

**PETROLEUM REFINING PROCESS WASTE
LISTING DETERMINATION**

**SUPPLEMENTAL
BACKGROUND DOCUMENT**

GROUNDWATER PATHWAY RISK ANALYSIS

**US Environmental Protection Agency
Office of Solid Waste
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1.0 BACKGROUND

1.1 GENERAL BACKGROUND

This document describes groundwater pathway analyses performed to support the petroleum refining listing determination. These analyses supplement the analyses carried out earlier as part of the EPA's proposal for the petroleum refining listing determination (USEPA, 1995a). The analyses were designed to determine the potential exposure, via the groundwater pathway, to human receptors from petroleum refining wastes, being managed and/or disposed in land management units. The exposure is expressed in terms of the contaminant concentration at a groundwater extraction well located down-gradient from the waste-management unit.

The contaminant concentrations were obtained using the EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) (USEPA, 1996c ,d ,e; USEPA, 1997d). EPACMTP simulates the subsurface fate and transport of waste constituents leaching from land disposal units. Wastestreams and waste constituents of potential concern are identified by comparing the model predicted exposure concentrations to health-based numbers (HBNs) for both carcinogens and non-carcinogens.

In the current modeling analyses, in addition to the two high-end parameter and the central tendency analyses, Monte-Carlo analyses were also performed to assess the potential groundwater exposures due to dissolved chemicals associated with the disposal of petroleum refining wastes in waste management units. The EPACMTP model was selected because of its capabilities to perform deterministic and full, Monte Carlo-based, probabilistic exposure assessments.

1.1.1 General Overview of Analyses

EPA received a number of comments related to the groundwater pathway analyses supporting the November 20, 1995 notice of proposed rulemaking (60 FR 57747, November 20, 1995). In responding to these comments, EPA performed a variety of additional analyses. A brief overview of what analyses EPA undertook and the general nature of the comments that prompted such analyses, are given below.

Volume Inputs and Waste Fractions. EPA received comments regarding the Agency's selection of volume inputs and the fraction of the landfill waste that was assumed to be the petroleum waste. As a result, EPA reexamined the approach it used and conducted additional analyses to better assess groundwater risks. EPA subsequently made revisions to the deterministic modeling approach, as described in Section 3.0. In addition, EPA conducted a full, Monte Carlo based, probabilistic exposure assessments as a way of confirming the deterministic modeling analyses. The Monte Carlo methodology is presented in Section 4.0.

Codisposal of Multiple Wastestreams. In the proposed rule, EPA assumed that only one wastestream is managed/disposed of in a unit at any time. One of the comments about volume inputs suggested that EPA should consider co-disposal of the evaluated wastes with other

refinery wastes. In response, the Agency evaluated the potential groundwater exposures due to the impact of codisposal of multiple wastestreams (codisposal scenarios) as well as the disposal of single wastestreams (baseline scenario). These results are described in Sections 3.4, 4.2 and 5.2.5.

Conditional Exemption and Contingent Management. In the proposed rule, EPA raised the option of a conditional exemption for one waste, Clarified Slurry Oil Storage Tank Sediment (CSO), if the regulations limited the way the waste is managed and disposed, i.e., a contingent management listing. Commenters indicated that EPA should assess what impact the conditional exemption might have on the listing decision, *i.e.*, examine the assumption that unless the waste is unconditionally listed all of it could potentially be disposed in Subtitle D landfills. This could substantially increase the volume of CSO wastes going to the allowed (Subtitle D) disposal practice (*e.g.*, landfills), since wastes previously land treated or managed in other ways may be landfilled (Subtitle D) to take advantage of the exemption from Subtitle C regulations. EPA evaluated the potential risk of increased landfilling as described in Sections 2.3.4 and 5.2.4.

Noningestion Risks from Groundwater Contamination. Commenters pointed out that the Agency ignored the noningestion risks arising from the use of contaminated groundwater. Such risks might arise from the inhalation of contaminants transferred to the air from showers, baths, etc. In response, EPA examined additional modeling approaches, as described in the Supplemental Background Document for Nongroundwater risk assessment pathways (USEPA, 1997c). The description of the calculation of the combined risk is presented in Section 5.1. Details of the models used to estimate exposure factors for inhalation and dermal risk are given in Section 6 of the Supplemental Background Document for Nongroundwater Risk Assessment (USEPA, 1997c).

Use of TCLP data that exceeds the Toxicity Characteristic. Commenters stated that EPA should calculate risks from Subtitle D landfilling of residuals using only the data that do not exceed the Toxicity Characteristic level (40CFR261.24), because such wastes should be handled as hazardous. The analyses conducted in response to this comment can be found in Section 5.2.6, and the input data are discussed in Section 2.3.

1.2 WASTESTREAMS AND MANAGEMENT SCENARIOS

The groundwater pathway analysis involved evaluating land disposal of a total of 2 listing wastestreams (Table 1.1) and 11 study wastestreams (Table 1.2). A complete description of listing and study wastestreams is presented in the appropriate background documents (USEPA, 1995a and USEPA, 1996a). Both single-wastestream disposal (baseline) and multi-wastestream disposal (codisposal) scenarios were evaluated. Table 1.1 presents a summary of the modeled listing wastestreams and landfill modeling scenarios. The study wastestreams (Table 1.2) were included only in the codisposal scenario.

1.3 REPORT ORGANIZATION

General technical approaches are outlined in Section 2. Detailed descriptions for the deterministic and Monte Carlo scenarios are presented in Sections 3, and 4, respectively. Modeling results and exposure risk calculations are presented in Section 5.

Table 1.1 Petroleum Refining Listing Wastestreams and Landfill Scenarios.

Wastestream		Landfill Scenarios			
		Single Wastestream Baseline		Codisposal	
		On-site	Off-site	On-site	Off-site
I.	Crude Oil Tank Sludge		x		x
II.	CSO Sludge	x	x	x	x
III.	Unleaded Gasoline Tank Sludge	x	x	x	x
IV.	Off-spec Product Fines (Coke Fines)	x	x	x	x
V.	Sulfur Complex Sludge	x	x	x	x
VI.	HF Alkylation Sludge	x	x	x	x
VII.	H ₂ SO ₄ Alkylation Sludge		x		x
VIII.	Claus Catalyst	x	x		
IX.	SCOT Catalyst	x	x		
X.	Hydrotreating Catalyst	x	x		
XI.	Hydrotreating Catalyst	x	x		
XII.	FCC Catalyst & Fines	x	x	x	x

Table 1.2 Petroleum Refining Study Wastestreams.

Wastestream		Landfill Scenarios			
		Single Wastestream Baseline		Codisposal	
		On-site	Off-site	On-site	Off-site
I.	Desalting Sludge				x
II.	Extraction Clay			x	x
III.	HF Treating Clay			x	x
IV.	Isomerization Clay			x	x
V.	Phosphoric Acid Catalyst			x	x
VI.	Process Sludge-Residual Upgrade				x
VII.	Off-Spec Sulfur			x	x
VIII.	Treating Clay from Clay-Filtering			x	x
IX.	Hydrocracking Catalyst		x		x
X.	Residual Oil Tank Sludge			x	x
XI.	Dimersol Catalyst			x	

2.0 GENERAL METHODOLOGY

This section outlines the general methodology used in the groundwater pathway analysis. It includes: an overview of the modeling approach, modeling scenarios, and descriptions of the data sources used in the analysis.

2.1 MODELING APPROACH

The groundwater pathway analysis determines the groundwater exposure concentrations resulting from the release of waste constituents from the waste management unit into the subsurface, and the subsequent fate and transport of the constituent, through the vadose zone and underlying saturated zone. The exposure concentration is evaluated at the intake point of a hypothetical groundwater drinking water well, located at a specified distance from the downgradient edge of the waste management unit. This well is referred to hereafter as the 'receptor well'. The modeled subsurface pathway is depicted schematically in Figure 2.1. The modeling approach may be divided into two major steps: (1) the release of waste constituents into the subsurface, *i.e.*, the model source term characterization, and (2) the fate and transport of constituents in the subsurface (in the vadose zone and the saturated zone). The modeling approach for the groundwater pathway analysis involves aqueous phase migration of waste constituents. Considering that the wastes associated with petroleum refining operations may contain a significant amount of non-aqueous phase liquids, *i.e.*, "oil", the potential may exist for migration of waste constituents via non-aqueous phase flow. However, an evaluation conducted for the 1995 Analysis indicated that multiphase flow would not be expected to be a concern for the wastestreams investigated. Laboratory analysis of petroleum waste samples also shows that the waste actually contains no or very little free flowing oil (USEPA, 1997a). Furthermore, it is very likely that petroleum waste parcels are buffered by daily soil cover, and other waste parcels with little or no free-flowing oil. For these reasons, the flow and transport in the vadose and saturated zones are considered significant in the dissolved phase only, and the EPACMTP model (USEPA, 1996c) is appropriate for the modeling analyses.

In the ensuing subsections, details of the following are presented:

- The EPACMTP model;
- Source-term modeling in the EPACMTP model;
- Processes in subsurface fate and transport in the EPACMTP model; and
- Monte Carlo simulation with a regional site-based approach using EPACMTP.

2.1.1 EPACMTP Model

EPACMTP (EPA's Composite Model for Leachate Migration with Transformation Products) (USEPA, 1995 a, b, c, d) is a computer simulation model for modeling the subsurface fate and transport of contaminants leaching from a land disposal site, *e.g.*, landfill, surface impoundment, waste pile, or land application unit. Fate and transport processes accounted for in the model are: advection, hydrodynamic dispersion, linear or nonlinear sorption, and chained-decay reactions. In cases where degradation of a waste constituent yields daughter products that

are also of concern, EPACMTP has the capability to simulate the fate and transport of up to six (grand-)daughter products. The composite model consists of a one-dimensional module that simulates infiltration and dissolved constituent transport through the unsaturated zone, and which is coupled to a three-dimensional saturated zone flow and transport module. The saturated zone flow module accounts for the processes affecting the magnitude and direction of groundwater flow such as leaching from

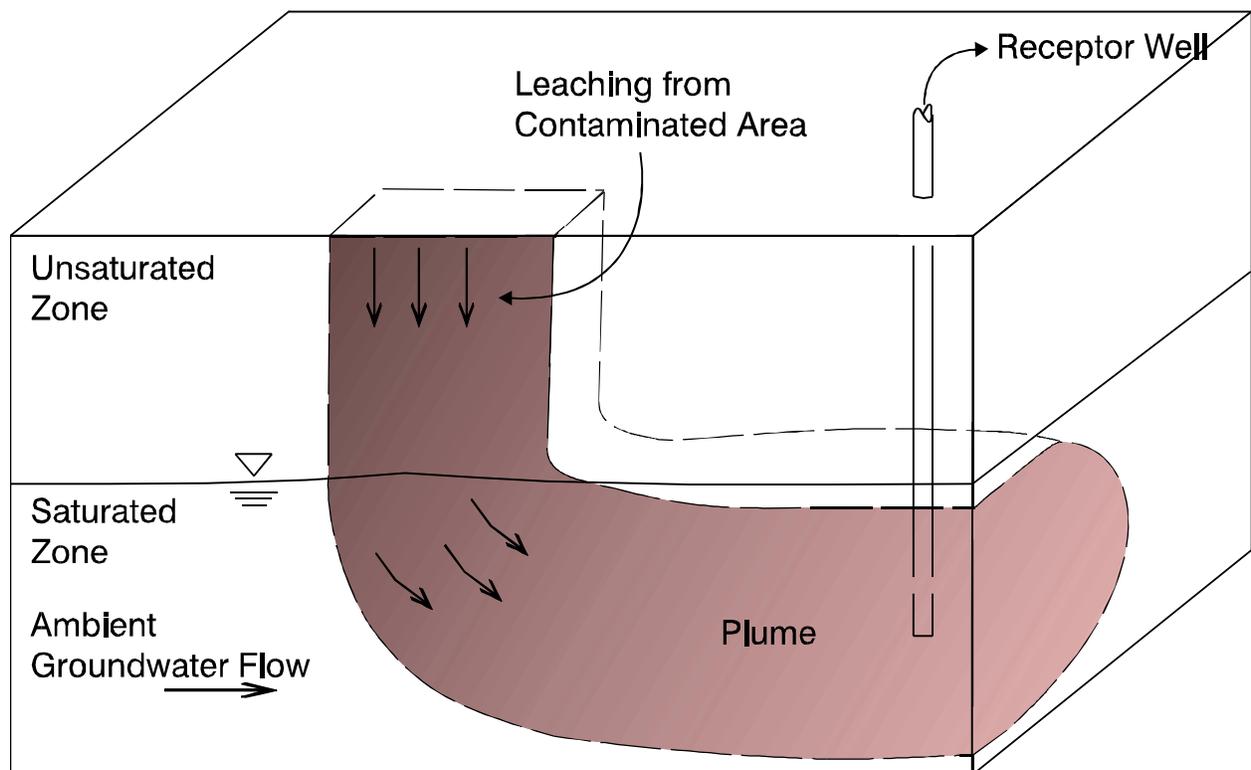


Figure 2.1 Schematic View of the Modeled Subsurface Pathway

the waste management unit and regional recharge. The saturated zone transport module accounts for three-dimensional advection and dispersion, chained-decay reactions involving up to seven different chemical species (*i.e.*, parent compound and up to six daughter products), and linear or nonlinear equilibrium sorption. EPACMTP simulates steady state flow in both the unsaturated zone and the saturated zone; contaminant transport can be either steady state or transient. The steady state modeling option is used for continuous source modeling scenarios; the transient modeling option is used for finite source modeling scenarios with optional accounting for source depletion. EPACMTP predicts the contaminant concentration arriving at a down gradient groundwater receptor well. This can be either a steady state concentration value, corresponding to the continuous source scenario, or a time dependent concentration, corresponding to the finite source scenario. In the latter case, the model can calculate either the peak concentration arriving at the well, or a time averaged concentration, corresponding to a specified exposure duration, *e.g.*, a nine year average residence time. EPACMTP has the capability to perform Monte Carlo simulations to account for parametric uncertainty or variability. The flow and transport simulation modules of EPACMTP are linked to a Monte Carlo driver which permits a probabilistic evaluation of uncertainty in model input parameters, as described by specified (joint) probability distributions.

EPACMTP replaces the EPA's Composite Model for Landfills (EPACML) which was used in 1990 Toxicity Characteristic (TC) Rule (55FR11798). EPACMTP extends the capabilities of the earlier EPACML model. The enhanced capabilities include accounting for three-dimensional groundwater flow, the finite source and transformation products options, and capability to simulate metals transport with nonlinear sorption isotherms through linkage with the MINTEQ geochemical speciation model. EPACMTP has been published in an international refereed journal (Kool, Huyakorn, Sudicky, and Saleem, 1994). It also has been extensively reviewed. The SAB (USEPA's Science Advisory Board) commended the Agency for its significant improvements to the model. They also stated that it represents the state of the art for such analyses. However, they also encouraged additional validation studies, especially for the metals (USEPA, 1995c).

2.1.2 Contaminant Source Term Modeling

The release of contaminants into the subsurface constitutes the source term for the fate and transport model. The conceptual differences between a landfill and other waste management scenarios are reflected in how the model source term is characterized in different scenarios. The modeled subsurface fate and transport processes are the same for each waste management scenario. The contaminant source term for the EPACMTP fate and transport model is defined in terms of four primary parameters: (1) area of the waste unit, (2) leachate flux rate emanating from the waste unit, (3) leachate concentration of each constituent, and (4) duration of the constituent release. Information on the on-site waste unit areas was obtained from responses to the 1992 RCRA §3007 Questionnaire of the Petroleum Refining Industry (1992 RCRA §3007 Survey Database). The off-site unit areas were obtained from the USEPA Office of Solid Waste (OSW) Industrial Subtitle D Waste Management Facility Database (USEPA, 1996c; USEPA, 1997d). Leachate flux and contaminant release rates were determined as a function of the design and operational characteristics of the different waste management and wastestream characteristics

(waste quantities and waste constituent concentrations). The modeling approach related to the design and operational characteristics for landfills is as follows:

The modeled landfill is a Subtitle D industrial landfill which has an earthen cover, but no liner or leachate collection system. The leachate flux through the landfill is the result of infiltration of ambient precipitation through the landfill cover. Leachate flux rates used in the analysis were determined using the HELP model (USEPA, 1996c and 197d). The net infiltration rate is calculated using a water balance approach, which considers, among other factors, precipitation, evapotranspiration, and surface run-off. The model was used to calculate landfill infiltration rates for a representative Subtitle D landfill with 2-foot earthen cover, using climatic data from 97 climatic stations located throughout the United States (USEPA, 1996c and 1997d). For the groundwater pathway analysis it is assumed that the landfill has a 20 year operational life, and that there are no losses due to volatilization while the landfill is in operation or due to mechanisms other than leaching after the landfill has been closed. The total amount of constituent in the landfill which is available for leaching is therefore given by the product of annual waste quantity disposed and constituent concentration in the waste, times 20 years. The 20-year time frame was chosen as representative of the average operational life for a typical landfill where petroleum wastes are disposed. This time period is based on a median active life of petroleum waste landfills (USEPA, 1997b) and on the average active lifetime of Municipal Subtitle D landfills (USEPA, 1988). In the groundwater pathway analysis it is assumed that each constituent initially leaches at a concentration given by the TCLP concentration of that constituent in the wastestream being analyzed, with a gradual decrease in leaching concentration due to source depletion (USEPA, 1996d). Assuming that all of the constituent mass in the waste may eventually leach out, with linear equilibrium partitioning of the constituent into the aqueous phase, the leaching concentration follows an exponential decrease with time according to (USEPA, 1996d):

$$C_L(t) = C_L^0 e^{-\frac{I t}{d F_w P_w \frac{C_w}{C_L}}} \quad (1)$$

where:

- $C_L(t)$ = Leachate concentration (mg/L) of a constituent at time t
- C_L^0 = Initial leachate concentration (mg/L) of a constituent
- C_w = Total concentration (mg/kg) of the constituent in the waste
- I = Infiltration rate (m/y)
- d = Depth of waste unit
- F_w = Volume fraction of waste in the waste unit
- P_w = Density of the waste (kg/L)
- t = Time (y)

The volume fraction of waste in the unit, F_w , is given by 20 times annual waste volume divided by the total volume of the waste unit.

2.1.3 Processes in Subsurface Fate and Transport Modeling

The primary transport mechanisms in the subsurface are downward movement along with infiltrating water in the vadose zone, and movement along with (ambient) groundwater flow in the saturated zone. The advective movement in the unsaturated zone is one-dimensional, while the saturated zone module accounts for three-dimensional flow and transport. The model also considers mixing due to hydrodynamic dispersion in both the unsaturated and saturated zones. In the vadose zone, the flow is gravity-driven and prevails in the vertically downward direction in the vadose zone. Therefore, it is reasonable to model flow in the unsaturated zone as one dimensional in the vertical direction. It is also assumed that transverse dispersion (both mechanical dispersion and molecular diffusion) is negligible in the vadose zone. This assumption is based on the fact that lateral migration due to transverse dispersion is negligibly small compared with the horizontal dimensions of waste management units. In addition, this assumption is conservative because it allows the leading front of chemicals to arrive at the water table relatively sooner, and in the case of finite source, with greater peak concentration.

Chemical constituents in the subsurface may be subject to a variety of bio-chemical transformation processes. EPACMTP accounts for transformations due to hydrolysis with first-order reaction kinetics. For those waste constituents which hydrolyze into toxic daughter products, the model also accounts for the formation and subsequent fate and transport of hydrolysis products. However, none of the organic constituents considered in the present analysis are subject to breakdown by hydrolysis (Kollig et al., 1993; Washington, 1995).

Biodegradation may be a significant removal process for some of the constituents considered in the analysis. However, biodegradation data obtained with methods that are consistent with the USEPA's protocol for measuring biodegradation rates exhibit inconsistent behaviors (long lag time, short lag time, no degradation, etc.). Furthermore, the data are presently not adequately available so as to be implemented in the subsurface fate and transport model. A preliminary evaluation of all available data and the documented anaerobic biodegradation studies of benzene suggest that in-situ anaerobic biodegradation of benzene rates may be strongly dependent on site-specific conditions. These degradation-controlling site-specific conditions are currently not exactly known, and may be time-dependent. In addition, several field studies and laboratory studies have revealed that benzene may be recalcitrant to anaerobic biodegradation (Krumholz et al., 1996; Salinitro, 1993). In the report by Krumholz et al. (1996), 12 of the total of 15 field studies showed no biodegradation. Salinitro (1993) reported 2 of the total of 26 field studies without biodegradation. The necessary conditions for anaerobic benzene biodegradation are poorly understood. The absence of biodegradation could be due to the presence of competing substrates, such as, toluene, xylenes, and ethylbenzene, as well as inadequate geochemical conditions and lack of proper electron acceptors (nitrate, sulfate, iron, etc.). Therefore, because of the lack of information to correlate site-specific controlling factors to biodegradation, the limited number of field data, and the field and laboratory evidence that benzene tends to be recalcitrant to anaerobic biodegradation, biodegradation of benzene is considered to be negligible in the current groundwater pathway analysis.

The groundwater pathway analysis accounts for (linear) equilibrium sorption of waste constituents in the soil and aquifer. For organic constituents the partition coefficient (K) is calculated as the product of the constituent-specific organic carbon partition coefficient (K_{oc}), and the fraction organic carbon (f_{oc}) in the soil and aquifer.

Therefore, for a number of the metals analyzed (*e.g.*, lead, chromium, mercury) the isotherms are highly nonlinear which adds considerably to the computational effort of the model simulations. For metals, the sorption isotherms used in the Monte Carlo analyses were determined using MINTEQA2 geochemical speciation model (USEPA, 1996e). These isotherms reflect varying subsurface geochemical conditions defined by four major geochemical parameters (pH, leachate organic matter, natural organic matter, and iron hydroxide absorbent). The values assigned to each of these parameters are allowed to vary over three ranges (low, medium, and high) to produce sorption isotherms representative of a wide range of subsurface geochemical conditions. In the Monte Carlo analyses of metals, the sorption isotherms used were based on the distributions of the four geochemical parameters.

For bounding and two high-end parameters analyses, partition coefficients (K_d s) were calculated based on metal-specific empirical relationships between K_d and pH. The median pH values from the nationwide distribution was used to calculate K_d s for metals.

2.1.4 Regional Site-Based Modeling Approach

The regional, site-based, Monte Carlo approach option available in EPACMTP was implemented for the Petroleum Refining groundwater pathway analysis. In general, the receptor well concentration downgradient from a waste management site is a function of the following: source (*e.g.*, area, volume), design (*e.g.*, cover, liner), climate (*e.g.* precipitation, evapotranspiration), hydrogeology (*e.g.*, depth to groundwater, aquifer thickness, hydraulic conductivity, hydraulic gradient), receptor location (*e.g.* depth and downgradient distance and chemical specific properties (*e.g.* retardation and decay). The location, area and volume of the waste management units used in the site-based approach represent the unit specific characteristics of an actual waste management site; the climatic parameters (*e.g.* precipitation, evaporation) used for a given waste management unit are given by the climatic characteristics in the region in the vicinity of the unit. Using the source characteristics of actual waste management units where possible and the hydrogeologic characteristics based on actual hydrogeologic information insures that the within-site dependence between source terms and between hydrogeologic characteristics is maintained.

The regional site-based approach attempts to approximate the ideal situation where a probability sample of sites has a complete description of the characteristics needed to estimate the site's receptor well concentration. This approach uses the site location to place the site within one of 13 hydrogeologic regions, (USEPA, 1996c; USEPA, 1997d) to define the site's hydrogeologic parameters and within one of 97 climatic regions (USEPA, 1996c; USEPA 1997d), thereby defining the site's climatic parameters.

The following step-by-step procedure is used to implement the regional site-based approach in EPACMTP (these steps are discussed in detail for the present petroleum refining groundwater pathway analysis in Section 4 of this document):

Step 1: Waste Site Selection. This step involves selecting a site at random, from the list of waste management facilities. The facility information includes location and for on-site landfills, area and volume. For off-site

landfills, an area and volume are selected at random from the OSW Industrial Subtitle D Waste Management Facility Database (USEPA, 1996c; USEPA, 1997d).

Step 2: Generate Recharge and Infiltration for Selected Waste Site.

Given the waste site's location, the climatic region in which the site is located can be identified and the corresponding precipitation and evaporation values specified. The precipitation and evaporation values for the site are used together with the soil (and cover type for landfills) of the unit to derive the recharge and infiltration values of the site. The soil and landfill cover types used at the sites are generated from a national joint probability distribution described in USEPA 1996c and 1997d.

Step 3: Generate Hydrogeologic Variables for Selected Site in OSW Industrial Subtitle D Facility Database.

Given the facility location, the USGS groundwater resources inventory maps (USGS, 1985) are used to identify the aquifer type for the site. The hydrogeologic parameters for the site are determined by using the characteristics of a groundwater investigation site selected at random from the Hydrogeologic Database (API, 1989; Newell et al., 1990) for the corresponding hydrogeologic environment. If the selected groundwater parameter set is missing any values, a joint distribution of the parameters derived for each region is used to fill in the missing values.

Step 4: Generate Remaining Parameters for Selected Waste Site.

The remaining parameters for the waste site (e.g. x, y, and z coordinates of the receptor well) are generated by using nationwide distributions based on data compiled by the USEPA from across the USA (USEPA, 1997d). The median and high end values of x, y, and z are given in Appendix C with the Two high-end parameter sensitivity analysis input parameters.

Step 5: Calculate the Receptor Well Concentration Value for Selected Waste Site.

Given the site data, hydrogeologic characteristics, and receptor well location generated in the previous four steps, and the chemical-specific characteristics, the groundwater transport model is used to compute the receptor well concentration value for the site.

Step 6: Repeat Steps 1-5 N (10,000) Times (N is a predetermined number of Monte Carlo iterations or parameter realizations based on a convergence test) and Estimate the National Distribution of Receptor Well Concentrations.

After Step 5, the receptor well concentration value for a specific realization is obtained. The process is repeated to yield N (10,000) values which represent the nationwide distribution of drinking water exposure concentrations. Given this distribution and the drinking water standards for the waste, the groundwater exposure risk can be

calculated for any level of protection (*e.g.* 85-th percentile, 90-th percentile, 95-th percentile).

A flow chart of the above procedure is shown in Figure 2.2.

2.2 MODELING SCENARIOS AND INPUT DATA

All of the modeling scenarios performed for the Petroleum Refining Groundwater Pathway Analysis, including the 1995 analyses are summarized in Table 2.1. Complete descriptions of each current analysis are presented in Sections 3 and 4 and the results are presented in Section 5. The 1995 Petroleum Refining Groundwater Pathway Analysis Background Document includes complete descriptions of the previous analyses conducted in 1995 (USEPA, 1995d).

Additional modeling analyses have been performed to further enhance the results of the 1995 Petroleum Refining Groundwater Pathway Analysis. The analyses included additional deterministic high-end analyses (Section 3) and several Monte Carlo scenarios (Section 4). Prior to performing the Monte Carlo simulations, waste constituents were screened based on the 1995 bounding analysis (USEPA, 1995d). Then, Monte Carlo analyses were performed for waste constituents not eliminated in the bounding analysis. Both the deterministic and Monte Carlo analyses include both single-wastestream baseline scenarios and multi-wastestream codisposal scenarios. For the multi-wastestream codisposal scenario, discussed further in Section 2.2.3, total codisposed 20-year petroleum waste quantities at each landfill were modeled based on the median active lifetime of 20 years for Subtitle D landfills (USEPA, 1997b). Volume weighted waste and leachate concentrations were calculated for both benzene and arsenic to estimate a representative effective leachate rate and an effective waste concentration for the landfills. Volume weighting of the input parameters was determined to be the most representative method for combining the concentration data. Other additional modeling considerations included a contingent CSO management scenario (Section 2.2.4) and TC Rule limitations on waste leachate concentrations (in all scenarios; Section 2.2.5). The source term input parameters (*e.g.* waste quantity, landfill size, waste concentration, and leachate concentration) used for modeling were obtained from responses to the RCRA §3007 Survey (1992 RCRA §3007 Survey Database) and the USEPA Record Sampling (USEPA, 1995a) and are provided in Appendices A and B. The parameters obtained from the OSW hydrogeological modeling database are listed in the EPACMP Background Document (USEPA, 1996c).

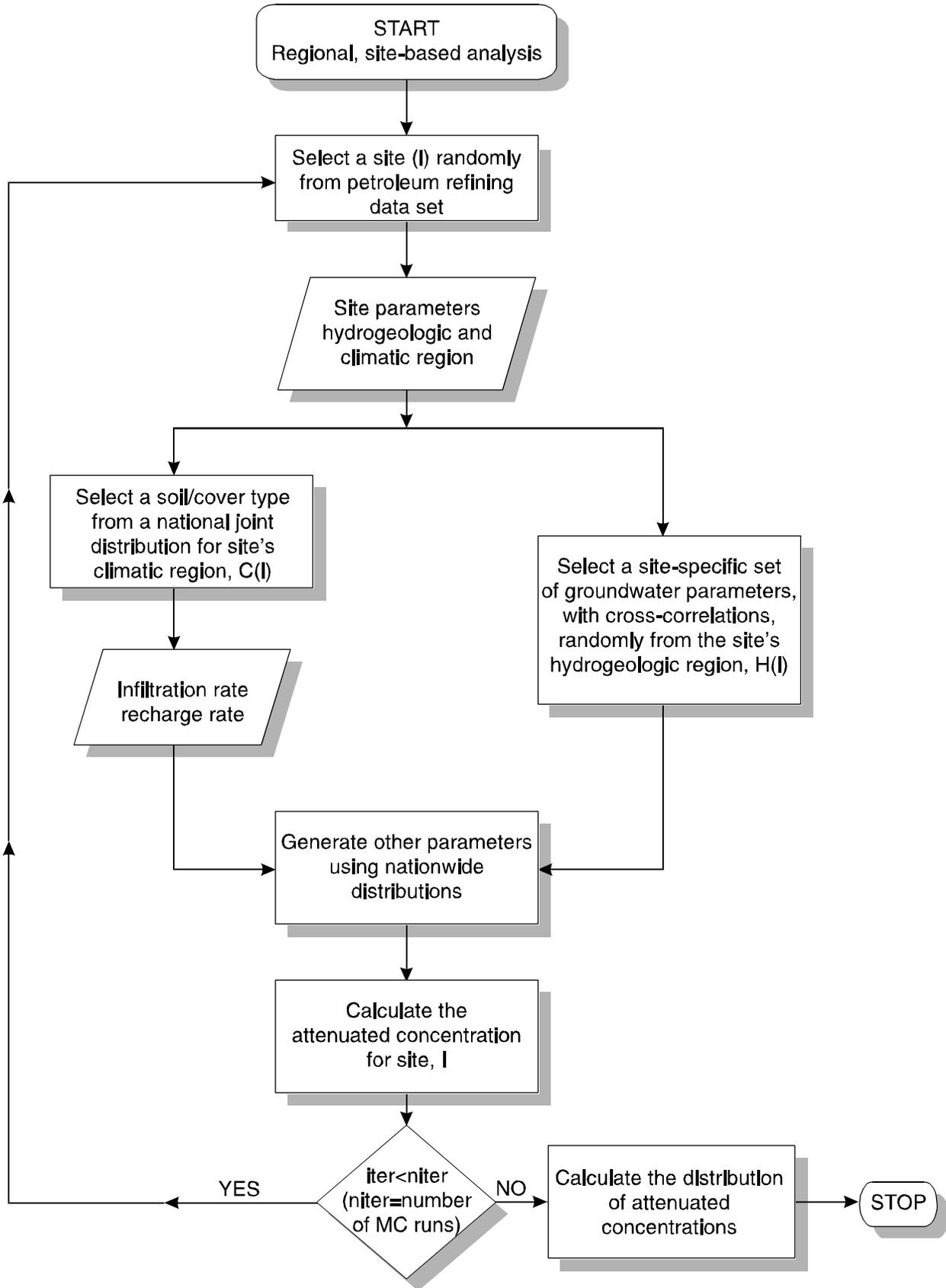


Figure 2.2 Flowchart of EPACMTP for the Regional Site-Based Monte Carlo Approach.

Table 2.1 Petroleum Refining Modeling Analyses Performed in 1995 and 1996

Year	Analysis	Description
Previous	Sensitivity	See 1995 Background Document (USEPA, 1995d)
Previous	Bounding Analysis	See 1995 Background Document (USEPA, 1995d)
Previous	High-End Parameter Analysis	See 1995 Background Document (USEPA, 1995d)
Previous	Central Tendency	See 1995 Background Document (USEPA, 1995d)
Previous	Biodegradation Sensitivity Analysis	See 1995 Background Document (USEPA, 1995d)
Previous	Multiphase Transport	See 1995 Background Document (USEPA, 1995d)
Current	Revised Two High-End Parameters Analyses for Sulfur Complex Sludge, and Unleaded Gasoline Tank Sludge.	Used actual 1992 waste volumes. Direct Risk, Total Risk and TC rule limited results reported for wastestreams not considered in sensitivity analyses.
Current	Contingent CSO - Two High-End Parameter	All quantities of CSO Sludge generated in 1992 were modeled with the exclusion of wastes recycled on-site in refinery processes, waste transferred for use as fuel, and waste used in an on-site industrial furnace.
Current	Codisposal - Two High-End Parameters Analyses	Benzene and Arsenic transport modeled using volume weighted average concentrations, 90-th percentile areas, and net 50-th percentile waste volumes. Hydrotreating and hydrorefining were excluded and analyses were performed both with and without hydrocracking catalyst.
Current	Sensitivity Analysis for Hydrotreating and Hydrorefining Catalysts, HF Alkylation Sludge, Crude Oil Tank Sludge CSO Sludge (contingent and non-contingent), and Off-Spec. Products and Fines	Deterministic sensitivity analyses using data statistics to determine two high-end parameters.
Current	Baseline - Monte Carlo	All wastes stream constituents not bounding out in 1995 Bounding analysis. For all Wastestreams except hydrotreating and hydrorefining, all Subtitle D wastes were modeled and correlated to landfill locations. For hydrotreating and hydrorefining, all non-Subtitle C waste quantities were correlated to landfill locations and one landfill was selected for each realization.
Current	Contingent CSO - Monte Carlo	All quantities of CSO Sludge generated in 1992 were modeled with the exclusion of wastes recycled on-site in refinery processes, waste transferred for use as fuel, and waste used in an on-site industrial furnace.

Year	Analysis	Description
Current	Codisposal - Monte Carlo	Benzene and Arsenic transport modeled for on and off-site codisposal considering all petroleum landfills in Monte Carlo simulation. Hydrotreating and hydrorefining catalysts excluded. Considered both with and without hydrocracking catalyst and TC Rule limit.

The following are described in subsections:

- Data sources;
- Hydroprocessing waste data;
- Multi Waste Stream Codisposal;
- Contingent CSO sludge management data; and
- Maximum TCLP data for TC-Rule constrained waste management.
- Off-Spec Products and Fines TCLP Data

2.2.1 Data Sources

Model input data pertaining to waste quantities and density, waste management scenarios and waste unit information (*e.g.*, area, volume; Appendix B) based on responses to the RCRA §3007 Survey of the Petroleum Refining Industry (1992 RCRA §3007; USEPA, 1995a). Waste quantities managed by petroleum refineries in on- and off-site landfills in 1992 and on-site waste unit information were provided in responses to the survey. For all wastestreams except hydrotreating catalysts, hydrorefining catalysts, and clarified slurry oil sediment (contingent management) the modeled waste quantities were based on annual 1992 Subtitle D landfill management (see sections 2.2.2 and 2.2.4 below for a discussion of the modeled waste quantities for those waste streams).

For waste managed in off-site landfills the following information provided in the RCRA §3007 Survey Database was used for the modeling analysis: the off-site landfill location, waste quantity managed in the off-site landfill in 1992 and a limited number of waste density values. For waste managed in on-site landfills, waste unit area and waste height were also available in addition to the 1992 waste quantity and density values (1992 RCRA §3007). Again, off-site waste unit areas and depths were obtained from the OSW database of industrial Subtitle D landfills (USEPA 1996c; USEPA, 1997d). Waste density values were available for only a limited number of locations and since density is relatively non-varying compared to other parameters in the analysis, average on-site and average off-site density values were used in the analysis. On-site waste unit information, 20-year waste quantity, and average on-site density values are listed for each modeled wastestream in Table B.1, Appendix B. Off-site 20-year waste volumes and average off-site densities are listed in Table B.2, Appendix B.

Information on wastestream composition, including waste concentrations and TCLP leaching concentrations, were obtained from record sampling data collected by the USEPA from each of the wastestreams investigated, as part of the Listing Determination (USEPA, 1995a). Leachate concentrations for all constituents in landfills are presented in Appendix A.

The 1992 RCRA §3007 Survey responses provided limited data on hydrogeological setting at the waste management unit locations (1992 RCRA §3007). Available information for on-site waste

management units was restricted to waste unit size (area and depth), geographical location of the unit, depth to groundwater and distance to the nearest drinking water well. However, the depth to groundwater and nearest drinking water well distance data available in the RCRA §3007 Database were not used in this modeling analysis because the hydrogeological data set was not complete. Well distances were not reported for approximately one-half of the refinery sites and the well distances that were provided in the §3007 responses were much larger than the median value in the OSW Industrial Subtitle D Waste Management Facility Database (*e.g.* an average of 2,600 meters versus a median value of 430 meters in the OSW database; 1992 RCRA §3007; USEPA, 1997d). In a number of cases the unsaturated zone and saturated zone thicknesses were given as a range of values indicating that the value was estimated rather than directly measured (*e.g.* 0 - 40 feet). For these reasons the OSW Database (USEPA, 1997d) and API Hydrogeological Database (API, 1989; Newell et al., 1990; USEPA, 1997d) were deemed to be more reliable sources of data for the hydrogeological parameters. The hydrogeological parameters from the API database are not selected from arbitrary nationwide distributions rather they are site based and correlated to the aquifer type located at the site.

For off-site units, the survey provided only the waste management unit location. The Monte Carlo OSW hydrogeological modeling database which is incorporated into EPACMTP (USEPA, 1996c and 1997d) was therefore used to obtain values for missing parameters. Data on constituent-specific k_{oc} values, as well as metals sorption isotherms, were also obtained from the OSW data base (USEPA, 1996c and 1997d).

2.2.2 Hydroprocessing Waste

Information provided by catalyst reclaimers indicates that because of the depressed metals markets, landfilling of catalysts is becoming significantly more cost-effective than reclamation. EPA predicts that if the risk assessment modeling shows no basis for listing hydroprocessing catalysts, landfilling will continue to increase in the future. Because of this trend, the Agency made the decision to also perform the modeling analysis using the entire distribution of waste volumes reported in 1992 (excluding volumes reported to go to Subtitle C management) for hydroprocessing wastes (hydrotreating, hydrorefining, and SCOT catalysts) rather than just the quantities reported to be managed in Subtitle D units (USEPA, 1995a). The total quantity of hydroprocessing waste generated by each refinery was compiled including recycled, reclaimed and stored waste (Subtitle C landfill waste quantities were excluded). For the on-site landfill analysis, each refinery's total hydroprocessing waste was modeled as disposed in the on-site landfill. Only refineries reporting on-site landfills were included in the data set to be modeled. In the case of off-site landfills, each refinery's total hydroprocessing waste was modeled as disposed at either the nearest off-site landfill or at an off-site landfill known to have received waste from that refinery based on other wastestream data. The 20-year non-Subtitle C landfill waste quantities modeled for hydroprocessing wastes are listed in Tables B.1 and B.2, Appendix B (1992 RCRA §3007 Database).

2.2.3 Multi Waste Stream Codisposal

In response to comments, the Agency has evaluated the potential groundwater exposures due to the impact of codisposal of multiple wastestreams. For the multi-wastestream codisposal scenario, total codisposed 20-year petroleum waste quantities at each landfill were modeled based on the median active lifetime of 20 years for Subtitle D landfills (USEPA, 1997b). Volume weighted waste and leachate concentrations were calculated for both benzene and arsenic to estimate a representative effective leachate rate and an effective waste concentration for the landfills. Volume weighting of the concentration data was determined to be the most representative method for combining the concentration data of the individual codisposed wastestreams. The rationale is presented below.

- To determine an effective constituent-specific leaching rate for codisposed wastestreams, it was conservatively assumed that the wastestreams codisposed in a landfill are configured in such a way that each wastestream occupies the landfill depth which is assumed to be uniform throughout the landfill, but occupies an area that is determined by the ratio of wastestream volume to total landfill volume. This configuration allows leachates with relatively high leaching concentrations to migrate unimpeded chemically by other wastestreams and/or wastestream solid matrices. With this configuration, the relative contribution of a wastestream to the effective leaching rate of the codisposed wastestreams at the base of a landfill is therefore dependent on the relative infiltration flux through the areal portion of the landfill attributed to that wastestream. The estimation of the effective leachate concentration of codisposed wastestreams is based on the consideration of conservation of the total leachate flux, thus:

$$\overline{C}_{Li} d F_h I \sum_{J=1}^n A_J = d F_h I \sum_{J=1}^n A_J C_{LJi} \quad \text{.....(2)}$$

Or

$$\overline{C}_{Li} = \frac{\sum_{J=1}^n V_J C_{LJi}}{\sum_{J=1}^n V_J} \quad \text{.....(3)}$$

where

C_{LJi} = Leachate concentration for constituent i, wastestream J;

\overline{C}_{Li} = Effective leachate concentration for constituent i;

d = Total landfill depth

F_h = Waste fraction (waste volume/landfill volume)

I = Infiltration rate

A_J = Areal coverage of wastestream J

V_J = Volume of wastestream J = $A_J d F_h$

n = Number of wastestreams.

Note that d and F_h are not related to the flux calculation. They are added to both sides of equation (2) to obtain the expression in equation (3).

- Following the above wastestream configuration assumption, the effective constituent specific waste concentration may be determined based on the mass conservation consideration:

$$\overline{C_{wi}} = \frac{\sum_{J=1}^n \frac{\rho_{sJ}(1-\theta_J)}{\overline{\rho_s(1-\theta)}} \frac{V_J}{\sum_{J=1}^n V_J} C_{wJi}}{\dots\dots\dots(4)}$$

where

C_{wJi} = Leachate concentration for constituent i, wastestream J;

$\overline{C_{wJ}}$ = Effective leachate concentration for constituent i;

ρ_{sJ} = Density of dry waste solid of wastestream J

θ_J = Porosity of wastestream J

n = Number of wastestreams.

$\overline{\rho_s(1-\theta)}$ = mean of $(1-\theta_J)\rho_{sJ}$

The waste solid density and porosity are not exactly known; however, the product $(1-\theta_J)\rho_{sJ}$ is very close to the reported wet waste density which does not vary significantly. Therefore, it may be inferred that the density- and porosity-related ratio is close to unity whereas the volume ratio may vary over a few orders of magnitude. Based on this reasoning, the effective waste concentration may be approximated by:

$$\overline{C_{wi}} = \frac{\sum_{J=1}^n V_J C_{wJi}}{\sum_{J=1}^n V_J} \dots\dots\dots(5)$$

Two high-end parameter (Section 3) and Monte Carlo simulations (Section 4) were performed for the Codisposal scenario. The results are presented in Section 5.

2.2.4 Contingent CSO Sludge Management

The disposal of Clarified Slurry Oil (CSO) Sludge was evaluated assuming two potential disposal scenarios: (1) only waste quantities disposed in Subtitle D Landfills in 1992 were modeled and (2) all quantities of CSO Sludge generated in 1992 were modeled with the exclusion of waste recycled on-site in refinery process units, waste transferred for use as fuel, and waste used in an on-site industrial furnace. The assumption is that under contingent management refinery wastes going to other non-hazardous disposal scenarios (such as land application units) would become hazardous and that therefore, facilities would choose to landfill those wastes. For the on-site landfill analysis, each refinery's total CSO sludge waste was modeled as disposed in the on-site landfill. Only refineries reporting on-site landfills were included in the on-site disposal scenario. In the case of off-site landfills, each refinery's total CSO sludge waste was modeled as disposed at either the nearest off-site landfill or at an off-site landfill known to have received waste from that refinery (based on other wastestream data). In some cases other wastestream information indicated that offsite landfills received waste from more than one refinery; and in some cases, the data indicated that several refineries sent their waste to more than one off-site landfill. The modeling scenario was constructed to reflect these possibilities; therefore, the Contingent CSO Sludge quantities presented in Table 2.2a (off-site volumes) unlike the on-site quantities, do not have a one-to-one relationship with the original refinery Contingent CSO data. Furthermore, refineries included in the on-site landfill disposal scenario were also included in the off-site disposal scenario under the assumption that refineries could elect to either dispose of their waste on- or off-site. The 20-year non-recycled/non-reused site-specific waste quantities modeled for CSO sludge are listed in Tables 2.2a and 2.2b for off-site and on-site disposal, respectively. Two high-end parameter data for modeling Contingent Management of CSO Sludge are listed in Appendix C with the results of the sensitivity analyses for contingent CSO Sludge.

Table 2.2(a) Off-Site CSO Contingent Management Data
(1992 RCRA §3007 Database)

Monte Carlo Site Specific Data:	
Off-Site Landfill Code Number*	20-Year Waste Volume (m³)
1	4,176
2	1,312
3	223
6	4,243
14	65
15	63,312

Monte Carlo Site Specific Data:	
Off-Site Landfill Code Number*	20-Year Waste Volume (m³)
16	1,892
18	13,514
19	2,558
21	1,351
22	2,270
23	42,473
25	39,324
26	2,365
35	236
37	8,851
38	81,135
39	811
40	14
42	3,797
45	8,851
46	77,378
47	8,365
50	2,027
52	5,647
53	3,432
61	13,514
63	2,365
67	85,622
69	42,473

Table 2.2(b) On-Site CSO Contingent Management Data
(1992 RCRA §3007 Database)

Monte Carlo Site Specific Data:	
On-Site Landfill Code Number*	20-Year Waste Volume (m³)
1	3,378
3	8,365
5	2,270
11	1,404
12	811
13	1,751

Monte Carlo Site Specific Data:	
On-Site Landfill Code Number*	20-Year Waste Volume (m³)
18	54
20	4,486
21	14

Note * The landfill code number is used to uniquely identify a landfill in the current analysis. Owing to the CH restrictions, details relating these landfills cannot be disclosed.

2.2.5 TC Rule Constrained Maximum TCLP

The Toxicity Characteristic (TC) Regulation requires all waste shown to exceed a specified leaching (TCLP) concentration to be managed as hazardous waste. Therefore, all petroleum waste shown to exceed the TC concentration limit will not legally be managed in Subtitle D landfills. As a consequence the TC Rule sets an upper limit on the leaching concentration for waste going to Subtitle D landfills. To reflect that maximum leachate concentration (TCLP) limitation, the baseline and codisposal groundwater pathway modeling analyses were also conducted with an upper limit set on the source leaching concentration for benzene and arsenic. The upper concentration limits in the modeling runs were set to the TC Rule value for the constituent, 0.5 mg/l for benzene and 5.0 mg/l for arsenic. TCLP data values less than the TC Rule limit were not changed. The “TC Rule Constrained” or “Capped” results are presented in Section 5.

TCLP data for all modeled constituents are listed in Table A.1, Appendix A.

2.2.6 Off-Spec Products and Fines TCLP Data

The Off-Spec Products and Fines TCLP data for benz(a)anthracene and benzo(a)pyrene consisted of one “J” value and five non-detect readings for benz(a)anthracene and four non-detect readings for benzo(a)pyrene. A “J” value is defined as an estimated concentration in the case where mass spectral data indicate the presence of a compound that meets the criteria for which the result is less than the laboratory quantitation limit, but greater than zero (EPA, 1995a). The estimated “J” values were 0.013 mg/L for benz(a)anthracene and 0.01 mg/L for benzo(a)pyrene in one sample and the ½ quantitation limit reported for the non-detect samples was .05 mg/L. Because of the large uncertainty in the TCLP data for these compounds, the high-end parameter and Monte Carlo analyses were conducted with the data treated in several different ways. The Monte Carlo Analysis results and the previous (1995) Two High-End Parameter Analyses for benzo(a)pyrene showed insignificant risk; therefore, additional Monte Carlo and Two High-End Parameter analyses were not performed for this chemical. Additional analyses were performed for benz(a)anthracene only.

Benz(a)anthracene and benzo(a)pyrene have strong tendencies to readily get sorbed to the soils because they have high organic carbon partition coefficients ($K_{oc}=219,000$ ml/g and $K_{oc}=631,000$ ml/g, respectively). These high K_{oc} values tend to retard their movement in soils.

significantly. Therefore, they tend not to show up in ground water or have very low concentrations in groundwater.

2.3.5.1 Monte Carlo Distributed Data

For the Monte Carlo Analysis, distributions consisting of individual data values are typically used. However, the TCLP data were used in two different ways for these wastes.

1. The “J” value was assumed to be the only reliable data point and it was used to represent a fixed value for the TCLP concentration of benz(a)anthracene. Other parameters were varied as before in the Monte Carlo Analyses.
2. The “J” value of 13 ppb was used with the five ½ quantitation limit values of 50 ppb to construct a leachate distribution.

2.3.5.2 High-End Parameter Data

The TCLP data were handled in two different ways for conducting the high-end parameter sensitivity analysis:

1. In the first case the “J” value was assumed to be the only reliable data point and it was assumed to represent the mean or expected value of the TCLP for benz(a)anthracene in off-spec products and fines. The sensitivity analysis was therefore conducted to determine the two high-end parameters for off-spec products and fines.
2. In the second case the “J” value was assumed to be the maximum or high-end TCIP value and the sensitivity analysis was therefore conducted to determine one other high-end parameter for the two high-end parameter analyses.

The results for the Off-Spec Products and Fines analysis are presented in Table 5.8.

3.0 DETERMINISTIC GROUNDWATER PATHWAY ANALYSES

3.1 BOUNDING ANALYSES

A bounding analysis was performed in the 1995 groundwater pathway modeling analysis to eliminate from further consideration those wastestreams and/or waste constituents which even under worst-case conditions do not show risk or HBN exceedance in groundwater (USEPA 1995d). According to EPA's Guidance on Risk Characterization (USEPA, 1992), bounding estimates are intended to purposely overestimate the exposure or dose in an actual population for the purpose of developing a statement that, the risk is "not greater than the results of the analysis". Therefore those constituents not posing risk in the bounding analysis can be eliminated from further consideration.

The bounding analysis consisted of deterministic EPACMTP groundwater transport runs with sensitive modeling parameters set to high end values and the remaining parameters set to median values. Assignment of parameters in the bounding analysis was as follows: the leachate concentration of each waste constituent was set to its maximum TCLP value; the waste unit area, infiltration rate, waste quantity, landfill waste fraction and waste concentration were set to their 90-th percentile values, and the receptor well was placed on the plume centerline, at the 10-th percentile of the down gradient distance and depth. Other parameters were set to their median values. In addition, the source depletion option was not used in the bounding analysis. Instead, the release of the waste constituents were modeled as a pulse with constant concentration equal to the maximum measured TCLP for the waste constituent. The peak receptor well concentration was used for both carcinogenic and non-carcinogenic constituents.

Single-wastestream baseline analyses were then performed in the 1996 Monte Carlo Groundwater Pathway Analyses for all wastestreams and waste constituents that showed risk in the 1995 bounding analysis, *i.e.*, if the HBN of a waste constituent was exceeded in the bounding analysis, the single-wastestream baseline analysis was performed for that waste constituent (see Section 5.1).

Qualitative results of the bounding analysis are shown in Table 3.1. The quantitative results are given in detail in the 1995 Groundwater Pathway Background Document, Appendix C (USEPA, 1995d).

3.2 TWO HIGH-END PARAMETERS BASELINE ANALYSES

According to EPA's Guidance on Risk Characterization, "The high end risk descriptor is a plausible estimate of the individual risk for those persons at the upper end of the risk distribution. The intent of this descriptor is to convey an estimate of risk in the upper range of the distribution, but to avoid estimates which are beyond the true distribution. Conceptually, high end risk means risks above the 90-th percentile of the population distribution, but not higher than the individual in the population who has the highest risk" (USEPA, 1992). If limited information on the distribution of exposure or dose factors is available, the high-end can be estimated by identifying the most sensitive parameters and using maximum or near-maximum values for one

or two of these variables, leaving other at their mean values. (USEPA, 1992). In order to identify the most sensitive parameters for performing a high-end analysis in the 1995 groundwater pathway analysis, a sensitivity analysis was conducted on crude oil tank sediment (USEPA 1995d) to determine the most sensitive waste source and receptor well parameters. This analysis was conducted by individually varying the source and well location parameters from 50-th to 90-th percentile values, and ranking them in terms of the corresponding change in predicted receptor well concentration. For the subsequent 1995 two high-end parameter groundwater impact analysis, the two most sensitive parameters were set to their 90-th percentile values, while the remaining model parameters were all kept at median values.

Table 3.1 Summary of Previous Groundwater Pathway Analysis Results (USEPA, 1995d)

Wastestream		Bounding Analysis					High-End Analysis (2-parameter case)			
		Landfill		Land Treatment		Surface Impound	Landfill		Land Treatment	
		On-site	Off-site	On-site	Off-site		On-site	Off-site	On-site	Off-site
I.	Crude Oil Tank Sludge (oily)	-	+	+	+	-	-	+	0	0
	Crude Oil T. Sl. (de-oiled)	-	+	+	+	-	-	+	0	+
	Crude Oil T. Sl. (combined)	-	-	-	-	-	-	+	-	-
II.	CSO Sludge (oily)	+	+	+	+	-	+	+	0	0
	CSO Sludge (de-oiled)	+	+	-	+	-	0	+	-	0
	CSO Sludge (combined)	-	-	-	-	-	+	+	-	-
III.	Unleaded G. T. Sludge	+	+	+	+	-	+	+	0	0
IV.	Off-spec Product Fines	+	+	-	-	-	0	+	-	-
V.	Sulphur Complex Sludge	+	+	+	+	-	0	+	+	0
VI.	HF Alkylation Sludge		+	+	+	-	+	+	+	0
VII.	H2SO4 Alkylation Sludge	-	0	0	0	-	-	-	-	-
VIII.	Spent Caustic from L.Tr.	-	-	-	-	-	-	-	-	-
IX.	Claus Catalyst	0	0	-	-	-	-	-	-	-
X.	SCOT Catalyst	0	+	-	-	-	-	0	-	-
XI.	Hydrotreating Catalyst	+	+	-	-	-	+	+	-	-
XII.	Hydrotreating Catalyst	+	+	-	-	-	+	+	-	-
XIII.	Reforming Catalyst	-	-	-	-	-	-	-	-	-
XIV.	FCC Catalyst	+	-	-	-	-	0	-	-	-
XV.	FCC Fines	+	-	-	-	-	0	-	-	-
XVI.	H2SO4 Alkylation Catalyst	-	-	-	-	-	-	-	-	-
XVII.	FCC Catalyst & Fines	+	-	-	-	0	+	-	-	-

Legend: + = scenario modeled, showed positive exceedences; 0 = scenario modeled but did not show positive exceedences;
- = scenario not modeled.

3.2.1 1995 Proposal Results

The modeling results presented in the 1995 petroleum refining waste listing determination rule proposal were the results of the 1995 two high-end parameter modeling analysis. For the two high-end parameter analysis, the two most sensitive parameters were set to their respective 90-th percentile values. The selection of the two high-end parameters was as follows for the landfill and land treatment scenarios:

Landfill: Waste Unit Area
 Distance to Well

Land treatment unit: Waste Unit Area
 Waste Quantity

It should be noted that in the case of the distance-to-well, the high-end value corresponds to the 10-th, rather than the 90-th percentile of the distribution, *i.e.*, a closer well will result in a more conservative assessment. The waste fraction that was used in the modeling analysis was calculated as the ratio of the median 20-year wastestream volume and the mean landfill volume. The mean landfill volume was chosen because its value was generally intermediate between the 50-th and 90-th percentile values, yielding a corresponding intermediate value for the waste fraction which was kept constant. The consequence of the parameter values used is that the modeled waste volume was derived from the pre-determined waste fraction. For most wastestreams, the modeled waste quantity used in the high-end analysis exceeded the actual median value of the reported wastestream volume, but under-estimated the median wastestream volume in the central tendency case.

In the single parameter high-end case, the single most sensitive variable was assigned to its 90-th percentile value, while all other model parameters were set to median values. This variable was the waste unit area for both landfills and land treatment units. In the high-end analysis the source depletion option was used for the landfill scenario. The receptor well was placed at half-way between the plume centerline and the lateral extent of the contaminant plume. In the evaluation of groundwater exposure concentrations, the 9-year maximum average concentration was used for carcinogens, and the peak concentration for non-carcinogens. Cancer risks and health-based number (HBN) exceedances for the high-end analysis are shown in Section 5 (Table 5.1 Summary of Groundwater Pathway Analysis Results) along with the revised two high-end parameter analysis results (see Section 3.2.2).

3.2.2 Revised Two High-End Parameters Analyses

In the 1995 Two High-End Parameters Analysis, the waste fraction was defined as the ratio between the median 20-year wastestream volume and the mean landfill volume, while the 20-year waste volume was treated as a derived parameter in the modeling (USEPA, 1995d). Consequently, as mentioned above, for most wastestreams the modeled waste volume was greater than actual 50th percentile waste volume. In response to comments on the 1995 Proposal most of the wastestreams were reanalyzed using the reported 1992 waste volumes in detailed sensitivity analyses (Section 3.2.3). In addition, the 1995 Two-High-End Parameter Scenario was

reanalyzed for two listing wastestreams, for which a detailed Two Parameter sensitivity was not performed (Sulfur Complex Sludge and Unleaded Gasoline Tank Sludge) using the reported waste volumes from the 1992 RCRA §3007 Survey (USEPA, 1995a). Table 3.2 shows a comparison between the waste volumes derived in the 1995 Proposal Groundwater Analysis and the reported waste volumes used in the revised Two High-End Parameters analysis. In the case of On-Site Unleaded Gasoline Tank Sludge the modeled waste quantity was less than the 1992 RCRA §3007 reported waste quantity (USEPA, 1995a). For the Off-Site Unleaded Gasoline Tank Sludge and Off-Site Sulfur Complex Sludge the modeled waste quantities were greater than the reported values (USEPA, 1995a: Table 3.2). A comparison between the 1995 groundwater risk results and the revised results are shown in Section 5 (Tables 5.1, 5.2, and 5.3).

3.2.3 Current Two Parameter Sensitivity Analysis

A sensitivity analysis was conducted in the current analysis to determine the two model input parameters which have the greatest impact on the receptor well concentration. These two parameters were set to their 90-th percentile when performing the two high-end parameters analysis.

The analysis focused on source-related parameters (area, waste and leachate concentration, infiltration, and waste volume) and the location of the receptor well (x-, y-, and z- coordinates). All other variables were assigned median values. Sensitivity analysis was performed on all the wastestreams that showed a significant risk in the 1995 analysis (USEPA, 1995d) and the 1996 Monte Carlo analysis. Table 3.3 shows a list of wastestreams and constituents for which sensitivity analysis was performed. Tables in Appendix C show the input parameter distributions used in the modeling analysis for each wastestream. In the case of constituent waste and leachate concentrations, instead of a statistical distribution, the average concentration measured across the samples was used for the 50th percentile and the maximum concentration was used for the high end. The relatively few waste and leachate samples available warranted this approach. The distributions of the source input parameters vary from wastestream to wastestream and constituent to constituent. Therefore, the combination of the two most sensitive parameters also varies and is dependent on wastestream and constituents.

Table 3.2 Comparison of 1995 and 1996 Modeled Waste Volumes

Wastestream	20-year Waste Quantity (MT)	
	50-th percentile Modeled in 1996	Derived Modeled in 1995
Sulfur Complex Sludge - On-Site	76.2	20.4
Sulfur Complex Sludge - Off-Site	76.2	126.4
Unleaded Gasoline Tank Sludge - On-Site	126	29.1
Unleaded Gasoline Tank Sludge - Off-Site	126	178.5

3.2.3.1 Approach

The analysis was carried out in two steps. First, the model was run for a base case scenario. A base case scenario represents a simulation in which all the input parameters are set to their respective median values. Then, a series of simulations were performed by setting a combinations of two parameters, at a time, at their 90-th percentile values. In total, 28 simulations were performed for each constituent in a wastestream. In the case of TC rule capped scenarios the leachate concentration distribution above the TC rule regulatory values was truncated. The sensitivity of each combination of two parameters, set at their 90-th percentile values, was determined based on the relative change in receptor well concentration from its base case. In the case of carcinogens, 9 year average receptor well concentrations were used to estimate the relative concentrations.

3.2.3.2 Sensitivity of Parameters

The relative sensitivities of the combination of two parameters set to their high-end values, for each constituent and wastestream are presented in Appendix C. A summary of the two most sensitive parameters for each constituent and wastestream is presented in Table 3.3. As discussed in the previous sections, it can be seen that the most sensitive parameters vary from wastestream to wastestream and also from constituent to constituent. Since the sensitivity analysis was performed by varying a combination of two parameters at a time, the synergism between the two parameters and their impacts on the receptor well concentration are clearly demonstrated (see Appendix C). All data values listed in Appendix C are from the 1995 Listing Background Document (USEPA, 1995a) with the exception of the offsite landfill dimensions. The offsite landfill areas and depths were obtained from USEPA RCRA Confidential Business Information Documents (RCRA CBI, 1995).

3.3 CENTRAL TENDENCY ANALYSIS

Central tendency analyses were performed in both the previous (1995) and current (1996) Groundwater Pathway Analyses to reflect the central estimate of exposure or dose. In these analyses, all parameters were set to their median (50th percentile) value except TCLP and waste concentration which were set to their mean values due to the limited number of data points.

3.3.1 1995 Analysis

Details and results of the previous (1995) central tendency analysis are presented in the 1995 Groundwater Pathway Analysis Background Document, Section 4 (USEPA, 1995d).

3.3.2 Revised Central Tendency Analysis

The central tendency analysis performed in 1996 (current analysis) was similar to the previous (1995) analysis. The one difference was that in the current analysis the waste fraction was treated as a derived parameter and the reported waste volume (1992 RCRA §3007 Survey; USEPA, 1995a) was used in the modeling. The results of the current central tendency analysis are presented in Appendix E. The median value parameters used in the current central tendency analysis are presented in Appendix C. The central tendency parameters are listed in the top row of each sensitivity table (Base Case).

3.4 TWO HIGH-END PARAMETERS ANALYSIS FOR CODISPOSAL

A two high-end parameters analysis was performed to investigate the impacts of waste codisposal on risks associated with benzene and arsenic in 20 wastestreams managed in on-site and off-site Subtitle

D landfills. Tables 1.1 and 1.2 list wastestreams included in the codisposal analyses. As indicated by Table 1.1, Hydrotreating and Hydrorefining Catalyst were not included in the codisposal analysis because these wastestreams are recommended to be listed, and would, therefore, not be codisposed with nonlisted wastestreams in Subtitle D landfills. Risks were also evaluated with and without Hydrocracking Catalyst to evaluate the relative contribution of Hydrocracking Catalyst to benzene and arsenic risk in the codisposal scenario.

All model runs were conducted in deterministic mode by setting two parameters (waste unit area and x-well distance) to their high-end values *i.e.* 90-th percentile for landfill area and 10-th percentile for the well distance. The two high-end parameters were selected based on the sensitivity analysis conducted in 1995 (USEPA, 1995d). Although a sensitivity analysis was not performed to determine the two most sensitive parameters for the codisposal scenario, the analysis results (Table 5.7) indicate that the selection of Area and X-Well as the two high-end parameters produced receptor well concentrations between the 95th and 99th percentile on the Monte Carlo distribution. The remaining input parameters of the model were assigned to their median values obtained from parameter specific distributions (USEPA, 1996c and 1997d). Codisposed values for each source parameter were calculated from the data values from the individual wastestreams as described below.

The on-site and off-site codisposed waste volumes were determined by adding up the 50-th percentile of the 20- year waste volumes for individual wastestreams. For other waste characteristics such as source leachate concentration, waste concentration, and density, the volume-weighted average values were used in the analyses for both on-site and off-site modeling scenarios. The waste management unit area used was the 90-th percentile of the 90-th percentile landfill areas. The waste unit depth was obtained similarly using the 50-th percentile of the 50-th percentile depth values. A summary of model input parameters used in the analysis are in Table 3.4. Tables showing the individual wastestream data that went into the calculation of the codisposal input parameters are shown in Appendix D.

As with the single wastestream scenarios, the codisposal scenario was evaluated both with and without a TC limitation (TC Cap) on the source leaching rate. The TC Cap scenario was evaluated by restricting the source leaching rate to be less than or equal to the toxicity characteristic (TC) value, 0.5 mg/L and 5.0 mg/L for benzene and arsenic, respectively. Consequently, whenever a constituent TCLP exceeded the TC Rule limit of a constituent, it was capped at the TC Rule limit. For the case of no TC Rule limit, risks were evaluated using source leachate concentrations (TCLP) collected from site record sampling (USEPA, 1995a). The two high-end parameters codisposal risks for benzene and arsenic are presented with the Monte Carlo risk results in Section 5 (Table 5.7).

Table 3.3 Summary of Two-High End Parameter Sensitivity Analysis

Waste Stream	Constituent	Two Parameters at High End	Area (m2)	Wst. Quant. (MT)	Wst. Vol (m3)	TCLP (mg/L)	Wst Conc (mg/kg)	Cw / Cl (L/kg)	Infil (m/yr)	X-well (m)	Y- Well (m)	Z-Well (m)	Maximum 9-Year Avg. Conc.(mg/L)
CSO Sludge - Onsite	Benzene	Xwell & Wst Vol	61514	62860	44900	0.06	1.20	20.34	0.17	102	127.63	6.5	1.91E-02
CSO Sludge - Offsite	Benzene	Area & Wst. Vol	162000	62860	44900	0.06	1.20	20.34	0.17	430	155.71	6.5	1.55E-02
Contingent CSO - Onsite	Benzene	Wst. Vol & Y- Well	24594	62860	44900	0.06	1.20	20.34	0.17	430	0.00	6.5	1.03E-02
Contingent CSO - Offsite	Benzene	Wst. Vol & Area	162000	62860	44900	0.06	1.20	20.34	0.17	430	155.71	6.5	1.55E-02
Crude Oil Tank Sludge - Offsite	Benzene	Area & Wst. Vol	162000	12640	8316	0.68	58.72	86.48	0.17	430	155.71	6.5	1.71E-01
Crude Oil Tank Sludge - Offsite	Benzene - TC Cap	Area & Wst. Vol	162000	12640	8316	0.50	58.72	117.44	0.17	430	155.71	6.5	1.34E-01
Hydrotreating Catalyst - Onsite	Benzene	Wst. Conc. & X-Well	29865	400	476	7.90	500.00	63.29	0.17	102	74.85	6.5	0.513
Hydrotreating Catalyst - Onsite	Benzene - TC Cap	X-Well & Infil	29865	400	476	0.50	116.38	232.76	0.46	102	74.85	6.5	1.20E-01
Hydrotreating Catalyst - Onsite	Arsenic	Wst. Vol & Wst Conc	29865	1548	1843	1.10	1600.00	1454.55	0.17	430	90.08	6.5	1.90E-02
Hydrotreating Catalyst - Offsite	Benzene	Y-Well & TCLP	2020	400	476	39.00	116.38	2.98	0.17	430	0.00	6.5	0.338
Hydrotreating Catalyst - Offsite	Benzene - TC Cap	Wst. Conc. & Area	162000	400	476	0.50	500.00	1000.00	0.17	430	155.71	6.5	8.87E-02
Hydrotreating Catalyst - Offsite	Arsenic	Wst. Conc. & Y- Well	2020	400	476	1.10	1600.00	1454.50	0.17	430	0.00	6.5	2.11E-02
Hydrorefining Catalyst - Onsite	Benzene	Wst. Vol. & X-Well	31323	10000	8333	1.49	43.73	29.35	0.17	102	76.13	6.5	2.54E-01
Hydrorefining Catalyst - Onsite	Benzene - TC Cap	Infil & Xwell	31323	1771	1476	0.50	43.73	87.46	0.46	102	76.13	6.5	1.52E-01
Hydrorefining Catalyst - Onsite	Arsenic	Wst. Vol & X-Well	31323	10000	8333	13.71	493.30	35.98	0.17	102	76.13	6.5	1.24E-01
Hydrorefining Catalyst - Onsite	Arsenic - TC Cap	Wst. Vol & X-Well	31323	10000	8333	5.00	493.30	98.66	0.17	102	76.13	6.5	1.20E-01
Hydrorefining Catalyst - Offsite	Benzene	Area & Wst. Vol	162000	10000	8333	1.49	43.73	29.35	0.17	430	155.71	6.5	2.26E-01
Hydrorefining Catalyst - Offsite	Benzene - TC Cap	Area & Wst. Vol	162000	10000	8333	0.50	43.73	87.46	0.17	430	155.71	6.5	1.19E-01
Hydrorefining Catalyst - Offsite	Arsenic	Ywell & Wst. Vol	2020	10000	8333	13.71	493.30	35.98	0.17	430	0.00	6.5	2.04E-01
Hydrorefining Catalyst - Offsite	Arsenic - TC Cap	Ywell & Wst. Vol	2020	10000	8333	5.00	493.30	98.66	0.17	430	0.00	6.5	1.18E-01
HF Alkylolation Sludge - Onsite	Benzene	Infil & Xwell	28328	28960	24542	0.08	4.30	56.58	0.46	102	73.47	6.5	3.60E-02
HF Alkylolation Sludge - Offsite	Benzene	Area & TCLP	162000	28960	24542	0.18	4.30	23.89	0.17	430	155.71	6.5	3.98E-02
Off-Spec. Products - Onsite ¹	Benz(a)anthracene	Wst. Vol & X-Well	145692	13180	10460	0.013	12.00	923.08	0.17	102	137.41	6.5	4.23E-04
Off-Spec. Products - Offsite ¹	Benz(a)anthracene	Y-Well & Infil	2020	1814	1440	0.013	12.00	923.08	0.46	430	0.00	6.5	3.85E-04
Off-Spec. Products - Onsite ²	Benz(a)anthracene	Infil & TCLP	145692	1814	1440	0.013	12.00	923.08	0.46	430	149.82	6.5	6.72E-05
Off-Spec. Products - Offsite ²	Benz(a)anthracene	Infil & TCLP	2020	1814	1440	0.013	12.00	923.08	0.46	430	52.84	6.5	9.29E-05

1. "J" value assumed to represent mean or expected TCLP value (see Section 2.2.6)
2. "J" value assumed to be the maximum of high-end TCLP value (see Section 2.2.6)
3. Data from USEPA, 1995a and CBI 1995.

Table 3.4 Two-Parameter High-End Input Data for Codisposal Scenario

Constituent	Vol. Wgt. Av. Cw mg/kg	Vol. Wgt. Avg. TCLP mg/l	Avg. TCLP TC-Rule mg/l	Vol. Wgt. Avg. Density MT/m³	Total Vol. m³	90-th Area m²	50-th Depth m
Arsenic/On-Site	5.51	4.66E-03	4.66E-03	1.23	43298.26	202350	4.57
Benzene/On-Site	5.12	0.11	0.0657	1.23	43298.26	202350	4.57
Arsenic w/HC Off-Site	6.82	0.01	0.01	1.26	54556.56	162000	2.60
Benzene w/HC Off-Site	5.99	0.14	0.0576	1.26	54556.56	162000	2.60
Arsenic w/o HC Off-Site	6.62	0.01	0.01	1.25	53292.19	162000	2.60
Benzene w/o HC Off-Site	3.08	0.06	0.0471	1.25	53292.19	162000	2.60

4.0 MONTE CARLO ANALYSES PROCEDURE

Monte Carlo simulations were performed to generate probability distributions of downgradient receptor well concentrations for each waste constituent of concern, *e.g.* benzene for all wastestreams which were not eliminated in the bounding analysis. The Monte Carlo simulations consisted of 10,000 groundwater chemical transport simulations, each with a different set of input parameters. A particular combination of parameters is referred to as a realization. In this analysis, for each Monte Carlo realization, a receptor well concentration was calculated by randomly selecting one landfill along with its correlated, site specific parameters and site-specific parameter databases. Each parameter with a statistical distribution was then selected from its distribution database. These distributed parameters were either correlated to the site, *e.g.* hydraulic conductivity or hydraulic gradient, or they were independent of the site, *e.g.* leachate concentration. Generic and site-specific data are further described below. Simulations were performed for each realization using the selected parameters. Receptor well concentrations calculated for all of the realizations were sorted to determine the concentration probability distribution.

Site-specific parameters are those modeling parameters which were correlated to the waste unit site location. Site-specific parameters were available either from responses to the RCRA §3007 Survey (1992 RCRA §3007 Database) or from a reference source such as the API hydrogeologic parameter data base (API, 1989; Newell et al., 1990; USEPA 1997d). Site-specific parameters were correlated to the refinery location. Site-specific parameters selected from a source other than the RCRA §3007 survey were correlated to the site based on the geographic location of the site through the assignment of a groundwater region code or a climatic region code. Generic parameters are those modeling parameters for which limited data or no reliable data exist for each landfill location. Consequently, generic parameters were randomly selected from distribution databases independently of the site selection. For example, a limited number of waste concentration and TCLP concentration data points were available for each wastestream. These data are used as source concentration input values in the groundwater model. Therefore, a generic source concentration distribution consisting of two to six paired concentration data values per wastestream was used for all sites. For each Monte Carlo realization, paired source concentration values were randomly selected from the concentration distribution. Site-specific and generic modeling parameters and their sources are summarized in Table 4.1.

4.1 SINGLE-WASTESTREAM BASELINE

The petroleum refining waste data were categorized into waste disposed at on-site refinery landfills and waste disposed at off-site industrial Subtitle D landfills. More detailed waste unit information was available for on-site landfills than for off-site landfills; therefore, different Monte Carlo procedures have been developed for on- and off-site landfills. In addition, separate Monte Carlo procedures have been developed to simulate multi-wastestream codisposal at on- and off-site landfills. The Monte Carlo procedures for each of the four scenarios are described in the following sections.

Single-wastestream baseline Monte Carlo analyses were performed for all wastestreams and waste constituents that showed risk in the bounding analysis, *i.e.* if the HBN of a waste constituent was exceeded in the bounding analysis, the single-wastestream baseline analysis was performed for that waste constituent.

4.1.1 On-Site Baseline Monte Carlo Analysis

Waste unit area and depth values and wastestream volume data are available for each on-site landfill. Therefore, single-valued site-specific parameters for on-site landfills include: waste unit area and

Table 4.1 Description of Monte Carlo Input Data and Data Sources

Source Parameters	On-site	Off-site
Waste Information:		
Waste Volume	site-correlated value for each on-site landfill (1992 RCRA §3007 Survey Database)	site-correlated value for each off-site landfill (1992 RCRA §3007 Survey Database)
Waste Density	industry-wide average of density values for each wastestream (1992 RCRA §3007 Survey Database)	industry-wide average of density values for each wastestream (1992 RCRA §3007 Survey Database)
Waste Concentration and TCLP	wastestream-specific distribution of paired TCLP and Waste Concentration values (USEPA, 1995a)	wastestream-specific distribution of paired TCLP and Waste Concentration values (USEPA, 1995a)
Waste Unit:		
Location	distribution for each wastestream consisting of all on-site locations where that wastestream was reported to be disposed (1992 RCRA §3007 Survey Database)	distribution for each wastestream consisting of all off-site locations where that wastestream was reported to be disposed (1992 RCRA §3007 Survey Database)
Area	site-correlated values for on-site landfill areas and depths (1992 RCRA §3007 Survey Database)	distribution of paired HWIR landfill areas and depths based on OSW Subtitle D Landfill Surveys (USEPA, 1997d)
Aquifer Parameters	On-site	Off-site
Unsaturated Zone :		
Thickness	distribution correlated to site location based on regional site specific groundwater region (API, 1989; USEPA, 1996c; USEPA, 1997d)	distribution correlated to site location based on regional site specific groundwater region (API, 1989; USEPA, 1996c; USEPA, 1997d)
Soil properties	nationwide distribution based on data from U.S Soil Conservation Service (USEPA, 1997d)	nationwide distribution based on data from U.S. Soil Conservation Service (USEPA, 1997d)
Saturated Zone:		
Thickness	distribution correlated to site location based on regional site specific groundwater region (API, 1989; USEPA, 1996c; USEPA, 1997d)	distribution correlated to site location (API, 1989; USEPA, 1996c; USEPA, 1997d)
Gradient	distribution correlated to site location based on regional site specific groundwater region (API, 1989; USEPA, 1996c; USEPA, 1997d)	distribution correlated to site location (API, 1989; USEPA, 1996c; USEPA, 1997d)
Groundwater Temperature	value correlated to each site (USEPA, 1997d)	value correlated to each site (USEPA, 1997d)
Hydraulic Conductivity	distribution correlated to site location based on regional site specific groundwater region (API, 1989; USEPA, 1996c; USEPA, 1997d)	distribution correlated to site location based on regional site specific groundwater region (API, 1989; USEPA, 1996c; USEPA, 1997d)
Aquifer pH, Porosity, Dispersivity, etc.	nationwide distribution (USEPA, 1997d)	nationwide distribution (USEPA, 1997d)
Well Location	nationwide distribution *(USEPA, 1997d)	nationwide distribution (USEPA, 1997d)

* See section 2.2.1 for an explanation of why the nationwide distribution was used for this parameter.

depth, wastestream volumes, and groundwater temperature. Site-correlated distribution information for each simulation includes infiltration rates, groundwater recharge rates, and aquifer flow and transport properties. Generic parameters are not correlated to site location and include wastestream and leachate concentrations (see explanation above), waste densities, and receptor well location.

4.1.1.1 Procedure

The step-by-step Monte Carlo procedure for the baseline on-site landfill scenario is outlined below:

STEP 1. A Wastestream is selected,

STEP 2. A Constituent is selected then,

For the I-th Monte Carlo realization:

STEP 3. An on-site landfill is selected which includes the following information:

- landfill area, waste unit depth and volume (information reported in responses to the RCRA § 3007 Survey; 1992 RCRA § 3007 Survey Database),
- wastestream volume (information reported in responses to the RCRA § 3007 Survey *20 year; 1992 RCRA § 3007 Survey Database),
(In a limited number of cases the landfill volumes reported in the RCRA § 3007 Survey were less than the reported 20 year waste volumes; in those cases the landfill waste fraction will be fixed at 1.00, thereby implicitly increasing the depth of the landfill; the calculated volume of a landfill (= total thickness (height + depth) x area) may be different from the reported volume due to the slopes of the sides of the landfill (assuming no other sources of errors)
- hydrogeologic region (and hydrogeologic parameters; API 1989 and USEPA, 1997d),
- climatic region (and climatic-related parameters; USEPA, 1997d and
- groundwater temperature.

STEP 4. Remaining parameters are selected such as well location and dispersivity, from nationwide distributions (USEPA, 1997d).

STEP 5. The receptor well concentration for the above selected parameters is calculated.

For each wastestream, and a constituent of that wastestream, the process (Steps 3 to 5) is repeated 10,000 times. The receptor well concentrations are then sorted and reported in terms of the 85-th, 90-th, 95-th and 99-th percentile exceedances (and/or Cancer Risks or Health Quotients).

Steps 2 to 5 are repeated for all constituents of the selected wastestream. Steps 1 to 5 are repeated for all wastestreams of interest.

4.1.1.2 Modeled Wastestreams and Constituents

The wastestreams and waste constituents shown in Table 4.2 were included in the single-wastestream baseline modeling analysis. In the previous bounding analyses (USEPA, 1995d), these wastestream constituents had been found to exceed their respective HBN values.

Table 4.2 Modeled Wastestreams and Constituents for On-Site Scenarios

<u>On-Site Landfill Wastestreams:</u>	<u>Waste Constituents:</u>
CSO Sludge	benzene
Unleaded Gasoline Tank Sludge	benzene, nickel
Off-Spec Product and Fines	benz(a)anthracene, benzo(a)pyrene,
Sulfur Complex Sludge	benzene, arsenic
Hydrotreating Catalyst	benzene, toluene, arsenic, nickel
Hydrorefining Catalyst	benzene, arsenic, nickel
FCC Catalyst & Fines	nickel
SCOT Catalyst	cadmium, vanadium
HF Alkylation Sludge	benzene, 3/4-methylphenol

4.1.2 Off-Site Baseline Monte Carlo Analysis

Monte Carlo simulations of the off-site landfill scenario similar to the on-site scenario were conducted. Locations were available for each off-site landfill. Therefore, hydrogeologic information were selected from an API database (API, 1989; Newell et al., 1990; USEPA 1997d) based on its geographic location. Those parameters were correlated with the landfill site along

with site-specific parameters such as waste volume, and groundwater temperature. As with the on-site scenario, the wastestream and leachate concentrations as well as receptor well locations, are generic and were randomly selected from distributions consisting of industry-wide site sampling data. Receptor well locations were selected from a uniform distribution of x and y well coordinates. Climate information (i.e., infiltration and recharge) was selected from a nationwide database for each landfill site based on its location. Waste unit depths and areas were not available for off-site landfills; therefore, paired values were randomly selected for each realization from the HWIR Subtitle D landfill database (USEPA, 1996c and USEPA, 1997d). A check was implemented to ensure that the selected landfill volume was greater than the wastestream volume; otherwise, the landfill was rejected and another area-depth pair was selected from the HWIR distribution.

4.1.2.1 Procedure

The Monte Carlo procedure for the single-wastestream baseline off-site landfill scenario is similar to the on-site baseline procedure except that after an off-site landfill and its hydrogeologic parameters are selected. The following steps are taken :

STEP 1. A Wastestream is selected,

STEP 2. A Constituent is selected then,

For the I-th Monte Carlo realization:

STEP 3. An off-site landfill is selected which includes the following information:

- wastestream volume (information reported in responses to the RCRA § 3007 Survey *20 years; 1992 RCRA § 3007 Survey Database).
- hydrogeologic region (and hydrogeologic parameters; API 1989; USEPA, 1997d),
- climatic region (and climatic-related parameters; USEPA 1997d), and
- groundwater temperature.

STEP 4. Paired landfill area and depth values are selected from the HWIR distribution of Subtitle D industrial landfills.

STEP 5. The volume of the selected landfill is computed and compared with the codisposed waste volume (see paragraph below). If the codisposed waste volume is greater than or equal to the landfill volume, the landfill area and depth pair are rejected and a new area-depth pair is selected until a pair is selected that meets the criteria of waste unit volume being greater than waste volume.

Waste management facility volumes are compared against codisposed wastestream volumes in both the single-wastestream (baseline) and codisposal scenario to ensure consistency between the scenarios and to ensure that unrealistically small landfill areas are not selected for the baseline analysis.

STEP 6. Remaining parameters are selected such as well location and dispersivity, from nationwide distributions (USEPA, 1997d).

STEP 7. The receptor well concentration for the above selected parameters is calculated.

For each wastestream, and a constituent of that wastestream, the process (Steps 3 to 7) is repeated 10,000 times. The receptor well concentrations are then sorted and reported in terms of the 85-th, 90-th, 95-th and 99-th percentile exceedances (and/or Cancer Risks or Health Quotients).

Steps 2 to 5 are repeated for all constituents of the selected wastestream. Steps 1 to 5 are repeated for all wastestreams of interest.

4.1.2.2 Modeled Wastestreams and Waste Constituents

The wastestreams and constituents shown in Table 4.3 were included in the baseline modeling analysis.

Table 4.3 Modeled Wastestreams and Waste Constituents for Off-Site Scenarios

<u>Off-Site Landfill Wastestreams:</u>	<u>Waste Constituents:</u>
CSO Sludge	benzene

<u>Off-Site Landfill Wastestreams:</u>	<u>Waste Constituents:</u>
Unleaded Gasoline Tank Sludge	benzene, nickel
Crude Oil Tank Sludge	benzene
Off-Spec Product Fines	benz(a)anthracene, benzo(a)pyrene,
Sulfur Complex Sludge	benzene, arsenic
Hydrotreating Catalyst	benzene, toluene, arsenic, nickel
Hydrorefining Catalyst	benzene, arsenic, nickel
FCC Catalyst & Fines	nickel
SCOT Catalyst	cadmium, vanadium
HF Alkylation Sludge	benzene, 3/4-methylphenol

4.2 CODISPOSAL MONTE CARLO ANALYSIS

Concerns raised in the public comments concerning the impact of codisposal of wastestreams in landfills were addressed by performing multi-wastestream codisposal modeling analyses similar to the single-wastestream baseline scenarios described in Section 3. However, instead of considering the wastestreams individually, information on codisposal at each landfill was used to model total petroleum waste volumes and volume averaged waste and leachate concentrations. The on- and off-site codisposal scenarios were simulated for benzene and arsenic transport using the entire set of either on-site or off-site landfills. Since hydrorefining and hydrotreating wastes are recommended to be listed and will not be codisposed with non-listed wastestreams in Subtitle D landfills, those wastes were excluded from the codisposal scenario. In the case of off-site landfills, analyses were performed both with and without hydrocracking waste to evaluate the impact of listing that wastestream.

4.2.1 On-Site Codisposal Monte Carlo Analysis Procedure

Monte Carlo simulations were performed to determine a probability distribution of receptor well concentrations for each constituent of concern. Again site-specific parameters were correlated to each refinery and generic parameters were randomly selected from distribution databases. The general Monte Carlo procedure is similar to that for on-site baseline analyses (Section 4.1.1). In this procedure, however, wastestream and leachate concentrations were volume-weighted averages of all wastestreams disposed of at a landfill. Volume-averaged TCLP and waste concentration values for each constituent of concern were calculated for the landfills as follows:

- Concentration values are selected at random from the TCLP, (C_{ij}), and waste concentration, (C_{wij}), data sets for each wastestream (I) disposed at an on-site landfill.

- The volume averaged TCLP (leachate) concentration and waste concentration values are calculated using the formula below,

$$\overline{C}_{ij} = \frac{\sum_{i=1}^n C_{ij} V_i}{\sum_{i=1}^n V_i} \quad (1)$$

$$\overline{C}_{wij} = \frac{\sum_{i=1}^n C_{wij} V_i}{\sum_{i=1}^n V_i} \quad (2)$$

$$j = \text{Random}(1,2,\dots,m) \quad (3)$$

Where the subscript, I, refers to the wastestream, j refers to the value selected at random from the concentration data set for wastestream I with m values, and V_i is the volume of wastestream I.

- If the TCLP data for a wastestream showed no indication of the presence of a particular constituent, then the wastestream is included in the codisposal with the TCLP of that constituent set to 0.0.

Site-specific parameters for codisposal at on-site landfills include waste unit information, total wastestream volume, and some aquifer parameters. Generic information for each simulation includes volume-weighted average densities, well location and some aquifer parameters.

4.2.1.1 Procedure

The Monte Carlo procedure for the on-site landfill codisposal scenario is outlined below:

- STEP 1. A Wastestream is selected
- STEP 2. A Waste Constituent is selected, then

For the I-th Monte Carlo realization:

STEP 3. An on-site landfill is selected which includes the following information:

- landfill area, waste unit depth and volume (information reported in responses to the RCRA § 3007 Survey; 1992 RCRA § 3007 Survey Database).
- wastestream volume for each wastestream codisposed in the landfill (information reported in RCRA § 3007 Survey *20 years) (*In a limited number of cases the landfill volumes reported in the RCRA 3007 survey are less than the reported 20 year waste volumes; in those cases the landfill waste fraction will be fixed at 1.00; see on-site baseline for additional explanation, Section 4.1.1*)
- hydrogeologic region (and hydrogeologic parameters; API 1989; Newell et al., 1990; USEPA, 1997d),
- climatic region (and climatic-related parameters; USEPA, 1997d), and
- groundwater temperature.

STEP 4. A 20-year codisposed waste volume for each landfill is calculated by summing the reported 1992 annual volumes of all wastestreams (including study wastestreams) disposed in that landfill and multiplying the volume by 20 years.

STEP 5. Volume averaged TCLP and waste concentration values for each constituent of concern are calculated for the landfills as follows:

- 5.1 Concentration values are selected at random from the TCLP and waste concentration data sets for each wastestream disposed at the selected landfill.
- 5.2 Volume-averaged TCLP (leachate) concentration and waste concentration values are calculated using Equations 1 and 2.
- 5.3 If the TCLP data for a wastestream showed no indication of the presence of a particular constituent, then the wastestream is included in the codisposal with the TCLP of that constituent set to 0.0.

STEP 6. Other parameters such as well location and dispersivity from nationwide distributions are selected.

STEP 7. Receptor well concentration for the above selected parameters is calculated.

The process (Steps 3 to 7) is repeated 10,000 times. The receptor well concentrations are reported as the 90-th, 95-th and 99-th percentile exceedances (and/or Cancer Risks or HQs).

Steps 2 to 7 are repeated for all constituents of the selected wastestream. Steps 1 to 7 are repeated for all wastestreams of interest.

4.2.2 Off-site Codisposal Monte Carlo Analysis Procedure

Off-site codisposal is simulated much the same as the off-site single wastestream disposal except that volume-weighted average concentrations and densities along with total wastestream volume were correlated with the landfill location.

4.2.2.1 Procedure

The Monte Carlo procedure for the on-site landfill codisposal scenario is outlined below:

STEP 1. Select a wastestream

STEP 2. Select a Waste Constituent, then

For the I-th Monte Carlo realization:

STEP 3. Select an off-site landfill which includes the following information

- wastestream volumes for each wastestream codisposed in the landfill (information reported in responses to the RCRA § 3007 Survey * 20 years; 1992 RCRA § 3007 Survey Database)
- hydrogeologic region (and hydrogeologic parameters; API 1989; Newell et al., 1990; USEPA 1997d),
- climatic region (and climatic-related parameters; USEPA 1997d), and
- groundwater temperature

STEP 4. A 20 year codisposed waste volume for each landfill is calculated by summing the reported 1992 annual volumes of all wastestreams disposed in that landfill and multiplying the volume by 20 years.

- STEP 5. Volume averaged TCLP and waste concentration values for each constituent of concern is calculated for the landfills as follows:
- 5.1 Concentration values are selected at random from the TCLP and waste concentration data sets for each wastestream(s) disposed at the selected landfill.
 - 5.2 Volume averaged TCLP (leachate) concentration and waste concentration values are calculated using Equations 1 and 2.
 - 5.3 If the TCLP data for a wastestream showed no indication of the presence of a particular constituent, then the wastestream is included in the codisposal with the TCLP of that constituent set to 0.0.
- STEP 6. Select paired landfill area and depth values from the HWR distribution of Subtitle D industrial landfills. The volume of the selected landfill is compared against the codisposed waste volume of the landfill selected in 3 above. If the codisposed waste volume is greater than or equal to the landfill volume, the landfill area and depth pair is rejected and a new area-depth pair is selected until a pair is selected that meets the criteria of waste unit volume being greater than waste volume.
- Waste management facility volumes are compared against codisposed wastestream volumes in both the single-wastestream (baseline) and codisposal scenarios to ensure consistency between the scenarios and to ensure that unrealistically small landfill areas are not selected for the baseline analysis (if the landfill volume is too small, that value of volume is rejected and a new volume is selected).
- STEP 7. Select other parameters such as well location and dispersivity from nationwide distributions.
- STEP 8. Calculate a receptor well concentration for the above selected parameters.

Repeat the process (Steps 3 to 8) 10,000 times. The receptor well concentrations are reported as the 90-th, 95-th and 99-th percentile exceedances (and/or Cancer Risks or HQs).

Steps 2 to 7 are repeated for all constituents of the selected wastestream. Steps 1 to 7 are repeated for all wastestreams of interest.

5.0 MODELING RESULTS AND GROUNDWATER RISK

After the modeling results were processed, receptor well concentrations were used to assess the potential for adverse health effects from both direct and indirect exposures to groundwater. Calculated exposure levels were compared to EPA's health-based numbers (HBN's). For carcinogens, where risk is expressed as a probability of getting cancer the HBN's were set at the exposure level where the risk is 1×10^{-6} . For non-carcinogens, HBN's were EPA's reference dose (RFD's) levels. RFD's are values at or below which adverse health effects are not expected to occur.

5.1 RISK CALCULATION

5.1.1 Direct Groundwater Risk

The groundwater pathway modeling analysis results consist of modeled receptor well concentrations. In the case of the two high-end parameter deterministic analyses, a single well concentration was calculated for each waste constituent. For the Monte Carlo analysis distributions of receptor well concentrations were generated for each waste constituent. To complete the risk analysis, well concentrations were compared with the health-based numbers (HBN's). The HBN values were calculated from standard equations for drinking water ingestion from the USEPA Risk Assessment Guidance for Superfund Volume I, Human Health Evaluation Manual (USEPA, 1989), using an exposure duration of 9 years, ingestion rate of 1.4 L/day and adult body weight of 70 kg. Ratios of the well concentration to the HBN's for the various model scenarios are summarized in Tables 5.1 - 5.5. The 85-th, 90-th, 95-th and 99-th percentile model results are presented for the Monte Carlo Analysis.

5.1.2 Indirect Groundwater Risk

An additional indirect risk due to inhalation during showering was added to the Benzene direct risk estimates to calculate a total estimated groundwater risk. The showering dose response for Benzene was calculated as 6.06×10^5 risk per 1.0 mg/l of Benzene in the showering water (USEPA, 1996b). Showering risks for other less volatile modeled constituents were determined to be negligible.

5.1.3 Total Risk

The indirect inhalation risk from showering combined with the direct ingestion risk produces a total dose-response of 1.606×10^4 risk per 1.0 mg/l of benzene. The estimated total groundwater risk for benzene was calculated from the product of the EPACMTP calculated well concentration (high-end parameter, 90-th, 95-th, or 99-th percentile) and the total dose response for benzene. The modeling results (risk estimates) listed in Tables 5.1 - 5.5 are presented as multiples of 1.0×10^6 risk or risk at 1.0×10^{-6} . The total risk for the other less volatile modeled constituents is equal to the direct risk; showering risks were not added.

5.2 MODELING RESULTS

Results for the two high-end parameter and Monte Carlo analyses are shown in Tables 5.1 through 5.7. The Monte Carlo results are presented as calculated 85-th, 90-th, 95-th, and 99-th percentile risk estimates. Both direct (ingestion) and total (ingestion plus showering inhalation) risks are presented for benzene and direct risk is presented for all other waste constituents. Risk estimates which exceed 1.0 are shown in bold. This corresponds to a hazard quotient exceeding 1.0 in the case of non-carcinogens and a cancer probability greater than 1 in a million (1×10^{-6} risk) in the case of carcinogens. The maximum 95-th percentile and two high-end parameter groundwater risks for each waste stream are summarized in Table 5.1.

5.2.1 Two High-End Parameters Results

The two high-end parameter results are presented for the baseline on-site landfill scenario in Table 5.2 and for the baseline off-site landfill scenario in Table 5.3.

5.2.2 Central Tendency Results

The central tendency results are presented for the baseline on-site landfill scenario in Table 5.2 and for the baseline off-site landfill scenario in Table 5.3.

5.2.3 Monte Carlo Results

The baseline on-site landfill Monte Carlo results are given in Table 5.4 and the off-site landfill Monte Carlo results are presented in Table 5.5.

5.2.4 Contingent CSO Management

Results for both Monte Carlo and two high-end parameter contingent CSO management analyses are presented in Table 5.6 along with the non-contingent CSO (only 1992 annual Subtitle D Landfill waste quantities).

5.2.5 Codisposal Results

On- and off-site codisposal results are shown in Table 5.7.

5.2.6 TC Capped Results

TC-Capped results are presented in Tables 5.1 to 5.5.

Table 5.1 Summary of Maximum Groundwater Risks (x10⁻⁶)

Waste	Constituent	95 High-End		Monte Carlo 95th Perc.	96 High-End	96 Central Tendency	TC Capped	
		Federal Register	Backgrnd Document				Monte Carlo (95th perc.)	High-End
CSO	benzene	not significant	6.E-01	1.E+00	3.E+00	5.E-01	NA ¹	NA ¹
Crude Tank Sludge	benzene	3.E+01	5.E-01	5.E+00	3.E+01	8.E-01	3.E+00	2.E+01
HT Catalyst	benzene	1.E+01	4.E+01	1.E+01	8.E+01	9.E+00	4.E+00	2.E+01
	arsenic	1.E+01	3.E+01	1.E+01	7.E+01	6.E+00	NA ¹	NA ¹
HR Catalyst	benzene	2.E+01	4.E+01	8.E+00	4.E+01	1.E+01	6.E+00	2.E+01
	arsenic	6.E+01	1.E+02	1.E+02	4.E+02	4.E+01	1.E+02	4.E+02
Unleaded Gas Sludge	benzene	2.E+00	4.E+00	2.E+00	5.E+00 *	1.E+00	1.E+00	3.E+00
HF Alkylation Sludge	benzene	3.E+00	3.E+00	2.E+00	6.E+00	1.E+00	NA ¹	NA ¹
Off-Spec Products	benz(a)anthracene	no risks of concern	1.E+01	5.E+00	2.E+01	5.E-01	NA ²	NA ²
FCC Catalyst and Fines	nickel	not significant	5.E-01 (RFD)	7.E-02	Not modeled	1.E-03	NA ¹	NA ¹
Sulfur Complex Sludge	benzene	not significant	2.E-02	1.E-01	4.E-03	3.E-03	NA ¹	NA ¹
	arsenic	not significant	5.E-01	2.E-01	1.E-01 *	1.E-01	NA ¹	NA ¹
SCOT Catalyst	cadmium	not significant	9.E-03	2.E-03	Not modeled	4.E-04	NA ²	NA ²
	vanadium	not significant	Not modeled	2.E-10	Not modeled	3.E-03	NA ²	NA ²

1. TCLP data were all below the Toxicity Characteristic (TC) Limit
2. The TC limit has not been set for this constituent.

* Because risks from both the 1995 analysis and the Monte Carlo analysis were not significant, a sensitivity analysis was not performed for this waste stream.
 Not Modeled - Because both the 1995 analysis and the Monte Carlo analyses indicated very low risks, additional Two High-End modeling was not performed for this waste stream.

Table 5.2 Summary of Groundwater Pathway Deterministic Analysis Risks ⁶ from On-Site Landfills

Waste Stream	Constituent	Two-High End Parameter Analysis				Central Tendency Analysis		
		1995 Background Document	Revised Results ² in Response to Comments	Revised Results ² w/Indirect Risk ¹	TC Capped Revised Total Risk ³	Direct Risk in Response to Comments	Total Risk ¹	TC Capped Total Risk ²
CSO sludge	Benzene #	0.6	1.9	3.1	NA	0.4	0.6	NA
Hydrotreating Catalyst ⁴	Benzene #	28.6	51.3	82.4	19.3	5.6	9.0	4.1
	Nickel	0.1	NA	NA	NA	0.1	0.1	NA
	Arsenic #	20.1	63.3	63.3	NA	4.5	4.5	NA
	Toluene	2.2E-02	NA	NA	NA	NA	NA	NA
Sulfur complex sludge ⁵	Benzene #	1.6E-03	2.2E-03	3.5E-03	NA	1.23E-03	1.97E-03	NA
	Arsenic #	0.1	0.1	0.1	NA	0.1	0.1	NA
Off-spec products and fines ⁷	Benz(a)anthracene #	0.3	21.2	21.2	NA	0.5	0.5	NA
	Benzo(a)pyrene #	0.0E+00	NA	NA	NA	NA	NA	NA
Off-spec products and fines ⁸	Benz(a)anthracene #	0.3	3.4	3.4	NA	NA	NA	NA
Hydrorefining catalyst ⁴	Benzene #	20.1	25.4	40.8	24.4	6.1	9.7	5.1
	Arsenic #	67.0	413.3	413.3	400.0	25.7	25.7	25.7
	Nickel	0.1	NA	NA	NA	NA	NA	NA
Unleaded gasoline tank sludge ⁵	Benzene #	0.6	1.1	1.7	1.1	0.8	1.2	11.9
	Nickel	6.4E-04	1.3E-03	1.3E-03	NA	9.02E-04	NA	NA
FCC catalyst and fines	Nickel	0.5	NA	NA	NA	1.02E-03	NA	NA
SCOT catalyst	Cadmium	NA	NA	NA	NA	2.09E-04	NA	NA
	Vanadium	NA	NA	NA	NA	1.60E-03	NA	NA
HFalkylation sludge	Benzene #	0.8	3.6	5.8	NA	0.6	1.0	NA
	Nickel	3.2E-03	NA	NA	NA	NA	NA	NA

1. Risk results for carcinogens are presented as HBN exceedance or HBN/well conc. This ratio corresponds to a 1 x 10⁻⁶ risk.
The HBN value for Benzene is 0.01 mg/l, which corresponds to a direct risk from drinking 1.4 l/day of water (1.0 x 10⁻⁴ risk per 1mg/l benzene). The total cancer risk for benzene also includes an indirect risk from showering (6.05 x 10⁻⁵ risk per 1mg/l benzene).
2. With the noted exceptions (see 5 below) the revised analysis consists of a Two Parameter Sensitivity Analysis.
3. Input leaching rates were capped on TC Regulatory levels for maximum allowable TCLP values for disposal in Subtitle D landfills (0.5 mg/l for benzene, and 5.0 mg/l for arsenic)
4. For hydrotreating and hydrorefining, all waste quantities, except those managed in Subtitle C landfills, were modeled including reclaimed waste.
5. Sensitivity analyses were not performed on these waste streams. Revised results were calculated using the two-high end parameters from the 1995 sensitivity analysis and 20-year 50 perc. waste volumes were used rather than derived waste volumes.
6. Results for carcinogens are presented as (1x10⁵) cancer risks. Results for noncarcinogens are presented as HBN exceedances or Hazard Quotients (HQ's)
7. "J" value assumed to represent mean or expected TCLP value (see section 2.3.5)
8. "J" value assumed to represent maximum or high-end TCLP value (see section 2.3.5)

NA : Modeling results are not available or not applicable because either preliminary modeling indicated low risk for the waste constituent or because TC values are not available for the waste constituent.

Table 5.3 Summary of Groundwater Pathway Deterministic Analysis Risks⁶ from Off-Site Landfills

Waste Stream	Constituent	Two-High End Parameter Analysis				Central Tendency Analysis		
		1995 Background Document	Revised Results ² in Response to Comments	Revised Results ² w/Indirect Risk ¹	TC Capped Revised Total Risk ³	Direct Risk in Response to Comments	Total Risk ¹	TC Capped Total Risk ²
CSO sludge	Benzene #	0.6	1.6	2.5	NA	4.8E-02	0.1	NA
Crude Oil Tank Sludge	Benzene #	0.5	17.1	27.5	21.5	0.5	0.8	0.6
Hydrotreating Catalyst ⁴	Benzene #	35.7	33.8	54.3	14.2	4.0	6.4	0.7
	Nickel	0.2	NA	NA	NA	0.1	NA	NA
	Arsenic *	31.6	70.3	70.3	NA	6.4	6.4	NA
	Toluene	3.7E-02	NA	NA	NA	4.43E-03	4.43E-03	NA
Sulfur complex sludge ⁵	Benzene #	1.6E-02	2.0E-03	3.2E-03	NA	1.94E-03	3.11E-03	NA
	Arsenic *	0.5	0.1	0.1	NA	0.1	0.1	NA
Off-spec products and fines ⁷	Benz(a)anthracene *	13.5	19.3	19.3	NA	0.5	0.5	NA
	Benzo(a)pyrene *	2.0E-04	NA	NA	NA	NA	NA	NA
Off-spec products and fines ⁸	Benz(a)anthracene *	13.5	4.6	4.6	NA	NA	NA	NA
Hydrorefining catalyst ⁴	Benzene #	34.6	22.6	36.3	19.1	1.1	1.8	0.6
	Arsenic *	126.7	680.0	680.0	393.3	39.0	39.0	34.3
	Nickel	0.2	NA	NA	NA	1.38E-03	1.38E-03	NA
Unleaded gasoline tank sludge ⁵	Benzene #	4.1	2.9	4.7	3.0	0.4	0.7	NA
	Nickel	4.3E-03	NA	NA	NA	1.43E-03	NA	NA
FCC catalyst and fines	Nickel	NA	NA	NA	NA	NA	NA	NA
SCOT catalyst	Cadmium	8.9E-03	NA	NA	NA	3.71E-04	NA	NA
	Vanadium	NA	NA	NA	NA	2.82E-03	NA	NA
HFalkylation sludge	Benzene #	3.1	4.0	6.4	NA	0.1	0.1	NA
	3/4-Methylphenol	0.4	NA	NA	NA	NA	NA	NA

1. Risk results for carcinogens are presented as HBN exceedance or HBN/well conc. This ratio corresponds to a 1×10^{-6} risk.

The HBN value for Benzene is 0.01 mg/l, which corresponds to a direct risk from drinking 1.4 l/day of water

(1.0×10^{-4} risk per 1mg/l benzene). The total cancer risk for benzene also includes an indirect risk from showering (6.05×10^{-5} risk per 1mg/l benzene).

2. With the noted exceptions (see 5 below) the revised analysis consists of a Two Parameter Sensitivity Analysis.

3. Input leaching rates were capped on TC Regulatory levels for maximum allowable TCLP values for disposal in Subtitle D landfills (0.5 mg/l for benzene, and 5.0 mg/l for arsenic)

4. For hydrotreating and hydrorefining, all waste quantities, except those managed in Subtitle C landfills, were modeled including reclaimed waste.

5. Sensitivity analyses were not performed on these waste streams. Revised results were calculated using the two-high end parameters from the 1995 sensitivity analysis and 20-year 50 perc. waste volumes were used rather than derived waste volumes.

6. Results for carcinogens are presented as (1×10^0) cancer risks. Results for noncarcinogens are presented as HBN exceedances or Hazard Quotients (HQ's)

7. "J" value assumed to represent mean or expected TCLP value (see section 2.3.5)

8. "J" value assumed to represent maximum or high-end TCLP value (see section 2.3.5)

NA : Modeling results are not available or not applicable because either preliminary modeling indicated low risk for the waste constituent or because TC values are not available for the waste constituent.

Table 5.4 Summary of Groundwater Pathway Monte Carlo Analysis Risks ⁶ from On-Site Landfills

Waste Stream	Constituent	85th Percentile			90th Percentile			95th Percentile			99th Percentile		
		Direct Risk	Total Risk	TC Capped Total Risk ³	Direct Risk	Total Risk	TC Capped Total Risk ³	Direct Risk	Total Risk	TC Capped Total Risk ³	Direct Risk	Total Risk	TC Capped Total Risk ³
CSO sludge	Benzene #	1.11E-02	1.78E-02	NA	5.0E-02	NA	NA	0.2	0.3	NA	0.6	1.0	NA
Hydrotreating Catalyst ⁴	Benzene #	0.2	0.3	3.95E-03	0.8	1.3	0.8	4.8	7.7	3.5	53.8	86.5	17.7
	Nickel	6.86E-03	6.86E-03	NA	5.4E-02	5.4E-02	NA	0.5	0.5	NA	11.6	11.6	NA
	Arsenic #	0.4	0.4	NA	1.5	1.5	NA	7.2	7.2	NA	41.2	41.2	NA
	Toluene	2.35E-04	2.35E-04	NA	8.2E-04	8.2E-04	NA	3.6E-03	3.6E-03	NA	7.3E-02	7.3E-02	NA
Sulfur complex sludge ⁵	Benzene #	1.50E-03	2.41E-03	NA	8.9E-03	1.4E-02	NA	0.1	0.1	NA	0.4	0.7	NA
	Arsenic #	1.51E-03	1.51E-03	NA	1.4E-02	1.4E-02	NA	0.1	0.1	NA	5.2	5.2	NA
Off-spec products and fines ⁷	Benz(a)anthracene #	5.53E-05	5.53E-05	NA	3.8E-03	3.8E-03	NA	0.1	0.1	NA	4.2	4.2	NA
	Benzo(a)pyrene #	1.22E-10	1.22E-10	NA	2.3E-08	2.3E-08	NA	2.1E-06	2.1E-06	NA	1.6E-02	1.6E-02	NA
Off-spec products and fines ⁸	Benz(a)anthracene #	5.57E-05	5.57E-05	NA	3.5E-03	3.5E-03	NA	0.1	0.1	NA	4.1	4.1	NA
Hydrotreating catalyst ⁴	Benzene #	0.5	0.9	4.88E-03	1.6	2.6	2.0	4.7	7.6	5.8	47.8	76.8	19.3
	Arsenic #	7.4	7.4	2.96E-04	28.1	28.1	27.1	111.7	111.7	109.0	904.7	904.7	830.3
	Nickel	3.34E-03	3.34E-03	NA	2.5E-02	2.5E-02	NA	0.3	0.3	NA	7.1	7.1	NA
Unleaded gasoline tank sludge ⁵	Benzene #	1.51E-02	2.43E-02	6.23E-03	0.1	0.1	0.1	0.4	0.6	0.6	2.4	3.9	3.8
	Nickel	1.90E-06	1.90E-06	NA	5.2E-05	5.2E-05	NA	7.7E-04	7.7E-04	NA	3.0E-02	3.0E-02	NA
FCC catalyst and fines	Nickel	2.91E-04	2.91E-04	NA	5.5E-03	5.5E-03	NA	6.6E-02	6.6E-02	NA	1.2	1.2	NA
SCOT catalyst	Cadmium	2.70E-05	2.70E-05	NA	2.0E-04	2.0E-04	NA	1.6E-03	1.6E-03	NA	3.5E-02	3.5E-02	NA
	Vanadium	3.28E-15	3.28E-15	NA	9.2E-13	9.2E-13	NA	1.8E-10	1.8E-10	NA	1.4E-08	1.4E-08	NA
HFalkylation sludge	Benzene #	5.45E-03	8.75E-03	NA	2.8E-02	4.5E-02	4.5E-02	0.1	0.2	0.2	0.9	1.4	1.4
	Nickel	3.32E-07	3.32E-07	NA	2.8E-05	2.8E-05	NA	1.0E-03	1.0E-03	NA	3.1E-02	3.1E-02	NA

1. Risk results for carcinogens are presented as HBN exceedance or HBN/well conc. This ratio corresponds to a 1×10^{-6} risk.

The HBN value for Benzene is 0.01 mg/l, which corresponds to a direct risk from drinking 1.4 l/day of water

(1.0×10^{-4} risk per 1mg/l benzene). The total cancer risk for benzene also includes an indirect risk from showering (6.05×10^{-5} risk per 1mg/l benzene).

2. With the noted exceptions (see 5 below) the revised analysis consists of a Two Parameter Sensitivity Analysis.

3. Input leaching rates were capped on TC Regulatory levels for maximum allowable TCLP values for disposal in Subtitle D landfills (0.5 mg/l for benzene, and 5.0 mg/l for arsenic)

4. For hydrotreating and hydrotreating, all waste quantities, except those managed in Subtitle C landfills, were modeled including reclaimed waste.

5. Sensitivity analyses were not performed on these waste streams. Revised results were calculated using the two-high end parameters from the 1995 sensitivity analysis and 20-year 50 perc. waste volumes were used rather than derived waste volumes.

6. Results for carcinogens are presented as (1×10^6) cancer risks. Results for noncarcinogens are presented as HBN exceedances or Hazard Quotients (HQ's)

7. "J" value assumed to represent mean or expected TCLP value (see section 2.3.5)

8. "J" value assumed to represent maximum or high-end TCLP value (see section 2.3.5)

NA : Modeling results are not available or not applicable because either preliminary modeling indicated low risk for the waste constituent or because TC values are not available for the waste constituent.

Table 5.5 Summary of Groundwater Pathway Monte Carlo Analysis Risks from Off-Site Landfills

Waste Stream	Constituent	85th Percentile			90th Percentile			95th Percentile			99th Percentile		
		Direct Risk	Total Risk	TC Capped Total Risk ³	Direct Risk	Total Risk	TC Capped Total Risk ³	Direct Risk	Total Risk	TC Capped Total Risk ³	Direct Risk	Total Risk	TC Capped Total Risk ³
CSO sludge	Benzene #	4.52E-02	0.1	NA	0.2	0.3	NA	0.7	1.1	NA	2.1	3.4	NA
Crude Oil Tank Sludge	Benzene #	0.1	0.2	4.62E-03	0.5	0.8	0.6	2.8	4.5	3.3	27.1	43.5	22.0
Hydrotreating Catalyst ⁴	Benzene #	0.4	0.6	3.78E-03	1.4	2.2	1.2	6.6	10.6	4.4	67.4	108.3	20.3
	Nickel	3.13E-02	3.13E-02	NA	0.2	1.8E-01	NA	1.3	1.3	NA	18.3	18.3	NA
	Arsenic *	0.6	0.6	NA	2.5	2.5	NA	9.6	9.6	NA	56.5	56.5	NA
Sulfur complex sludge ⁵	Toluene	3.28E-04	3.28E-04	NA	1.2E-03	1.2E-03	NA	4.8E-03	4.8E-03	NA	0.1	0.1	NA
	Benzene #	9.73E-04	1.56E-03	NA	4.4E-03	7.1E-03	NA	3.0E-02	4.7E-02	NA	0.5	0.7	NA
Off-spec products and fines ⁷	Arsenic *	2.30E-03	2.30E-03	NA	1.4E-02	1.4E-02	NA	0.2	0.2	NA	4.9	4.9	NA
	Benz(a)anthracene *	0.1	0.1	NA	0.7	0.7	NA	5.4	5.4	NA	73.8	73.8	NA
Off-spec products and fines ⁸	Benzo(a)pyrene *	2.36E-04	2.36E-04	NA	1.0E-02	1.0E-02	NA	0.2	0.2	NA	4.1	4.1	NA
	Benz(a)anthracene *	0.1	0.1	NA	0.6	0.6	NA	4.4	4.4	NA	52.6	52.6	NA
Hydrotreating catalyst ⁴	Benzene #	0.8	1.2	4.86E-03	2.1	3.3	2.6	5.1	8.3	6.3	53.0	85.1	20.5
	Arsenic *	8.3	8.3	2.97E-04	32.6	32.6	31.3	124.9	124.9	123.0	1034.0	1034.0	936.7
	Nickel	4.00E-03	4.00E-03		3.1E-02	3.1E-02	NA	0.4	0.4	NA	6.4	6.4	NA
Unleaded gasoline tank sludge ⁵	Benzene #	4.41E-02	0.1	4.05E-03	0.2	0.3	0.2	1.1	1.7	1.0	8.2	13.2	8.0
	Nickel	2.17E-06	2.17E-06	NA	8.0E-05	8.0E-05	NA	2.0E-03	2.0E-03	NA	0.1	0.1	NA
FCC catalyst and fines	Nickel	4.66E-04	4.66E-04	NA	4.7E-03	4.7E-03	NA	4.4E-02	4.4E-02	NA	0.6	0.6	NA
SCOT catalyst	Cadmium	2.36E-09	2.36E-09	NA	9.2E-07	9.2E-07	NA	2.2E-04	2.2E-04	NA	0.0	0.0	NA
	Vanadium	2.29E-19	2.29E-19	NA	1.1E-14	1.1E-14	NA	2.6E-11	2.6E-11	NA	0.0	0.0	NA
HFalkylation sludge	Benzene #	0.2	0.3	NA	0.4	0.7	0.7	1.0	1.6	1.6	3.0	4.8	4.8
	3/4-Methylphenol	7.17E-03	7.17E-03	NA	1.6E-02	1.6E-02	NA	3.5E-02	3.5E-02	NA	0.1	0.1	NA

- Risk results for carcinogens are presented as HBN exceedance or HBN/well conc. This ratio corresponds to a 1×10^{-6} risk.
The HBN value for Benzene is 0.01 mg/l, which corresponds to a direct risk from drinking 1.4 l/day of water (1.0×10^{-4} risk per 1mg/l benzene). The total cancer risk for benzene also includes an indirect risk from showering (6.05×10^{-5} risk per 1mg/l benzene).
- With the noted exceptions (see 5 below) the revised analysis consists of a Two Parameter Sensitivity Analysis.
- Input leaching rates were capped on TC Regulatory levels for maximum allowable TCLP values for disposal in Subtitle D landfills (0.5 mg/l for benzene, and 5.0 mg/l for arsenic)
- For hydrotreating and hydrotreating, all waste quantities, except those managed in Subtitle C landfills, were modeled including reclaimed waste.
- Sensitivity analyses were not performed on these waste streams. Revised results were calculated using the two-high end parameters from the 1995 sensitivity analysis and 20-year 50 perc. waste volumes were used rather than derived waste volumes.
- Results for carcinogens are presented as (1×10^6) cancer risks. Results for noncarcinogens are presented as HBN exceedances or Hazard Quotients (HQ's)
- "J" value assumed to represent mean or expected TCLP value (see section 2.3.5)
- "J" value assumed to represent maximum or high-end TCLP value (see section 2.3.5)

NA : Modeling results are not available or not applicable because either preliminary modeling indicated low risk for the waste constituent or because TC values are not available for the waste constituent.

Table 5.6 CSO Contingent Management Scenario Results

Waste Stream	Constituent	On-Site					Off-Site				
		Well Conc. (mg/L)	Direct Risk	Total Risk	Two High-End Parameters		Well Conc. (mg/L)	Direct Risk	Total Risk	Two High-End Parameters	
Two High-End Parameter:											
Contingent Management ¹	Benzene	1.0E-02	1.0	1.7	Waste Vol.	Y-Well	1.6E-02	1.6	2.5	Waste Vol.	Area
Non-Cont. Management	Benzene	1.9E-02	1.9	3.0	Waste Vol.	X-Well	1.6E-02	1.6	2.5	Waste Vol.	Area
1995 Background Document	Benzene	6.1E-03	0.6	NA	NA	NA	6.1E-03	0.6	NA	NA	NA
Contingent Management Monte Carlo:											
90-th Percentile	Benzene	1.1E-03	0.1	0.2	NA	NA	2.2E-03	0.2	0.3	NA	NA
95-th Percentile	Benzene	3.2E-03	0.3	0.5	NA	NA	6.6E-03	0.7	1.1	NA	NA
99-th Percentile	Benzene	1.2E-02	1.2	1.8	NA	NA	2.0E-02	2.0	3.2	NA	NA
Non-Contingent Management Monte Carlo:											
90-th Percentile	Benzene	5.00E-04	5.0E-02	0.1	NA	NA	1.76E-03	0.2	0.3	NA	NA
95-th Percentile	Benzene	1.58E-03	0.2	0.3	NA	NA	6.84E-03	0.7	1.1	NA	NA
99-th Percentile	Benzene	6.34E-03	0.6	1.0	NA	NA	2.14E-02	2.1	3.4	NA	NA

1. Contingent Management of CSO Sediment includes all generated waste quantities except recycled waste; whereas, the 1995 proposal scenario and revised proposal analyses included only Subtitle D landfilled waste quantities.

2. The HBN value for Benzene is equal to 0.01 mg/l, which corresponds to a direct risk from ingesting 1.4 l/day of water (1.0 x 10⁻⁴ risk per 1 mg/l benzene). The total risk also includes an indirect risk from showering (6.06 x 10⁻⁵ risk per 1mg/l benzene).

Table 5.7 Codisposal Scenario Results

Scenario	Constituent	Two-Parameter High End			Monte Carlo								
					90-th Percentile			95-th Percentile			99-th Percentile		
		Direct Risk	Total Risk	TC-Rule ² Total Risk	Direct Risk	Total Risk	TC-Rule ² Total Risk	Direct Risk	Total Risk	TC-Rule ² Total Risk	Direct Risk	Total Risk	TC-Rule ² Total Risk
On-Site	Arsenic	4.9	4.9	4.9	0.1	0.1	0.1	0.6	0.6	0.6	7.8	7.8	7.8
	Benzene	5.0	8.0	4.8	5.0E-02	0.1	0.1	0.3	0.4	0.4	1.6	2.5	2.0
Off-Site w/ Hydrocracking	Arsenic	7.4	7.4	7.4	0.2	0.2	0.2	0.8	0.8	0.8	6.2	6.2	6.2
	Benzene	5.5	8.9	3.8	0.1	0.2	0.1	0.5	0.9	0.7	4.8	7.6	4.0
Off-Site w/o Hydrocracking	Arsenic	7.3	7.3	7.3	0.1	0.1	0.1	0.8	0.8	0.8	7.3	7.3	7.3
	Benzene	2.4	3.8	3.1	0.1	0.2	0.1	0.5	0.8	0.7	4.1	6.6	3.7

1. Risk results are presented as HBN exceedance or HBN/well conc. This ratio corresponds to a 1×10^{-6} risk.

The HBN value for Benzene is 0.01 mg/l, which corresponds to a direct risk from drinking 1.4 l/day of water

(1.0×10^{-4} risk per 1mg/l benzene). The total risk also includes an indirect risk from showering (6.05×10^{-5} risk per 1mg/l benzene).

2. Input leaching rates were capped on TC Regulatory levels for maximum allowable TCLP values for disposal in Subtitle D landfills (0.5 mg/l for benzene, and 5.0 mg/l for arsenic)

Table 5.8 Off-Spec Products and Fines Summary of Analyses Results for Benz(a)anthracene

Analysis	95-th Perc. Well Conc. (mg/L)		(1x10 ⁻⁶) Risk	
	On-Site	Off-Site	On-Site	Off-Site
1. Monte Carlo Analysis+	2.68E-06	8.86E-05	0.13	4.43
2. Monte Carlo Analysis*	2.74E-06	1.09E-04	0.14	5.45
1. High-End Analysis**	4.23E-04	3.85E-04	21.15	19.25
2. High-End Analysis***	6.72E-05	9.29E-05	3.36	4.65

+ Using only J value = 13 ppb

* Using J value and 5 values of 1/2 quantitation limit (= 50 ppb)

** With J value = mean; determine 2 other high-end parameters

***With J value = high-end value; determine one other high-end parameter

6.0 REFERENCES

- 1992 RCRA §3007 Survey of the Petroleum Refining Industry Database.
- API, 1989. Hydrogeologic Database for Groundwater Modeling, API Publication No. 4476 American Petroleum Institute.
- Chappelle, F.M., 1993. Groundwater Microbiology and Geochemistry. John Wiley and Sons, New York.
- Kool, J.B., P.S. Huyakorn, E.A. Sudicky, and Z.A. Saleem, 1994. A composite modeling approach for subsurface transport of degrading contaminants from land disposal sites. *Journal of Contaminant Hydrology*, vol.17 pp. 69-90.
- Kollig, H.P., J.J. Ellington, E.J. Weber, and N.L. Wolfe. Pathway analysis of chemical hydrolysis for 14 RCRA chemicals. U.S. EPA Environmental Research Brief EPA/600/M-89/009.
- Krumholtz, L., M.E. Caldwell and J.M. Suflita. 1996. Biodegradation of BTEX Hydrocarbons Under Anaerobic conditions. Chapter in "Bioremediation: Principles and Applications" R. Crawford & D. Crawford, eds. Cambridge University Press.
- Newell, C.J., L. P. Hopkins, and P. B. Bedient, 1990. A Hydrogeologic Database for Groundwater Modeling. *Groundwater*, Vol. 28, No. 5, pp. 703-714.
- RCRA CBI Documents, 1995. Document Control Numbers BP9500077 and BP9500086. (On and Offsite Petroleum Refining Waste Landfill Statistics).
- Salinitro, J.P., 1993. The Role of Bioattenuation in the Management of Aromatic Hydrocarbon Plumes in Aquifers. *Groundwater Monitoring and Remediation*, p. 1-29. Batelle Press. Columbus, Ohio.
- USEPA, 1988. Draft National Survey of Solid Waste (Municipal) Landfill Facilities, EPA/530-SW-88-034, U.S. Environmental Protection Agency, Washington D.C.
- USEPA, 1989. USEPA Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual. Washington D.C., 20460.
- USEPA, 1992. Guidance on Risk Characterization for Risk Managers, USEPA Memorandum, Washington, D.C., 20460.
- USEPA, 1995a. Listing Background Document for the 1992-1996 Petroleum Refining Determination. U.S. EPA Office of Solid Waste, Washington, D.C., 20460.

- USEPA, 1995b. Assessments of Risks from the Management of Petroleum Refining Waste Background Document. U.S. EPA Office of Solid Waste, Washington, D.C., 20460.
- USEPA, 1995c. Review of EPA's Composite Model for Leachate Migration with Transformation Products-EPACMTP. Science Advisory Board Exposure Model Subcommittee of the Environmental Engineering Committee. Report EPA-SAB-EEC-95-O10, August. U.S. EPA Science Advisory Board.
- USEPA, 1995d. Background Document for Groundwater Pathway Analysis. U.S. EPA Office of Solid Waste, Washington, D.C., 20460.
- USEPA, 1996a. Study of Selected Petroleum Refining Residuals, Industry Study. U.S. EPA Office of Solid Waste, Washington, D.C., 20460.
- USEPA, 1996b. Assessments of Risks from the Management of Petroleum Refining Waste Background Document. U.S. EPA Office of Solid Waste, Washington, D.C., 20460.
- USEPA, 1996c. EPA's Composite Model for Leachate Migration with Transformation Products. Background Document, Office of Solid Waste, Washington, D.C., 20460.
- USEPA, 1996d. Background document for EPACMTP: Finite Source Methodology for Degrading Chemicals with Transformation Products. U.S. EPA, Office of Solid Waste, Washington, D.C., 20460.
- USEPA, 1996e. Background Document for Metals. EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP). Volume I: Methodology. U.S. EPA, Office of Solid Waste, Washington, D.C., 20460.
- USEPA, 1997a. Docket Report Petroleum Waste Listing Notice of Data Availability: Analyses Regarding Leaching of Oily Waste. U.S. EPA, Washington D.C.
- USEPA, 1997b. Docket Report Petroleum Waste Listing Notice of Data Availability: Active Lives of Landfills Used for the Disposal of Petroleum Refining Wastes. U.S. EPA Washington D.C.
- USEPA, 1997c. Supplemental Background Document; Nongroundwater Pathway Risk Assessment, Petroleum Process Waste Listing Determination, U.S. EPA, Washington D.C.
- USEPA, 1997d. EPA's Composite Model for Leachate Migration with Transformation Products. User's Guide, Office of Solid Waste, Washington, D.C., 20460.
- USGS, 1985. National Water Summary, 1984, United States Geological Survey Water-Supply Paper 2275.

Washington, J.W., 1995. Hydrolysis Rates of Dissolved Volatile Organic Compounds Principles, Temperature Effects and Literature Review. *Groundwater* 33(3): 415-424.