable concentration of the of the constituent freely dissolved in surface water is calculated using Equation 4-97.

$$C_{dw} = \frac{C_{fish}}{BAF \lor BCF} \qquad \text{(4-97)}$$

where:

			Default
C_{dw}	=	maximum allowable dissolved phase water concentration in the second order stream (mg/kg)	calculated
C_{fish}	=	maximum allowable concentration of constituent in fish tissue (mg/kg)	Equation 4-96
BAF	=	bioaccumulation factor of waste constituent (L/kg)	chem-specific (Appendix A-1)
or			
BCF	=	bioconcentration factor of waste constituent (L/kg)	chem-specific (Appendix A-1)

Using Equation 4-98, the maximum allowable dissolved phase water in the second order stream is converted to the total concentration of the waste constituent in water column (C_{sw}):

$$C_{sw} = C_{dw} \, [1 + Kd_{sw} \cdot TSS \cdot 1 \times 10^{-6}] \qquad (\,4\text{-}98)$$

where:

			Default
C_{dw}	=	Dissolved phase water concentration (mg/L)	Equation 4-97
C_{sw}	=	Waste concentration in water column (mg/L)	calculated
Kd_{sw}	=	Suspended sediments/surface water partition coefficient (L water/kg suspended sediment)	chem-specific (Appendix A-1)
TSS	=	Total suspended solids concentration (mg/L)	Equation 2-52
1×10^{-6}		Units conversion factor (kg/mg)	

Finally, C_{sw} is used in Equation 4-99 to back calculate the delisting level ($C_{dl\text{-}fish}$) for the fish ingestion pathway.

$$C_{dl\text{-}fish} = \frac{C_{sw} \cdot Q_{2ndstream}}{A \cdot A_w} \qquad \text{(4-99)}$$

where:

			Default
$C_{dl\text{-}fish}$	=	pathway total concentration delisting level for fish ingestion (mg/kg)	calculated

C_{sw}	=	maximum allowable concentration in water column of constituent in 2nd order stream (mg/L)	Equation 4-98
A_w	=	rate of waste ans soil erosion from landfill (kg/[acre-year])	Equation 2-51
$Q_{2ndstream}$	=	volumetric flow of second-order stream (L/year)	3.3×10^9 (U.S. EPA 1994a)
A	=	area of waste management unit (acres)	Equation 2-12 or -13

If the total concentration of a given waste constituent exceeds its pathway total concentration delisting level, $C_{dl\text{-}fish}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of hazard analysis calculations presented in Section 4.4.2.2.2.

4.4.2.2.2 Hazard Analysis

In the hazard analysis, the DRAS computes the hazards associated with the fish ingestion exposure pathway. The DRAS computes each noncarcinogenic waste constituent's *HQ* for this pathway using Equation 4-100.

$$ HQ = \frac{C_{fish} \cdot CR_{fish} \cdot EF \cdot ED}{BW \cdot RfD \cdot AT \cdot 365 days/year} \tag{4-100} $$

where:

			Default
HQ	=	hazard quotient (unitless)	calculated
C_{fish}	=	concentration of constituent in fish tissue (mg/kg)	Equation 4-51
CR_{fish}	=	fish consumption rate (kg/day)	0.02 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)
BW	=	body weight (kg)	72 (U.S. EPA 1997b)
RfD	=	reference dose (mg/kg-day)	chem-specific (Appendix A-1)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)

The concentration of the waste constituent in fish tissue, C_{fish}, is computed using Equation 4-51. This equation is based on an estimate of the dissolved fraction (C_{dw}) of the waste constituent concentration present in a second-order stream. The DRAS sums the *HQ*s for the noncarcinogenic waste constituents using Equation 4-5 to determine the total HI_p for the fish ingestion pathway.

4.4.3   Air Exposure Pathways

The DRAS includes an analysis of the human health hazards associated with exposures to noncarcinogens via three air exposure pathways: (1) inhalation of particulates from solid wastes disposed of in landfills, (2) inhalation of volatiles from solid wastes disposed of in landfills, and (3) inhalation of volatiles from liquid wastes disposed of in surface impoundments. An adult receptor is assumed for all three pathways. The delisting level for the inhalation of particulates pathway is expressed in terms of the total constituent concentration in the waste. Leachate concentration delisting levels are generated for the inhalation of volatiles pathways.

The risks associated with inhalation exposure to particulate and volatile matter can typically be determined only when inhalation HBNs are available. Inhalation reference concentrations derived from oral reference doses are only used when specifically recommended by IRIS or when target organ endpoints are far from the respiratory system (U.S. EPA 2006).

The methods used to evaluate the release and transport of noncarcinogenic particulates and volatiles from waste disposal units are the same as those used for carcinogens; only the assessment calculations differ. A discussion of the source of the methods is presented in Section 4.3.3.

The following sections describe the equations and default parameters used to calculate pathway delisting levels and assess hazards associated with exposure to waste constituents via the air exposure pathways. Section 4.4.3.1 presents the equations used to compute pathway delisting levels for standard multi year delistings. Section 4.4.3.2 presents the equations used to compute constituent-specific and pathway-specific hazards for one-time delistings.

4.4.3.1 Delisting Level Analysis

This section describes the equations used to calculate air exposure pathway delisting levels for noncarcinogenic waste constituents. Before the delisting levels can be calculated, each constituent's maximum allowable respirable air concentration at the POE, C_{air}, must be calculated. C_{air} is calculated at the target hazard quotient, as shown in Equation 4-101.

$$C_{air} = \frac{THQ \cdot RfC \cdot AT \cdot 365 \ days/year}{ED \cdot EF} \qquad \textbf{(4-101)}$$

where:

			Default
C_{air}	=	constituent's maximum allowable respirable air concentration at POE (mg/m³)	calculated
THQ	=	target hazard quotient (unitless)	user specified (0.1 default U.S. EPA 1997b)
RfC	=	constituent reference concentration (mg/m³)	chem-specific (Appendix A-1)
AT	=	averaging time (years)	30 (U.S. EPA 1997b)
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)

C_{air} is used with the air transport equation (Equation 2-25) and the particulate and volatile air emission equations (Equation 2-24 for particulates, and Equation 2-33 for volatiles) to back-calculate the pathway total concentration and leachate concentration delisting levels, respectively. The following sections describe the methods used to calculate delisting levels for landfill particulates ($C_{dl-air-p}$), landfill volatiles ($C_{dl-air-v}$), and surface impoundment volatiles (C_o). If the total concentration of a given noncarcinogenic waste constituent exceeds $C_{dl-air-p}$, or the TCLP concentration of a constituent exceeds either $C_{dl-air-v}$ or C_o, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of hazard analysis calculations presented in Section 4.3.3.2.

Landfill Particulate Delisting Levels

First the maximum allowable emission rate of the constituent, Q_p, is calculated using in C_{air} using Equation 4-102.

$$Q_p = \frac{C_{air} \cdot \Sigma_z \cdot U \cdot L_v}{2.03 \cdot F \cdot F_{inhal}}$$

(4-102)

where:

			Default
Q_p	=	maximum allowable total constituent emission rate (mg/s)	calculated
C_{air}	=	constituent's maximum allowable air concentration at POE (mg/m³)	Equation 4-101
Σ_z	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1994a)
L_v	=	distance from virtual point to compliance point located 1,000 feet (304.8 m) downwind (m)	Equation 2-27
F	=	frequency that wind blows across waste unit toward receptor (unitless)	0.15 (U.S. EPA 1994a)
F_{inhal}	=	fraction of particles inhaled	0.125 (U.S. EPA 1994a)

Then the pathway total concentration delisting level for respirable landfill in air particulates, $C_{dl-air-p}$, is calculated by setting the maximum allowable total emission rate for respirable particulates, Q_{p10}, as equal to Q_p and using Equation 4-103.

$$C_{dl-air-p} = \frac{Q_{p10}}{(E_{w10} + E_{v10} + E_{l10}) \cdot \frac{10^3 \ mg}{1 \ g} \cdot \frac{1 \ hr}{3,600 \ s} \cdot \frac{10^{-6} \ kg}{1 \ mg}} \qquad (4\text{-}103)$$

where:

			Default
$C_{dl-air-p}$	=	pathway total concentration delisting level for respirable landfill particulates in air (mg/kg)	calculated
Q_{p10}	=	emission rate of waste constituent particulates up to 10 µm (mg/s)	set equal to Q_p (Equation 4-102)
E_{w10}	=	wind erosion emission rate of particulates up to 10 µm (g/hr)	Equation 2-9
E_{v10}	=	vehicle travel emission rate of particulates up to 10 µm (g/hr)	Equation 2-19
E_{l10}	=	waste loading and unloading emission rate of particulates up to 10 µm (g/hr)	Equations 2-21 and 2-22

Landfill Volatile Delisting Levels

First the maximum allowable volatile emission flux of the constituent, E_i, from the landfill is calculated by setting the maximum allowable total emission rate of volatiles, Q_v, as equal to Q_p (calculated in Equation 4-102) and using Equation 4-104.

$$E_i = \frac{Q_v}{1000 \ mg \ / \ g} \qquad (4\text{-}104)$$

where:

			Default
E_i	=	maximum allowable volatile emission flux of constituent (g/s)	calculated
Q_v	=	maximum allowable constituent volatile emission rate (mg/s)	set equal to Q_p (Equation 4-102)
1000mg /g conversion factor			

Then, E_i is used to calculate the pathway total delisting level concentration for volatiles from a landfill, $C_{dl-air-v}$, using Equation 4-105.

$$C_{dl-air-v} = \frac{E_i \cdot d \cdot P_T^2 \cdot 1x10^6 \cdot 1x10^4}{D_a \cdot P_a^{10/3} \cdot A_{exposed} \cdot C_{si}} \tag{4-105}$$

where:

Default

$C_{dl-air-v}$	=	pathway total waste concentration delisting level for volatiles from landfill (mg/kg)	calculated
E_i	=	maximum allowable volatile emission flux of constituent (g/s)	Equation 4-55
d	=	depth of soil cover (m)	0.1524 (U.S. EPA 1994a)
P_T	=	total sand porosity (unitless)	0.4 (U.S. EPA 1994a)
D_a	=	diffusivity of constituent in air (cm²/s)	chem-specific (Appendix A-1)
P_a	=	air-filled sand porosity (unitless)	0.4 (U.S. EPA 1994a)
$A_{exposed}$	=	surface area (m²)	Equation 2-15
C_{si}	=	saturation vapor concentration of i in landfill (g/m³)	Equation 4-106
$1x10^6$	=	conversion from kilograms to milligrams	
$1x10^4$	=	conversion from m² to cm²	

Finally, the saturation vapor concentration (C_{si}) of waste constituent i for volatiles from a landfill ($C_{dl-air-v}$) is calculated using Equation 4-106.

$$C_{si} = \frac{p_i \cdot MW_i}{R \cdot T} \tag{4-106}$$

where:

Default

C_{si}	=	saturation vapor concentration of i in landfill (g/m³)	Equation 4-56
p_i	=	vapor pressure of waste constituent i (at)	chem-specific (Appendix A-1)
MW	=	molecular weight of waste constituent i	chem-specific (Appendix A-1)
R	=	universal gas constant (atm-m³/mol-K)	8.21×10^{-5}
T	=	standard temperature (K)	298

Surface Impoundment Volatile Delisting Levels

The pathway leachate concentration delisting level for volatiles from waste disposed of in a surface impoundment is calculated by setting the maximum allowable total emission rate of volatiles, Q_v, as equal to Q_p (calculated in Equation 4-102) and using Equation 4-107.

$$C_{dl-air-si} = \frac{Q_v \cdot tp \cdot 86,400 \, s/1 \, day}{V \cdot \frac{1000L}{m^3} \cdot e^{\left(1- \left(\frac{K \cdot A_{si} \cdot 4,046.8 \, m^2/1 \, acre \cdot tp \cdot 86,400 \, s/1 \, day}{V}\right)\right)}} \qquad (4-107)$$

where:

			Default
$C_{dl\text{-}air\text{-}si}$	=	pathway leachate concentration delisting level for volatiles from surface impoundment (mg/L)	calculated
Q_v	=	maximum allowable constituent volatile emission rate (mg/s)	set equal to Q_p (Equation 4-102)
tp	=	time period for mass emission (days)	
t_f	=	time for constituent concentration to reach 1 percent of C_L (days)	Equation 4-59
V	=	volume of liquid in surface impoundment (m³)	unit-specific (user-provided)
K	=	overall mass transfer coefficient (m/s)	Equation 4-60
A	=	area of waste management unit (acres)	Equation 2-12 or 2-13
t_r	=	retention time for liquid in surface impoundment (days)	Equation 2-40

4.3.3.2 Hazard Analysis

Hazard as a function of the effective air concentration of a particulate or volatile noncarcinogenic constituents, C_{air}, is calculated for each of the three air exposure pathways as shown in Equation 4-108.

$$HQ = \frac{C_{air} \cdot ED \cdot EF}{RfC \cdot AT \cdot 365 days/year} \qquad \textbf{(4-108)}$$

where:

			Default
HQ	=	hazard quotient for waste constituent (unitless)	calculated
C_{air}	=	effective concentration of constituent in air at POE (mg/m³)	
		Particulates	Equation 4-66
		Landfill volatiles	Equation 4-68
		Surface impoundment volatiles	Equation 4-73
ED	=	exposure duration (years)	30 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
RfC	=	constituent reference concentration (mg/m³)	Chem-specific (Appendix A-1)

AT = averaging time (years) 30 (U.S. EPA 1997b)

C_{air} at the POE is determined separately for each of the three air exposure pathways using the air emission and transport equations derived in Section 2.3 and presented in Section 4.3.3.2.

Using Equation 4-108, the DRAS calculates the waste constituent HQs for receptors at the POE for the three air exposure pathways. The program then sums the individual constituent HQs using Equation 4-5 to determine the HI_p for each of the air inhalation pathways.

4.4.4   Soil Exposure Pathway

This section presents equations used to calculate pathway total concentration delisting levels and hazards constituents associated with exposures of children to soils contaminated with noncarcinogenic waste constituents at a POE 1,000 feet from a waste disposal unit. The soil contamination is assumed to be the result deposition of waste particulates from the air. The equations used to compute the delisting levels and hazards are based on a method described in U.S. EPA Headquarters delisting docket materials (U.S. EPA 1993a, 1993b).

Section 4.4.4.1 presents the equations used to compute pathway total concentration delisting levels for standard multi year delistings. Section 4.4.4.2 presents the equations and methods used to compute constituent-specific and pathway- hazards for one-time delistings.

4.4.4.1   Delisting Level Analysis

This section describes computation of the pathway total concentration delisting level for exposure to noncarcinogens via ingestion of soil, $C_{dl\text{-}soil}$. First, the maximum allowable concentration of each constituent in soil at the POE, C_{soil}, is calculated. C_{soil} is the maximum concentration of the waste constituent in soil that does not cause the risk from soil ingestion to exceed the target hazard quotient. C_{soil} is calculated using Equation 4-109.

(4-109)

$$C_{soil} = \frac{THQ \quad RfD \quad BW_c \cdot AT \cdot 365 days/year}{CR_{soil} \cdot ED \cdot EF} \quad 1x10^6 mg/kg$$

where:

<u>Default</u>

C_{soil}	=	maximum allowable concentration of constituent in soil at the POE (mg/kg)	calculated
THQ	=	target hazard quotient (unitless)	user specified (0.1 default U.S. EPA 1997b)
RfD	=	constituent reference dose (mg/kg-day)	chem-specific (Appendix A-1)
BW_c	=	body weight of child (kg)	15 (U.S. EPA 1997b)
AT	=	averaging time (years)	6 (U.S. EPA 1997b)
CR_{soil}	=	soil consumption rate (mg/day)	200 (U.S. EPA 1997b)
ED	=	exposure duration (years)	6 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)

Using C_{soil}, the DRAS back-calculates the maximum allowable constituent concentration in air at the POE, C_{air}, assuming a constituent accumulation period in the soil of 1 year. C_{air} is calculated, at a depth of mixing of 1 cm as shown in Equation 4-110.

$$C_{air} = \frac{\rho_b \cdot t \cdot C_{soil} \cdot \frac{10^3\ mg}{1\ g} \cdot \frac{10^6\ cm^3}{1\ m^3} \cdot \frac{1\ kg}{10^6\ mg}}{v_d \cdot \frac{31,536,000\ s}{1\ year}} \cdot 1/year \qquad (4\text{-}110)$$

where:

			Default
C_{air}	=	maximum allowable concentration of constituent in air at POE (mg/m³)	calculated
$ñ_b$	=	soil bulk density (g/cm³)	1.45 (Brady 1984)
t	=	soil thickness from which particles can be ingested (m)	0.01 (U.S. EPA 1994a)
C_{soil}	=	maximum allowable concentration of constituent in soil at the POE (mg/kg)	Equation 4-109
v_d	=	deposition velocity (m/s)	0.03 (U.S. DOE, 1984)

Finally, once C_{air} is known, the total concentration delisting level is computed using Equation 4-111.

$$C_{dl\text{-}soil} = \frac{C_{air} \cdot \Sigma_z \cdot U \cdot L_v \cdot \frac{1,000\ g}{1\ kg}}{2.03 \cdot E_{T30} \cdot F \cdot \frac{1\ hr}{3,600\ s}} \qquad (4\text{-}111)$$

where:

			Default
$C_{dl\text{-}soil}$	=	pathway total concentration delisting level for soil ingestion (mg/kg)	calculated

C_{air}	=	maximum allowable concentration of constituent in air at POE (mg/m^3)	Equation 4-110
$_z$	=	vertical dispersion coefficient (m)	Equation 2-26
U	=	mean annual wind speed (m/s)	4 (U.S. EPA 1994a)
L_v	=	distance from virtual point to compliance point located 1,000 feet (304.8 m) downwind (m)	Equation 2-27
E_{T30}	=	annual average emission rate of particles up to 30 μm (g/hr)	Equation 4-75 (also see Section 2.3.1.3)
F	=	frequency that wind blows across waste unit toward receptor (unitless)	0.15 (U.S. EPA 1994a)

If the total concentration for a given noncarcinogenic waste constituent exceeds its pathway total concentration delisting level, $C_{dl\text{-}soil}$, the waste may not qualify for a standard multi year delisting. However, the waste may qualify for a one-time delisting, depending on the results of hazard analysis calculations presented in Section 4.4.4.2.

4.4.4.2 Hazard Analysis

In the hazard analysis, the DRAS computes the hazard associated with the soil ingestion exposure pathway. The hazard for each noncarcinogenic waste constituent associated with soil ingestion at the POE is calculated. Only the child receptor is considered. The focus on children reflects the higher daily soil intake rates for children and their lower body weights. The constituent-specific hazard from ingestion of soil is calculated using Equation 4-112.

$$HQ \; = \; \frac{C_{soil} \cdot CR_{soil} \cdot ED \cdot EF}{BW_c \cdot RfD \cdot AT \cdot 365 days/year \cdot 1x10^6 mg/kg} \qquad \textbf{(4-112)}$$

where:

			Default
HQ	=	constituent hazard quotient (unitless)	calculated
C_{soil}	=	concentration of constituent in soil POE (mg/kg)	Equation 4-78
CR_{soil}	=	soil consumption rate (mg/day)	200 (U.S. EPA 1997b)
ED	=	exposure duration (years)	6 (U.S. EPA 1997b)
EF	=	exposure frequency (days/year)	350 (U.S. EPA 1997b)
BW_c	=	body weight of child (kg)	15 (U.S. EPA 1997b)
RfD	=	constituent reference dose (mg/kg-day)	chem-specific (Appendix A-1)
AT	=	averaging time (years)	6 (U.S. EPA 1997b)

C_{soil} is calculated based on the constituent's rate of deposition onto the soil. Assuming that at any given time the soil is burdened with 1 year's accumulation of constituent from air deposition and that the mixing depth of the constituent into the soil is 1 cm, Equation 4-78 is used to calculate C_{soil}. Then, using Equation 4-112,

the DRAS calculates the *HQ* associated with ingestion of soil for each constituent. Finally this program sums the

constituent-specific *HQ*s using Equation 4-5 to determine the total HI_p for the soil ingestion pathway.