Appendix C

Risk Assessment Methodology and Results

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Attachments

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Appendix C

Risk Assessment Methodology and Results

C.1 Appendix Overview and Discussion of Results

The purpose of this appendix is to present the tiered risk assessment methodology developed by EPA to characterize the risks associated with chemical constituents managed in surface impoundments considered in this study. This appendix builds on Chapter 3 of the study report, and provides an in-depth description of the methodology, assumptions, models, data sources, results, and uncertainties involved in this assessment. As appropriate, this appendix includes elements of the approach and terminology proposed in the *Surface Impoundment Study Technical Plan for the Human Health and Ecological Risk Assessment* (U.S. EPA, 2000c), referred to hereafter as the *Technical Plan*.

Appendix C is organized in six major sections. Section C.1 provides an overview of the methodology and a crosswalk between the tiered risk assessment conducted for the Surface Impoundment Study (SIS) and the two-phased risk assessment approach described in the Technical Plan. This section begins by summarizing the key results from this analysis and presents a discussion of key uncertainties that are relevant to any of the pathways for which quantitative risk results were predicted. In addition to an overall presentation of methods and results, Appendix C.1 presents a methods summary, key results, and a discussion of uncertainty for each of the three stages of this assessment: preliminary screen, release assessment, and risk modeling. This first section is organized as follows:

C.1.1 *Overview*
C.1.2 *Phase IA: Preliminary Screen - Human Health*
C.1.3 *Phase IB: Release Assessment - Human Health*
C.1.4 *Results of Phase IA and IB - Human Health*
C.1.5 *Phase IC/II: Risk Modeling - Air Pathway*
C.1.6 *Phase IC/II: Risk Modeling - Groundwater Pathway*
C.1.7 *Phase IC/II: Risk Modeling - Groundwater to Surface Water Pathway*
C.1.8 *Phase IC/II: Indirect Exposure Pathway Assessment - Human Health*
C.1.9 *Phase IA: Preliminary Screen - Ecological Risk*
C.1.10 *Results of Special Interest*

The other major sections of Appendix C include

C.2 *Air Pathway*
C.3 *Groundwater Pathway*
C.4 *Groundwater to Surface Water Pathway*
C.5 *Indirect Exposure Pathway*
C.6 *Ecological Risk Screening*

The major sections provide a detailed description of the methodology, including assumptions, input parameters, and data sources, for each pathway. The discussion of key results and uncertainties for each of these pathways is discussed in Section C.1.1.

C.1.1 Overview

EPA proposed the *Technical Plan* for this assessment in February 2000. That *Technical Plan* was peer-reviewed and largely implemented in the SIS. However, based on an evaluation of the peer review comments, and in consideration of the initial sets of risk results from the screening stages of the analysis, EPA modified the methodology presented in the *Technical Plan.* As the assessment strategy evolved, EPA introduced these modifications to address the peer review comments and to reflect an increasing understanding of the technical risk assessment issues. This section provides a crosswalk with the technical plan that will allow the reader to identify features that were implemented largely as presented in the *Technical Plan* and provides a full description of the methods not covered by the technical plan but added to the assessment to better accomplish the goal of characterizing impoundment risks at a national level.

There are two principal differences between the *Technical Plan* and the tiered risk assessment methodology used to produce the national risk estimates presented in Chapter 3. First, EPA determined that the level of resolution offered by the release assessment (referred to as Phase IB in the *Technical Plan*) was insufficient to winnow down the number of facilities, impoundments, and constituents to be evaluated using a multimedia risk model to a reasonable number (referred to as Phase II in the *Technical Plan*). EPA decided that uncertainty in the results from the release assessment could be greatly reduced by conducting additional modeling using currently available peer-reviewed modeling tools, such as EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP). Site-specific data on receptor locations, surface water flow, and other site characteristics were used as input to the risk models to predict pathway-specific risks. Second, EPA determined that the 3MRA model (multimedia, multipathway, multireceptor risk assessment model) selected for Phase II was not sufficiently developed to provide reliable risk estimates within the timeframe for this study. The 3MRA model represents the state-of-the-science in multimedia modeling at EPA; however, EPA is currently evaluating peer review comments on the beta version of that model, and the subsequent version that addresses those comments would be a much more appropriate tool for this national assessment. The Phase II multimedia modeling plan was integrated with the prioritization scheme to identify facilities indirect pathway modeling as described in the *Technical Plan* (referred to as Phase IC). This integration produced a risk modeling approach that made full use of available site data to rank facilities for additional modeling and used peer-reviewed models to evaluate facilities that exceeded risk criteria during the release assessment for direct exposure to groundwater and air and indirect exposure through the groundwater to surface water pathway. For the assessment of other indirect exposure pathways, EPA developed a series of criteria based on a variety of data sources (including the survey responses) and created a numeric ranking of facilities according to their potential for completion of indirect exposure pathways such as the farm food chain. This integrated approach, referred to in this section as the Phase IC/II approach for a convenient reference to the *Technical Plan*, is described in substantial detail in Sections C.2 through C.5 of this appendix. Table C.1-1 provides a crosswalk between

Table C.1-1. Risk Assessment Methodology—Crosswalk with *Technical Plan*

Analysis Stage	SIS Approach	*Technical Plan* as Proposed	Modifications to *Technical Plan*
Preliminary Screen	• Based on health and ecological screening factors • Cumulative risks summed across pathways for each facility • Direct exposure to air • Direct exposure to groundwater • Includes human health and ecological risk • Indirect exposure through groundwater to surface water pathway • Facilities and impoundments that exceed risk criteria progress to **release assessment** • Constituents lacking adequate data to estimate an air concentration progress to **release assessment** for air	• Referred to as **Phase IA** • Based on health and ecological screening factors • Cumulative risks summed across pathways for each facility • Direct exposure to air • Direct exposure to groundwater • Direct exposure to sludge • Includes human health and ecological risk • Facilities and impoundments that exceed risk criteria progress to **Phase IB** for human health • Subset of facilities and impoundments that exceed risk criteria progress to **Phase II** for ecological risk	• Added methods to evaluate groundwater to surface water pathway by comparing leachate concentrations to ambient water quality criteria • Ecological risks were not evaluated beyond the preliminary screen • Direct exposure to sludge was considered but, due to the high uncertainty in modeling a postclosure scenario, the sludge exposure pathway was not modeled and only looked at in the indirect exposure pathway screening • Virtually all volatile and semivolatile constituents progressed to the **release assessment** for air due to a lack of suitable data to derive an air concentration
Release Assessment	• Based on human health screening factors • Cumulative risks summed within pathway for each facility • Screening-level modeling using IWEM for groundwater • Screening-level modeling using IWAIR for air • Dilution attenuation factors used to estimate groundwater concentration delivered to surface water • Facilities, impoundments, and constituents that exceed criteria progress to **risk modeling**	• Referred to as **Phase IB** • Based on human health screening factors • Cumulative risks summed within pathway for each facility • Screening-level modeling using groundwater screening model • Screening-level modeling using air screening model • Facilities, impoundments, and constituents that exceed criteria progress to **Phase II** for human health	• Added methods to compare estimate of groundwater concentration to ambient water quality criteria

continued

Table C.1-1 (Continued)

Analysis Stage	SIS Approach	*Technical Plan* as Proposed	Modifications to *Technical Plan*
Risk Modeling	• Cumulative risks summed within pathway and across impoundments for each facility • Ranking methodology developed to identify priority sites for groundwater modeling • Monte Carlo simulation using EPACMTP, and exposure/risk model used for groundwater pathway • Modeling for air pathway conducted using IWAIR at actual receptor distances • Ranking methodology developed to identify priority sites for surface water modeling • Modeling (screening) for surface water pathway using EPACMTP for infiltration rate and simplistic surface water dilution algorithm • Facilities that manage bioaccumulative chemicals identified for indirect exposure evaluation • Methodology developed to rank facilities according to their potential for complete indirect exposure pathways	• Referred to as **Phase II** • Cumulative risks summed within pathway and across impoundments for each facility • Prioritization of facilities that manage bioaccumulative chemicals referred to as **Phase IC** • Identified 3MRA model (multimedia, multipathway, multireceptor risk assessment model) to increase resolution of direct pathway modeling and to predict indirect pathway risks	• Referred to as **Phase IC/II** in the Section C.1.1 • Referred to as **risk modeling** in Chapter 3 • **Phase II** in the *Technical Plan* replaced by - direct exposure pathway risk modeling - indirect exposure pathway risk modeling for surface water - ranking scheme for indirect exposure pathway potential • **Phase IC** in the *Technical Plan* replaced by - ranking methodologies to identify additional sites for risk modeling for both direct and indirect exposure pathways

the *Technical Plan* proposed by EPA and the tiered risk assessment approach described in Chapter 3.

C.1.1.1 Methods Summary. As shown in Table C.1.1, EPA designed an analytical framework that progressed from precautionary screening stages to more realistic, site-based modeling using peer-reviewed simulation models. EPA used several different measures of chronic risk and hazard in the risk assessment. Cancer risks were expressed as individual lifetime excess probability of cancer; a threshold of 1 in 100,000 was used as the criteria for determining whether a constituent posed a risk of concern. The hazard associated with exposure to noncancer constituents was measured using a hazard quotient (HQ). The HQ is the ratio of the estimated exposure concentration to an EPA reference dose (RfD) for ingestion or reference concentration (RfC) for inhalation. RfDs and RfCs are threshold measures of hazard that are set at a level that EPA has estimated will not result in adverse effects in humans. The human health threats associated with surface water contamination were evaluated using ratios of estimated surface water concentrations to ambient water quality criteria for human health (HH-AWQC). The screening stages referred to in the technical plan as Phase IA and Phase IB, were based on clear science decision rules related to threshold concentrations of potential concern and low likelihood of exposures. These decision rules allowed EPA to screen out those constituents, impoundments, and facilities presenting negligible potential risks and to focus the risk modeling efforts on those facilities that may present higher potential risks. EPA used risk criteria of 10^{-5} for carcinogenic risk and HI = 1 for noncarcinogenic risk throughout the analysis. In this report, these stages are referred to as "preliminary screening" and "release assessment," respectively, to provide the reader with more descriptive terms for the risk assessment steps.

The **human health risk screening** of direct pathways consisted of a staged analysis described as a preliminary screen and release assessment. These stages can be summarized as follows:

- The preliminary screen (Phase IA) compared reported constituent concentrations in surface impoundments to concentrations protective of human health (called human health screening factors) for the air pathway and the groundwater pathway. This stage is described in detail in Section C.1.2 of this appendix.

- The release assessment (Phase IB) estimated human health risk levels based on exposure concentrations predicted using screening-level models for the air pathway, the groundwater pathway, and the groundwater to surface water pathway. The Phase IB risk screening was only performed for constituents not eliminated from further evaluation based on Phase IA. This stage is described in detail in Section C.1.3 of this appendix.

The **human health risk screening** of the groundwater to surface water pathway also consisted of a staged analysis described as a preliminary screen and release assessment. Because this pathway analysis was not discussed in the *Technical Plan*, it is described in Section C.4 of this appendix.

- The preliminary screen (Phase IA) compared reported constituent concentrations in surface impoundments to ambient water quality criteria developed for the protection of human health from ingestion of contaminated aquatic organisms and drinking water.

- The release assessment (Phase IB) estimated human health risk levels based on exposure concentrations predicted using screening-level models for the air pathway, the groundwater pathway, and the groundwater to surface water pathway. The Phase IB risk screening was only performed for constituents not eliminated from further evaluation based on Phase IA.

In addition to screening direct exposure pathways and the groundwater to surface water pathway, the **human health risk screening** also involved an assessment of the potential for other indirect exposure pathways to be completed at facilities that manage bioaccumulative chemical constituents. This screening assessment was qualitative and integrated information on site physiography, potential receptors, and impoundment characteristics into a numeric framework to rank facilities according to their potential for concern for indirect exposure. This methodology is based on Phase IC in the *Technical Plan*. It includes chemical-specific evaluations for bioaccumulative potential and a ranking scheme that takes full advantage of several data sources, including the survey responses, geographic information system (GIS) tools, and results from the Phase IB screening analysis. This methodology also borrows from Phase II of the *Technical Plan* in that it seeks to quantify the potential for indirect exposures at the facility level using an array of explicit criteria. Section C.5 of this appendix provides a complete discussion of the methods developed for this study to evaluate indirect pathways.

The **ecological risk screening** consisted of a single stage that parallels the human health Phase IA screening of direct pathways for noncancer chemicals:

- The preliminary screen (Phase I) compared reported constituent concentrations to concentrations protective of ecological receptors in freshwater aquatic, wetland, and terrestrial habitats, (called ecological screening factors). Exposure pathways included direct ingestion of contaminated plants, prey, and media, as well as direct contact with a contaminated medium for certain types of receptors such as soil biota. This assessment is presented in detail in Section C.6 of this appendix.

Based on the results of the release assessment, the **human health risk modeling** of direct pathways and surface water was conducted using peer-reviewed models, such as EPACMTP to develop site-based risk estimates for the air, groundwater, and groundwater to surface water pathways.[1] For the groundwater and groundwater to surface water pathways, EPA determined that the screening risk results were not sufficient justification to perform risk modeling. In many instances, the site characteristics did not support the completion of the exposure pathway. To identify those sites appropriate for risk modeling, EPA developed a series of criteria to rank

[1] The surface water modeling is considered a screening-level model and, although the methodology has been peer-reviewed, the approach does not involve modeling tools developed to the same level of sophistication as those used for the air and groundwater pathways.

facilities based on site attributes relevant to completion of a given pathway. For example, EPA reviewed technical reports on groundwater hydrology submitted by the survey respondents as input to a numeric ranking scheme. For each site, the available information on the stratigraphy (the composition of subsurface layers) and the location of receptor wells was assigned a numeric score for ranking purposes. Once this ranking was completed, EPA evaluated the potential for adverse impacts on water quality from the groundwater to surface water pathway for all of the highest ranked facilities.

- For the air pathway, EPA used Industrial Waste Air Model (IWAIR) to model risk at the actual location of the nearest receptor, identified using topographic maps and aerial photos. This methodology is described in detail in Section C.2 of this appendix.

- For the groundwater pathway, EPA conducted a Monte Carlo simulation of the fate and transport and exposure to predict the distribution of cancer risks and noncancer hazard, as appropriate, for chemicals of potential concern managed at each facility. This methodology is described in detail in Section C.3 of this appendix.

- For the groundwater to surface water pathway, EPA performed screening risk modeling using a simplified fate and transport construct to predict the surface water concentrations and compared those levels with the ambient water quality criteria. This methodology is described in detail in Section C.4 of this appendix.

C.1.1.2 Key Results of the Analysis. Table C.1-2 illustrates the progression of facilities in the sample population from the risk screening stages through the risk modeling stage.[2] Note that the results in this table are not weighted and that we do not distinguish between concentrations based on reported values and those based on surrogate protocols or detection limits (DLs). This table is intended to show that the analytical framework designed by EPA provided an effective tool for reducing the number of facilities/impoundments/constituent combinations requiring risk modeling. Notice that, at each stage, fewer facilities and impoundments enter the subsequent stage. For example, of the 71 facilities that exceed the risk criteria, only 10 facilities entered into the risk modeling stage; of these 10 facilities, only 7 facilities show risk exceedances, indicating that the conceptual approach of eliminating facilities from consideration because of very low potential risks is sound. Indeed, the peer review comments on the technical plan were, without exception, supportive of this framework. The results generated at each stage were updated so that the risk modeling results could be integrated with the screening results and ultimately weighted up to present a national risk characterization.

The overall results for the analysis are presented in Tables C.1-3 through C.1-6. Tables C.1-3 and C.1-4 present results at the facility level, and Tables C.1-5 and C.1-6 present results at the impoundment level. This set of tables presents the national risk characterization produced by weighting up the sample population results presented in Table C.1-2. The weighting methodology is described in detail in Appendix A. The tables contain information on the number

[2] This table presents results only for the direct pathways, air, and groundwarter.

Table C.1-2. Summary of Screening Process and Risk Analysis Results for Direct Pathways

Category	Number of Facilities in Sample	Number of Impoundments in Sample	Number of Chemicals in Sample	Number of Impoundment/ Chemical Combos in Sample
In SIS long survey				
Eligible	195	661	215	
With in-scope impoundments	157	531	215	9767
In-scope impoundments with chemical data	133	471	204	9462
Entered direct exposure pathway screening[a]				
Any pathway	133	442	193	8117
Inhalation	85	304	193	3125
Groundwater ingestion	133	436	193	7976
Exceeded risk criterion after direct exposure pathway screening[a]				
Any pathway	116	395	147	4097
Inhalation	85	290	90	2754
Groundwater ingestion	106	350	129	2123
Consider for site-based modeling (exceeded risk criterion after screening-level modeling)				
Any pathway	75	225	92	795
Inhalation	33	75	42	180
Groundwater ingestion-modeled	10	37	36	191
Groundwater ingestion-evaluated but not modeled	61	177	72	484
Exceeded risk criterion after site-based modeling				
Any pathway	15	36	25	74
Inhalation	11	17	11	23
Groundwater ingestion	7	204	15	53

[a] For inhalation, survey data on air concentration needed to perform direct exposure pathway screening were unavailable for most of the facilities. These facilities, impoundments, and chemicals are included here under the following categories: direct exposure pathway screening, exceeded risk criterion after direct exposure pathway screening, and entered screening-level modeling.

Table C.1-3. Facility-Level Overview of Human Health Results by Decharacterization Status

Facility Status	Below Risk Criteria		Environmental Release All Values		Exceeds Risk Criteria [a] All Values		Total	
Never Characteristic [b]	2,031 (46%)		1,410 (32%)		196* (4%)		3,638 (82%)	
	56%	91%	39%	74%	5%*	65%*	100%	82%
Decharacterized [c]	212 (5%)		499 (11%)		107* (2%)		818 (18%)	
	26%	9%	61%	26%	13%	35%*	100%	18%
All facilities	2,244 (50%)		1,909 (43%)		304* (7%)		4,457 (100%)	
	50%	100%	43%	100%	7%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

[a] Results are for groundwater, air, and groundwater to surface water pathways.

[b] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

Table C.1-4. Facility-Level Overview of Human Health Results by Decharacterization Status—Reported Values and Surrogate/DL Values[a]

Facility Status	Below Risk Criteria		Environmental Release[b] Reported Values		Environmental Release[b] Surrogate/ DL Values		Exceeds Risk Criteria[b] Reported Values		Exceeds Risk Criteria[b] Surrogate/ DL Values		Total	
Never Characteristic	2,031 (46%)		598 (13%)		812 (18%)		196* (4%)		0 (0%)		3,638 (82%)	
	56%	91%	16%	64%*	22%	83%	5%*	83%*	0%	0%	100%	82%
Decharacterized	212 (5%)		330 (7%)		169 (4%)		41* (0.9%)		66* (1%)		818 (18%)	
	26%	9%	40%*	36%*	21%	17%	5%*	17%*	8%*	100%	100%	18%
All facilities	2,244 (50%)		928 (21%)		981 (22%)		237* (5%)		66* (1%)		4,457 (100%)	
	50%	100%	21%	100%	22%	100%	5%	100%	1%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

DL = Detection limit.

[a] Results are for groundwater, air, and groundwater to surface water pathways.

[b] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

Table C.1-5. Impoundment-Level Overview of Human Health Results by Decharacterization Status[a]

Impoundment Status	Below Risk Criteria		Environmental Release[b] All Values		Exceeds Risk Criteria[b] All Values		Total	
Never Characteristic	5,329 (45%)		3,813 (32%)		202* (2%)		9,344 (79%)	
	57%	88%	41%	70%	2%	51%*	100%	79%
Decharacterized	697 (6%)		1,630 (14%)		193 (2%)		2,520 (21%)	
	28%	12%	65%	30%	8%	49%*	100%	21%
All Impoundments	6,025 (51%)		5,442 (46%)		396 (3%)		11,863 (100%)	
	51%	100%	46%	100%	3%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

[a] Results are for groundwater, air, and groundwater to surface water pathways.

[b] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

Table C.1-6. Impoundment-Level Overview of Human Health Results by Decharacterization Status—Findings Shown for Reported Values and Surrogate/DL Values[a]

Impoundment Status	Below Risk Criteria		Environmental Release[b] Reported Values		Environmental Release[b] Surrogate/ DL Values		Exceeds Risk Criteria[b] Reported Values		Exceeds Risk Criteria[b] Surrogate/ DL Values		Total	
Never Characteristic	5,329 (45%)		1,703 (14%)		2,110 (18%)		187* (2%)		16* (0.1%)		9,344 (79%)	
	57%	88%	18%	60%*	23%	80%	2%	78%*	0.2%	10%*	100%	79%
Decharacterized	697 (6%)		1,117 (9%)		513 (4%)		54* (0.5%)		140 (1%)		2,520 (21%)	
	28%	12%	44%	40%*	20%	20%	2%	22%*	6%	90%*	100%	21%
All Impoundments	6,025 (51%)		2,820 (24%)		2,623 (22%)		240* (2%)		155 (1%)		11,863 (100%)	
	51%	100%	24%	100%	22%	100%	2%	100%	1%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.
DL = Detection limit.

[a] Results are for groundwater, air, and groundwater to surface water pathways.

[b] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

of facilities in each category (shown as numerical values), the percent of the total weighted population (shown in parentheses), and the percent within each category for both rows and columns. Consequently, the tables may be used to provide insight on total numbers of facilities and impoundments, percentages of the national picture, and percentages within categories of interest such as characterization status.[3] Attachment C-4 to Appendix C presents the complete array of tables, along with standard errors, for characterization status and regulatory classification (direct versus zero dischargers) developed for this analysis.

Table C.1-3 presents the overall results across the three pathways for which risks were quantified—air, groundwater, and groundwater to surface water— with facilities classified according to waste characterization categories. Table C.1-4 presents this same information according to whether the source concentration data were based on reported values or surrogate/DL values. Facilities with even one impoundment that manages formerly characteristic waste were classified under the "decharacterized" category; a facility was grouped under "never characteristic" only if none of the impoundments receive formerly characteristic waste. Notice that the results that are reported as "below risk criteria" are identical between Tables C.1-3 and C.1-4. This is because the "below risk" category was effectively removed from consideration, or screened out, in the analysis, and the focus was on characterizing those results indicating risk criteria exceedances or environmental releases. This same information is presented at the impoundment level in Tables C.1-5 and C.1-6. For the entire series of tables, it is important to realize that the categories of "reported values" and "surrogate/DLs" are mutually exclusive. That is, an impoundment or facility with one or more reported values that falls into the "exceeds risk criteria" or "environmental release" categories contributes only to the results under the reported values column. Also, an impoundment or facility that "exceeds risk criteria" if even one constituent and impoundment is reported only in that category. As discussed throughout this report, EPA regards the reported values as of sufficient quality to support risk findings.

The key findings from this series of tables can be summarized as follows:

- EPA estimates that 7 percent of all facilities may exceed risk criteria for one or more direct pathways and/or the groundwater to surface water pathway. The majority of results for those facilities are based on reported values; therefore, the risk exceedance estimates are largely based on reported data, not surrogate protocols or detection limits.

- Less than half the facilities (43 percent) were classified in the environmental release category. This percentage is based on the facilities that exceeded criteria after the screening-level modeling *and* did not show exceedances in the risk modeling stage either because (1) the facility was determined to be a low priority for risk modeling or (2) the results from the risk modeling were below levels of concern.

[3] The total percentages shown in the first table of each set will sometimes be slightly higher than the percentages shown in the detailed table with both reported and surrogate/DL concentrations. This is due to the convention adopted for these tables to limit entries to two significant figures. Hence, 19 percent may be shown in the table as 20% and, therefore, the totals do not appear to match exactly.

- The percentage of facilities that may exceed risk criteria is higher than the percentage of impoundments that may exceed risk criteria. Many facilities have multiple impoundments, and this finding suggests that, where risk exceedances occur, they generally include only a subset of the impoundments at the facility. Thus, facilities predicted to exceed risk criteria have proportionally fewer impoundments that exceed risk criteria than the entire group of facilities evaluated in this study. That is, the risk estimates at the impoundment level are below the risk estimates at the facility level.

C.1.1.3 Discussion of Key Uncertainties. This section describes the key uncertainties that EPA identified in the risk characterization of surface impoundments that are relevant to the entire study, regardless of the exposure pathway considered. The discussion is presented in order of importance, beginning with the uncertainties associated with a tiered risk assessment approach, and ending with the background concentrations. Additional pathway-specific discussions of uncertainty are included in Sections C.1.5 through C.1.9.

Uncertainties Associated with the Approach. A tiered risk assessment offers some distinct advantages with respect to the resources required to develop risk estimates across a large population of facilities, impoundments, and chemical constituents. In addition, the a tiered approach allows for the use of all information, both quantitative and qualitative, in characterizing risks. That is, the tiered framework is not constrained by an inflexible list of data requirements. For instance, only 15 of the 69 facilities that were classified under "environmental releases" in the release assessment stage of the analysis progressed to screening risk modeling. Because many of those facilities and impoundments did not exceed the risk criteria (i.e., ambient water quality criteria), EPA concluded that the ranking scheme developed to identify high-priority facilities was successful. Similarly, EPA conducted risk modeling for only 10 of the 71 facilities that exceeded the risk criteria during the screening-level modeling using Industrial Waste Evaluation Model (IWEM). If all 10 facilities that were evaluated during the risk modeling had shown risk exceedances, then EPA might have concluded that the numeric ranking criteria were not protective enough and that additional facilities needed to be modeled. If none of the facilities had shown risk exceedances, then EPA might have concluded that the early screening stages were excessively protective and that the final modeling was, in some cases, unnecessary. However, the final modeling showed that some facilities pose potential risks while others do not, and EPA concludes from this that the first two stages of analysis performed well in that they did not introduce a systematic bias to the risk estimates. EPA also concludes that the third stage served as a useful discriminator of facilities that should be considered to have risks of potential concern.

This logic notwithstanding, there are inherent uncertainties in a tiered approach that introduce uncertainty into the risk estimates. Specifically, it is not possible to determine with absolute certainty that the predicted risks for facilities that were *not* assessed in the risk modeling would not exceed risk criteria if they were modeled. Consequently, there is uncertainty with respect to our ability to identify all potential risk exceedances. However, given the relatively low level of risk exceedances for reported values (approximately 5 percent), and the apparent effectiveness of the ranking schemes developed for the groundwater and groundwater to surface

water pathways, respectively, it appears that the uncertainty in missing false positives (i.e., facilities that may exceed risk criteria but were not modeled) is low.[4]

Source Concentration Data. One of the most sensitive parameters in risk modeling is the source concentration term. Frequently, this term is associated with a high level of uncertainty because (1) the data on concentration may not be sufficient to characterize the variability due to changing waste streams, impoundment conditions, and other characteristics; and (2) the analytical methods may be insufficient to quantify the concentration term, so there is a lack of knowledge as to what the actual concentration might be or which chemicals are actually managed in given impoundment. The former has serious cost implications for industry because the reporting requirements to capture the entire picture of concentration variability would be prohibitive. The latter also has cost implications in that analytical packages with lower detection limits tend to be more costly. However, this may be a serious source of uncertainty because it is not known whether a chemical concentration reported as "below the detection limit" is slightly below the limit, 3 orders of magnitude below the limit, or simply an artifact of the sampling/analysis package chosen by a particular facility. To investigate the uncertainty in the source concentration data extracted from the survey responses, EPA conducted field sampling and analysis of a subset of facilities that received the survey. EPA evaluated the potential risks for direct exposure pathways using the sampling data, and compared those results to the results based on survey responses; these responses included reported detection limits or default detection limits if none were reported. Appendix E describes the field sampling and analysis program, including the methodology for sampling and a comparison of results to the survey data. The following discussion summarizes that approach and discusses the implications of the findings.

An Example of Sampling Data Indicating the Presence of Chemical Constituents

A facility reported no in-scope chemicals in their survey response, so were classified as not having an in-scope impoundment. No risk modeling was performed on this facility based on survey data.

The sampling program detected concentrations of 10 chemicals at this facility: 9 metals and 1 inorganic. None of these constituents are volatile, so air modeling was not conducted. However, groundwater modeling was conducted using sampling data. All but one metal (arsenic) screened out in the direct exposure pathway screening, and arsenic screened out at the screening-level modeling (assuming no liner, since actual liner data were not provided in the survey response).

Therefore, based on the sampling data, this facility would be classified as below risk criteria.

Risk Screening Approach. Risk modeling for the direct pathways (air and groundwater) was conducted on the sampling data, using the same methodology described in Section C.1.1.1.

[4] It was not necessary to develop a ranking scheme to identify facilities for risk modeling of the air pathway. Because of the limited number of facilities that exceeded risk criteria in the air release assessment, and because of the computational speed of IWAIR, EPA decided to model all facilities indicating the potential for environmental releases.

At each stage, some impoundment-chemical combinations dropped out, and the remainder progressed to the next stage. For groundwater, EPA conducted a preliminary screen (Phase IA) and release assessment (Phase IB) and compared the results for each facility to those obtained with the survey data at the conclusion of screening-level modeling. Site-based risk modeling was not conducted for groundwater for the sampling data. For air, the sampling data did not include the appropriate data for conducting a preliminary screen (this step requires air emissions or air concentration data, which were not obtained in the sampling program). Therefore, we conducted screening-level modeling and site-based risk modeling (as needed) for air. Because the sampling data represent a small subset of the facilities surveyed (12 of 195), national weights were not applied to these results.

Risk Results Using Sampling Data. None of the sampling data risk results exceeded the risk criteria; most of the risk results fell below the risk criteria, although a few qualify under the environmental release category. Table C.1-7 shows the impoundments with environmental releases for either air or groundwater based on the sampling data in contrast to the survey-based results for these impoundments. In all cases, the sampling-based risk result is the same or below the survey-based result.

Table C.1-7. Impoundment-level Results Comparison for Environmental Releases Based on Sampling Data

		Groundwater		Air	
Facility	**Impoundment**	**Survey-based Result for Impoundment**	**Sample-based Result for Impoundment**	**Survey-based Result for Impoundment**	**Sample-based Result for Impoundment**
6	2	Environmental release	Environmental release	Environmental release	Environmental release
68	2	Environmental release	Environmental release	Below risk criteria	Below risk criteria
135	1	Environmental release	Environmental release	Below risk criteria	Below risk criteria
173	4	Environmental release	Below risk criteria	Environmental release	Environmental release

Additional chemical-specific details for the groundwater pathway results that indicated potential environmental releases for the sampling data are presented in Table C.1-8. This table compares the risk results and underlying concentrations based on the survey data with the corresponding results and data from the sampling data. Of these seven impoundment-chemical combinations, five had been modeled based on survey data (although four of those five were modeled based on surrogate data rather than reported data). The sampling concentrations are generally higher than the survey concentrations. Three of the five impoundment-chemical combinations resulted in environmental release using the survey data; two resulted in risks below the risk criterion using survey data. Although all three of the facilities showing environmental

releases using sampling data also had environmental releases using survey data, none of the three was chosen for further evaluation because these facilities were ranked relatively low in the numeric ranking for groundwater risk modeling (see Attachment C-8 for ranking results). As discussed in Section C.3, these factors include environmental setting, hydrogeologic conditions, and direction and distance to receptor wells. In this example, the sampling data results support our results using survey data. As a result, we are confident that the sampling results are not of sufficient concern to merit additional groundwater modeling.

Table C.1-8. Environmental Releases for Groundwater Based on Sampling Data

Facility	Impoundment	Chemical	Survey-based Result	Survey Medium[a]	Survey Concentration (mg/L)	Sampling Medium	Sample Concentration (mg/L)
6	2	Fluoride[b]	Below risk criteria	Leachate	0.26	WW in impoundment	3.5
6	2	Chloroform[b]	Below risk criteria	Leachate	0.053	WW in impoundment	0.71
68	2	Arsenic	Environmental release	Leachate	0.17	WW in impoundment	0.023
135	1	Fluoride[b]	Environmental release	Leachate	3.75	WW in impoundment	11.6
135	1	Benzo(a)pyrene	Not modeled	NA	NA	WW influent	0.046
135	1	Benz(a,h)anthracene	Not modeled	NA	NA	WW influent	0.09
135	1	Arsenic[b]	Environmental release	Leachate	0.0014	WW in impoundment	0.052

NA = Not available.
WW = Wastewater.
[a] All impoundment-chemical concentrations also had wastewater within the impoundment concentrations, which were equal to the leachate concentrations.
[b] Survey result based on surrogate concentration data.

Additional, chemical-specific details for the air pathway results that indicated potential environmental releases for the sampling data are presented in Table C.1-9. This table compares the risk results and underlying concentrations based on the survey data with the corresponding results and data from the sampling data. Risk modeling was not performed for either of these impoundment-chemical combinations for the air pathway using survey data. Nevertheless, EPA conducted site-based modeling on both these impoundment-chemical combinations using actual receptor distances (roughly 1,000 meters in both cases) and obtained risks below the risk criterion, leaving them in the environmental release category.

Table C-1-9. Environmental Releases for Air Based on Sampling Data

Facility	Impoundment	Chemical	Survey-based Result	Survey Medium	Survey Concentration (mg/L)	Sampling Medium	Sample Concentration (mg/L)
6	2	Chloroform	Not modeled	NA	NA	WW influent	0.81
173	4	Chloroform	Not modeled	NA	NA	WW influent	0.071

The risk results comparison between the survey and sampling data suggest that the concentration data reported in the surveys may not constitute a serious source of uncertainty in this assessment. Although there are some differences in the concentrations reported in the sampling program, and some chemicals detected in the sampling program were not reported in the survey,[5] the sampling data do not change the impoundment-level results for any impoundment. Interestingly, the majority of survey-based results for impoundment-chemical combinations showing environmental releases were based on surrogate/DL protocols used to infer chemical concentrations (see Appendix A for a complete discussion of these protocols). Although EPA considers risk results based on surrogate/DL concentration values to be more uncertain, this comparative exercise with the sampling-based risk modeling suggests that the decisions regarding the use of surrogate data worked as intended.

Data Limitations. Virtually every input parameter required for risk modeling is associated with some data limitations and uncertainty. Health and ecological benchmarks, human health and ecological exposure factors and behavior patterns, and environmental characteristics of each site rely on data sources of differing quality and are incomplete to some degree. For example, human health benchmarks for inhalation were not available for all constituents evaluated in this study. The absence of air risk results for these constituents does not imply that there are no significant inhalation risks associated with those constituents or the facilities and impoundments in which they are managed. The absence of air risks for chemicals lacking inhalation benchmarks is a source of uncertainty that cannot be quantified given the current state-of-the science and available data. The implications of missing benchmarks along with other sources of uncertainty are discussed below.

Human Health and Ecological Benchmarks. Sources of uncertainty in toxicological benchmarks include one or more of the following: extrapolation from laboratory animal data to humans or ecological receptors, variability of response within the population of interest, extrapolation of responses at high experimental doses under controlled conditions to low doses under highly variable environmental conditions, and adequacy of the database (number of studies available, toxic endpoints evaluated, exposure routes evaluated, sample sizes, length of study, etc.). Toxicological benchmarks are designed to be protective (i.e., to potentially overestimate

[5] As reported in Appendix A, EPA expected to find chemical constituents not reported in the survey responses in some impoundments because the analytical methods used by EPA included lower detection limits for some chemicals.

risk) because of the uncertainties and challenges associated with condensing toxicity data into a single quantitative expression.

Cancer Slope Factors. Cancer slope factors (CSFs) were derived as the 95 percent upper confidence limit of the slope of the dose-response curve using a linear, no-threshold dose-response model. The cancer slope factor is, therefore, an upper-bound estimate of the cancer risk per unit dose and, for this reason, may overstate the magnitude of the risk. In addition, the use of CSFs in projecting excess individual cancer risk introduces uncertainty stemming from a number of factors, including

- Limited understanding of cancer biology
- Variability in the response of animal models
- Differential response in animal models versus humans
- Difference between animal dosing protocols and human exposure patterns.

A key step in CSF development is high- to low-dose extrapolation. Depending on the model used to fit the data, extrapolations to the low dose range can vary by several orders of magnitude, reflecting the potential uncertainty associated with the cancer slope factor.

Reference Doses and Reference Concentrations. Uncertainty in the toxicological and epidemiological data from which reference doses and reference concentrations are derived is accounted for by applying uncertainty factors. An RfD (or RfC) is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (U.S. EPA, 2000b). RfDs and RfCs are based on the no observed adverse effect level (NOAEL) or lowest observed adverse effects level (LOAEL) for the most sensitive effect in the most sensitive or most relevant species. A series of standard uncertainty factors are applied to the NOAEL or LOAEL to derive the RfD or RfC. The following uncertainty factors account for areas of scientific uncertainty:

- Intraspecies variation: accounts for variation in sensitivity among humans (including sensitive individuals such as children, the elderly, or asthmatics)
- Interspecies variation: accounts for extrapolating from animals to humans
- LOAEL to NOAEL extrapolation
- Subchronic to chronic: accounts for extrapolating from a subchronic NOAEL or LOAEL to a chronic NOAEL or LOAEL
- Incomplete database; accounts for the lack of data for critical endpoints (e.g., reproductive and developmental).

Uncertainty factors of 1, 3, or 10 are used. The default value is 10; however, an uncertainty factor of 3 may be used, for example, if appropriate pharmacokinetic data (or models) are available. In addition, a modifying factor may be applied to account for additional

uncertainties in accordance with professional judgment. The default value for the modifying factor is 1. All uncertainty factors (UFs) and the modifying factor (MF) are multiplied together to derive the total uncertainty factor (e.g., U.S. EPA, 1994e). Therefore, the RfD (or RfC) is derived using the following formula:

$$RfD = NOAEL/(UF \times MF).$$

The effect of applying uncertainty and modifying factors is to lower the estimate of the reference dose and increase the hazard quotient for a given exposure.

Exposure Factors. The uncertainty in selection of health and ecological exposure factors changes depending on which stage of the risk analysis is considered. For the preliminary screen (Phase IA) and release assessment (Phase IB), screening factors[6] were derived using protective, default values for exposure as discussed in the *Technical Plan*. The default exposure factors for human health are presented in Table C.1-10; because of the number of ecological receptors, the ecological exposure factors are presented in Attachment C-21. For the risk modeling of the air pathway, the default exposure factors for IWAIR are virtually identical to those shown in Table C.1-10 and, as a result, the choice of exposure factors for the inhalation pathway will also tend to overpredict risk. As described in the *Technical Plan*, the IWAIR model is not currently set up to run Monte Carlo simulations, and these protective exposure factors were used. These exposure factors are, by design, protective of human health and wildlife and, therefore, tend to overpredict risk.

Table C.1-10. Exposure Parameter Values Used to Calculate Human Health Risk Screening Factors

Receptor	Inhalation Rate (m^3/d)	Ingestion Rate of Water (L/d)	Ingestion Rate of Soil (mg/d)	Exposure Frequency (d/yr)	Exposure Duration (yr)	Body Weight (kg)
Child < 1	4.5	0.3	ID	350	1	9.1
Child 1-5	7.55	0.7	200	350	5	15.5
Child 6-11	11.75	0.79	50	350	6	30.8
Child 12-18	14	0.96	50	350	7	58.4
Adult Resident	13.3	1.38	50	350	11	71.4

ID = Insufficient data.

In contrast, the risk modeling of the groundwater pathway involved the use of distributions generated by fitting the data summaries in the *Exposure Factors Handbook* (EFH) (U.S. EPA, 1997c, 1997d, 1997e), in most cases by fitting distributions to selected percentiles. It is assumed that little information is lost by fitting to percentiles versus fitting to raw data. Three

[6] See Attachment C-3 for a complete list of human health screening factors, and Attachment C-23 for a complete list of ecological risk screening factors.

standard two-parameter probability statistical distributions (gamma, lognormal, and Weibull) were used in the groundwater pathway simulation. Other statistical distributions are possible (e.g., U.S. EPA, 2000d), but the technique used in this analysis offered considerable improvement over using a lognormal model in all cases.

Although they offer significant improvement in objectivity over visual estimation, goodness-of-fit tests used to determine which statistical distribution to use for a particular parameter are themselves subject to some uncertainty. One area of concern is uncertainty about how the survey statistics in the EFH (U.S. EPA, 1997c, 1997d, 1997e) were calculated. All of the statistics that have been used to assess goodness-of-fit assume a random sample, which may or may not be a valid assumption for EFH data. Specifically, many of the EFH data sources are surveys that, in many cases, do not involve purely random samples. Rather, they use clustering and stratification, primarily for economic reasons. The effect of this uncertainty on the risk modeling results is unknown.

Natural Background Exposures. In certain cases, EPA performs a risk assessment on wastes that contain contaminants that also are present in the environment as a result of both natural processes and anthropogenic activities. Under these circumstances, receptors potentially receive a "background" exposure that may be greater than the exposure resulting from release of contaminants from the waste. For national analyses like this assessment, the inclusion of background concentrations as part of the analysis is not feasible due to the variability of background concentrations nationwide and the lack of data on national background concentrations for each constituent. Although the margin of exposure and risk predicted during the tiered risk assessment may be used to represent the risk attributable to chemicals managed in surface impoundments, the methodology does not allow us to calculate risks or hazards that reflect both impoundment releases and other environmental sources. For instance, the margin of exposure attributable to a particular facility may be below levels of concern; however, in addition to other background exposures, the *total* risk to residents attributed to the facility and other sources of chemical exposure may be above levels of concern. The variability in background exposures is not reflected in this analysis and is considered a source of uncertainty that is not quantifiable in this analytical framework.

C.1.2 Phase IA: Preliminary Screen - Human Health

As described in the *Technical Plan*, the human health risk screening calculation was performed for each constituent in each surface impoundment for each of the in-scope sample facilities. For this phase, the screening risk estimates were constituent-specific cancer risks or hazard indices (HIs) summed across exposure pathways. Cumulative risks were then calculated for each impoundment and each facility and for each constituent (summed over all impoundments at the facility). The cumulative risk estimates were used to build initial risk distributions for the surface impoundments within the scope of the study. Risk distributions were generated by characterization status and regulatory status and divided into cancer risks and noncancer hazard. These risk estimates were used to exclude constituents, impoundments, and facilities from further analysis.

C.1.2.1 Methods Summary. The groundwater ingestion pathway was evaluated whenever wastewater concentrations or leachate concentrations were available. The air inhalation pathway was evaluated if the constituent was a volatile organic chemical (VOC) or a semivolatile organic chemical (SVOC), and airborne chemical concentration or emissions data were provided in the survey. The soil ingestion pathway was considered; however, EPA believed that uncertainties in characterizing the exposure scenario for postclosure were sufficiently high to render the screening risk results of little value. Environmental releases of sludge particles could occur through erosion/runoff or windblown emissions only assuming that: (1) the impoundment was not capped at closure, (2) the impoundment was completely filled with sludge to grade; and (3) no vegetation was allowed to grow on the sludge. This pathway was evaluated, instead, under the indirect exposure pathway assessment described in Section C.5. Once the air and water concentrations were determined from the survey results, the risks were calculated by dividing the concentration by the appropriate health screening factor, and then multiplying by the appropriate risk criterion. If the screening factor was based on a regulatory standard such as a maximum contaminant level (MCL), then the ratio of concentration to the screening factor was calculated. Finally, the constituent risk and HI were calculated by summing the risks and hazard quotients for all pathways for that particular constituent. If the screening for the constituent has used a regulatory standard, then the maximum ratio of all pathways for that constituent was selected.

Concentration data from the facility survey questionnaire provided the direct exposure concentrations for the Phase IA risk estimates. A special condition existed for calculating air inhalation risks from survey data: if the survey questionnaire did not provide an air concentration or emission rate for a VOC or SVOC constituent, the constituent automatically progressed to Phase IB.

Cumulative Risk Calculation. The calculated screening risks for each constituent for a specific impoundment and facility were combined to generate three cumulative risk estimates: impoundment risk, constituent risk, and facility risk. The cumulative risks were used in the risk screening and risk distributions, as described below.

The impoundment risk (i.e., risk for a particular impoundment for a particular facility) was determined as follows:

- For carcinogenic risks, sum risks from all carcinogenic constituents.
- For noncarcinogenic risks, sum the HIs for all constituents potentially affecting the same target organ, then select the maximum HI from the target organ HIs.

The constituent risk (i.e., risk for a particular constituent for a particular facility) was determined as follows:

- For carcinogenic risks, select the maximum risk for the constituent across all impoundments for the particular facility.
- For noncarcinogenic risks, select the maximum HI for the constituent across all impoundments for the particular facility.

Facility risks were calculated as follows:

- For carcinogenic risks, sum the constituent risks.
- For noncarcinogenic risks, sum the HIs from all constituents potentially affecting the same target organ, then select the maximum HI from the target organ HIs.

Note that this approach takes into account that an individual receptor's exposure factors will only be counted once for the entire facility (e.g., 1.4 L ingested per day or 13 m^3 inhaled per day).

Risk Distribution Development. Cumulative frequency histograms of the risks/HIs were developed from the impoundment, constituent, and facility cumulative risks. A risk cumulative histogram was defined by a set of six class intervals or "bins." The carcinogenic risk ranges defining those bins are: 0 to 10^{-8}, 10^{-8} to 10^{-7}, 10^{-7} to 10^{-6}, 10^{-6} to 10^{-5}, 10^{-5} to 10^{-4}, and 10^{-4}. An HI cumulative histogram was defined by six bins: 0 to 0.01, 0.01 to 0.1, 0.1 to 1.0, 1.0 to 10, 10 to 100, and greater than 100. For the nationally weighted risk results, all of the risk results below the risk criteria were aggregated into a single bin; however, the risk data were not aggregated in this manner prior to the application of national weights.

Risk Screening. The Phase IA risk screening used the three cumulative risk distributions to identify

- Constituents, impoundments, and facilities that have risks below a decision criterion and, therefore, are considered to have negligible risks and are not assessed further.
- Constituents, impoundments, and facilities that have risks above a decision criterion and that will be assessed in Phase IB.

The screening procedure first screened facilities by comparing the facility cumulative risk to the risk decision criteria. If the facility had a risk above the screening criteria, then the impoundment cumulative risk for each impoundment for that facility was compared to the screening criteria. If the impoundment had a risk above the screening criteria, then the constituent cumulative risk for that facility was compared to the screening criteria. If the constituent had a risk above the screening criteria, then the constituent passed to Phase IB for further screening. The constituent was further evaluated **only** for those impoundments at the facility that had risks above the screening criteria. The risk screening was performed for both cancer and noncancer risks.

EXAMPLE. Calculating the cumulative risks and risk screening for a facility.

The example facility has the risk estimates shown in Table C.1-11. The first table presents the risk estimates for each chemical in each of the four impoundments.

The second part of the table shows the cumulative facility, impoundment, and constituent risks. The impoundment risk is the sum of the chemical risks for the impoundment; the impoundment HI is the maximum HI of the two target organ HIs. For instance, for Impoundment A, the carcinogenic risk of 3.7×10^{-4} is the sum of Chemicals 1 and 4. The HI of 0.5 is the HI for Target Organ B.

The constituent risks and HIs are the maximum of risks and HI for all four impoundments. For instance, Chemical 1 is detected in Impoundments A, B, and D. Impoundment A has the maximum risk of 3.7×10^{-4} (from Impoundment A).

The facility risk of 3.7×10^{-4} is the summation of all carcinogenic constituent risks (Chemicals 1, 4, and 6). The facility HI of 11.05 is the summation of constituent HIs for target organ A. Specifically, this is Chemical 2 from Impoundment A and Chemical 5 from Impoundment B.

The third part of the table shows the risk screening results for the facility. One impoundment and three chemicals are screened from further assessment at this facility. Three chemicals at three impoundments move on for further assessment in Phase IB.

C.1.3 Phase IB: Release Assessment - Human Health

As described in the *Technical Plan*, the human health risk screening was performed for each constituent in each surface impoundment for each of the in-scope sample facilities that exceeded the risk criteria in Phase IA. As with Phase IA, the screening risk estimates were constituent-specific cancer risks or HIs summed across exposure pathways. Cumulative risks were then calculated for each impoundment and each facility and for each constituent and used to update the Phase IA risk results. Risk distributions were generated by characterization status and regulatory status and divided into cancer risks and noncancer hazard. These risk estimates were used to exclude constituents, impoundments, and facilities from further analysis.

C.1.3.1 Methods Summary. EPA used screening models to supplement the initial screening performed under Phase IA. Use of screening models provided additional characterization of exposure by evaluating the fate and transport of constituents from their release from the surface impoundment through the environmental media to the point of exposure.

Table C.1-11. Example Screening Risks for a Facility

			HI	
Impoundment	**Chemical**	**Risk**	**Target Organ A**	**Target Organ B**
Impoundment A	Chemical 1	3.7E-04		
	Chemical 2		0.05	
	Chemical 3			0.3
	Chemical 4	1e-08		
Impoundment B	Chemical 1	2.0E-05		
	Chemical 3			0.007
	Chemical 4	8.0E-08		
	Chemical 5		11.00	
Impoundment C	Chemical 2		0.0004	
	Chemical 3			0.8
	Chemical 5		0.003	
Impoundment D	Chemical 1	5.0E-12		
	Chemical 6	3e-08		
Cumulative risk		Risk	HI	
Impoundment risk				
	Impoundment A	3.7E-04	0.3	
	Impoundment B	2.0E-05	11.00	
	Impoundment C	-	0.8	
	Impoundment D	3.0E-08	-	
Constituent risk				
	Chemical 1	0		
	Chemical 2		0.05	
	Chemical 3		0.8	
	Chemical 4	8e-08		
	Chemical 5		11	
	Chemical 6	3e-08		
Facility risk		0	11.05	

Risk Screening Results:		
Tier 1	**Facility**	Risk and HI > decision criteria[a]
Tier 2	**Impoundment A**	Risk and HI > decision criteria[a]
	Impoundment B	Risk and HI > decision criteria[a]
	Impoundment C	HI > decision criteria[a]
	Impoundment D	Risk < decision criteria[a]
Tier 3	**Chemical 1**	Risk > decision criteria[a]
	Chemical 2	HI < decision criteria[a]
	Chemical 3	HI > decision criteria[a]
	Chemical 4	Risk < decision criteria[a]
	Chemical 5	HI > decision criteria[a]
	Chemical 6	Risk < decision criteria[a]
Conclusion	Impoundment A: Chemicals 1 and 3 to be assessed in next phase	
	Impoundment B: Chemicals 1 and 5 to be assessed in next phase	
	Impoundment C: Chemical 3 to be assessed in next phase	
	Impoundment D: No further assessment of chemicals 1 and 6; no further assessment at this facility	

[a] Decision criteria: 10^{-5} for cancer risk; 0.1 for noncancer risk.

The Phase IB screening addressed only the major routes of exposure that were expected to contribute significantly to potential risks (i.e., ingestion of drinking water and inhalation of air). However, because constituents from specific units may be screened from further analysis, the Phase IB modeling approach used several precautionary assumptions, such as assessing risks for close-in receptors.

The EPA screening models IWAIR and IWEM, developed for use under the Industrial D guidance, were used to calculate screening risk estimates. These risk estimates replaced the corresponding Phase IA screening risk estimates and, therefore, decreased the uncertainty of the overall screening risk distributions developed in Phase I.

Phase IB Human Health Screening Models. IWAIR and IWEM assess the risks from potential exposure of air and groundwater, respectively, from constituents released from surface impoundments. The screening models, as described below, use different approaches. However, both models provided screening analyses that are useful in characterizing exposure, and both models incorporated additional site-specific data. Despite the difference in modeling approaches, the results from each of the Phase IB models constitute a defensible basis to provide screening-level estimates of risk.

IWAIR. The IWAIR model (U.S. EPA, 1998b) was used to calculate risks due to inhalation of airborne volatile and semivolatile constituents released from surface impoundments. IWAIR incorporates the CHEMDAT8 volatile emission model to calculate the constituent release (i.e., emission rate) from an impoundment, uses dispersion factors developed from Industrial Source Complex Short Term (ISCST3) modeling simulations to calculate an air concentration, uses exposure and risk calculations following EPA guidance (*Risk Assessment Guidance for Superfund,* U.S. EPA, 1989b), and uses a chemical and toxicological database to calculate carcinogenic and noncarcinogenic chronic inhalation risks. CHEMDAT8 has undergone extensive review by both EPA and industry representatives and is publicly available. ISCST3 is another regulatory standard model that has undergone substantial review and use by industry. Dispersion factors for multiple source area sizes, receptor distances, and meteorological conditions are provided.

IWAIR uses the same exposure factors as Phase IA from the *Exposure Factors Handbook* (U.S. EPA, 1997d). An age-weighted resident was considered for carcinogenic chemicals. An adult resident was considered for noncarcinogenic chemicals. Phase IA toxicological benchmarks were used (in place of IWAIR toxicological benchmarks) to calculate screening risks with IWAIR. For SIS constituents that were not included in the IWAIR chemical database, the physicochemical properties from CHEMDAT8 and Phase IA toxicity benchmarks were added to IWAIR to calculate the constituent risks and HIs.

The IWAIR model is computationally fast and easy to use and requires input data on impoundment characteristics and meteorological conditions. The data required were obtained from the survey to the extent possible; these data include constituent waste concentration, impoundment depth, area, annual wastewater flow rate, and whether or not aeration occurs. Default or additional site-specific data were used for aeration

parameters and wastewater parameters important for biodegradation. The data protocols established to populate the data files for IWAIR are described in detail in Attachment C-5 of this appendix.

IWEM. The IWEM Tier 1 (U.S. EPA, 1999c) model was used to calculate the risks due to exposure to groundwater containing constituents released from surface impoundments. IWEM Tier 1 is based on a health-protective Monte Carlo probabilistic analysis that accounts for the nationwide variability of groundwater modeling parameters. The Monte Carlo approach used in EPACMTP and IWEM has been applied in various EPA regulatory efforts, including the proposed 1995 Hazardous Waste Identification Rule (HWIR) and hazardous waste listing evaluations. As such, the Monte Carlo procedure and its applicability to national analyses has been reviewed extensively within EPA and by the Science Advisory Board and has been subject to public review and comment (U.S. EPA, 1999a). The Monte Carlo procedure randomly drew input parameter values from representative statistical distributions for each parameter. A set of input parameter values was developed and the model was run to compute the groundwater monitoring well concentration and the dilution attenuation factor (DAF) at 150 m from the source along the centerline of the plume. This process was repeated thousands of times until a distribution of thousands of output values (DAFs) was produced. The DAF values were ranked from high to low, and the 90^{th} percentile DAF was determined. The 90^{th} percentile DAF represents the amount of dilution and attenuation that would occur in at least 90 percent of the cases modeled. In other words, the DAF is protective in at least 90 percent of the modeled cases. The selection of 90^{th} percentile DAF is based on

- The need to choose a level of protection that is protective and consistent with other EPA analyses, including the proposed HWIR of 1995 (U.S. EPA, 1995b) and hazardous waste listing evaluations (e.g., the Petroleum Refinery Waste Listing Determination, U.S. EPA, 1997g)

- The desire to have a large degree of confidence that the results are adequately protective of human health and the environment given the degree of uncertainty inherent in the data and the analyses.

Leachate concentration threshold values and DAFs are included for three impoundment liner scenarios in IWEM: no liner, single liner, and a composite liner. The no liner scenario represents an impoundment that is relying upon location-specific conditions such as low-permeability native soils beneath the unit or low annual precipitation rates to mitigate the release of contaminants to the groundwater. The single liner scenario represents a 3-foot-thick clay liner with a low hydraulic conductivity (10^{-7} cm/s) beneath the impoundment. The composite liner scenario consists of a 3-foot-thick clay liner beneath a well-installed and operated 40-mil-thick high-density polyethylene (HDPE) flexible membrane liner.

For each chemical, the DAF from the appropriate liner scenario was multiplied by the carcinogenic or noncarcinogenic risk screening factor from Phase IA to adjust the leachate concentration values in the IWEM Tier I table to reflect the same exposure

factors that were used in the Phase IA analysis. For example, the age-adjusted ingestion rates used in the Phase IA drinking water screening are different from the standard ingestion rate used to construct the IWEM Tier I table (i.e., adult-only rates). In effect, the Tier I table was normalized to the same exposure factors used throughout the Phase IA preliminary risk screening.

A number of SIS constituents are not included in the IWEM Tier 1 table. For these constituents, a leachate concentration threshold value using a DAF from a surrogate chemical was calculated (see Section C.3 for DAFs). The leachate concentration threshold value was calculated by using the IWEM procedure for estimating DAFs of chemicals for which EPACMTP was not simulated, as follows: the DAF was determined by interpolating between the DAFs of chemicals whose hydrolysis rate and retardation factor are in the same range as the hydrolysis rate and retardation factor of the new chemical.

Human Health Risk Calculation. Because IWAIR must represent wind conditions across the continental United States, IWAIR contains wind dispersion data based on 29 meteorological stations.[7] Because the wind pattern may not be representative of the actual site conditions, a close-in receptor at 25 m was assumed for the Phase IB screen. If a constituent was not currently in IWAIR, its physicochemical and toxicological data were added to the IWAIR chemical database.

The Phase IB groundwater risk calculation considered the type of lining at each impoundment in determining the appropriate groundwater screening factor, called the leachate concentration threshold value (LCTV) in IWEM. The risk calculation mirrors the Phase IA calculation: calculate the ratio of the leachate concentration to the LCTV and multiply by the risk criteria.

Cumulative Risk Calculation. The calculated screening risks for each constituent for a specific impoundment and facility were combined to generate three cumulative risk estimates: impoundment risk, constituent risk, and facility risk , as described in Section C.1.2.1. It is important to note that the cumulative risks are a combination of the Phase IA and Phase IB calculated risks for each constituent, because the Phase IB risk estimate is considered a refinement of the initial Phase IA risk estimate.

Risk Distribution Development. The risk distribution approach was identical to that defined in Phase IA. Because the Phase IB cumulative risks are a combination of the results from Phase IA and IB, the risk distributions also represent the combined analysis of Phase IA and IB. That is, overall results were updated using the Phase IB results.

Risk Screening. The risk screening approach is also identical to that defined in Phase IA.

[7] Dispersion data for 12 additional meteorological stations were added to IWAIR for this study.

C.1.4 Results of Screening Assessment—Phase IA and IB

The combined Phase IA and IB screening risks for each constituent, impoundment, and facility provided the initial screening-level risk distribution profiles for the sample population. The refinement of the screening-level risk distribution from Phase IA to Phase IB is shown in Figures C.1-1 and C.1-2 for cancer risks associated with the groundwater pathway, for decharacterized and never characteristic impoundments, respectively. These figures present the actual risk results derived for the Phase 1A and 1B analyses of the groundwater pathway on the sample population. Notice that these results are not aggregated according to the three bins described in Chapter 3—below risk criteria, environmental release, and potential concern—because these results are unweighted. The figures illustrate the progression of impoundment-chemical combinations through the screening process. Risk results calculated in Phase IA are shown as lightly shaded in the figures and are always below the risk criterion because any combinations that were above the risk criteria in Phase IA progressed to the Phase IB release assessment. The results of Phase IB darkly shaded in the figures indicate that, while a number of impoundments fell below the risk criteria, a significant number would be considered for risk modeling of the groundwater pathway and, ultimately, would either be shown as "environmental release" or "may exceed risk criteria." The impoundments that are shown to be above the risk criteria in these histograms became the subset that was considered for the groundwater pathway risk modeling described in detail in Section C.3. However, only those impoundments (and facilities) that were at the top of the numeric ranking scheme progressed to the risk modeling stage of the analysis.

C.1.5 PhaseIC/II: Risk Modeling— Air Pathway

C.1.5.1 Methods Summary and Key Results. In the risk modeling of the air pathway, EPA evaluated the risk to a person inhaling air contaminated with the chemicals released from surface impoundments. These chemicals reach the air by volatilizing from the surface impoundment. They may then be transported some distance from the impoundment before a person inhales them. The farther the person is from the impoundment, the lower the concentration of the chemical in the air and the lower the risk. Each of the screening steps described above is similar in that the risk criteria were established at 1E-5 for risk or 1 for hazard, and the release assessment and risk modeling used IWAIR. This model uses emissions data from the survey or, if no data are available, estimates emissions from concentration and other site-specific data from the SIS survey. IWAIR then estimates the concentration in air at some distance from the impoundment. The farther from the impoundment, the lower the air concentration. In the risk modeling stage, the default receptor distance of 25 meters was replaced with a site-specific distance identified in the survey responses or gleaned from GIS sources and a review of aerial photographs. Because the actual distance to the nearest receptor was typically higher than the default IWAIR distance of 25 meters, the risk estimates in this stage generally were lower than those predicted in the release assessment. Table C.1-12 presents the results for the air pathway with facilities classified according to waste characterization categories. Table C.1-13 presents this same information according to whether the source concentration data were based on reported values or surrogate/DL values. The complete risk results, standard errors, and additional descriptors on regulatory status (direct vs. zero dischargers) and impoundment type (e.g., aerated vs. nonaerated) are presented in Attachment C-7 to this appendix.

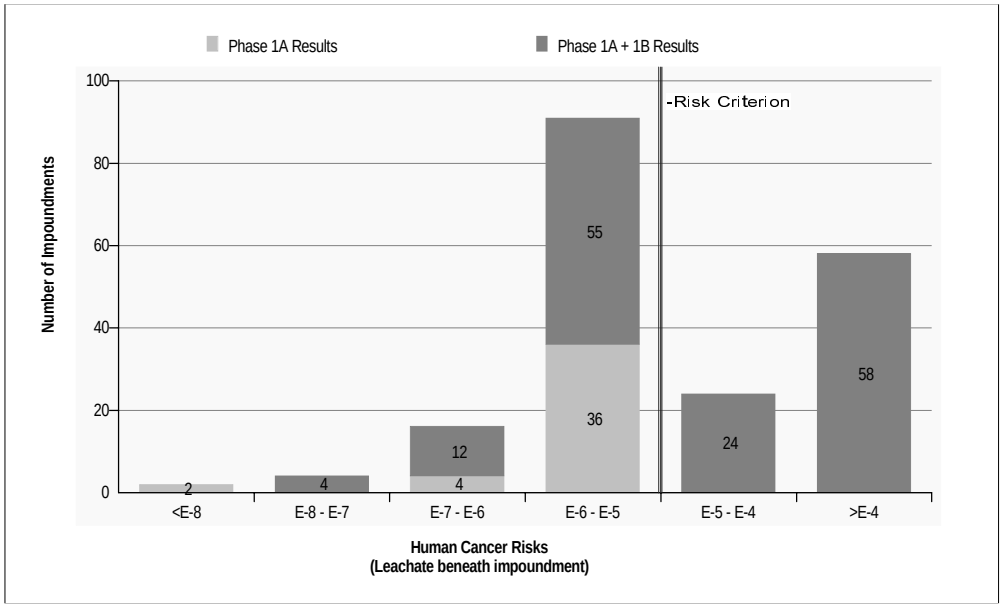


Figure C.1-1. Unweighted cancer risk results for sample population of impoundments for the groundwater pathway—decharacterized.

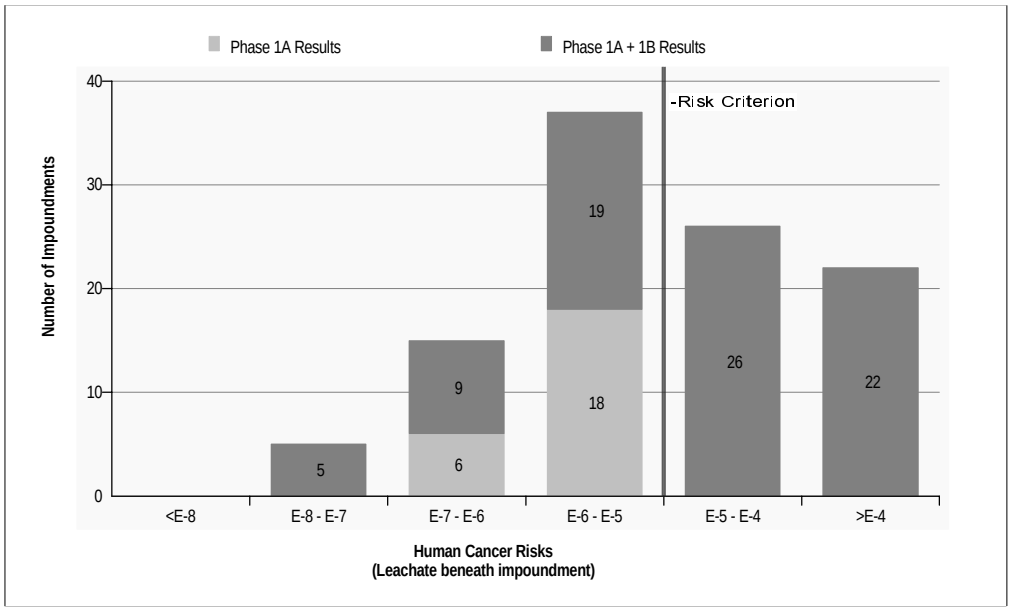


Figure C.1-2. Unweighted cancer risk results for sample population of impoundments for the groundwater pathway—never characteristic.

The results of the air pathway analysis indicate that, for facilities that may exceed the risk criteria, the weighted risk estimates may be associated with a significant standard error. Indeed, Table C.1-13 indicates that the national risk estimates may not be reliable for the facilities that may exceed the risk criteria based on reported concentration data. Although the standard errors associated with these results are large, the data suggest a trend that facilities that manage never characteristic wastes are associated with potentially higher risk levels than facilities that manage decharacterized waste.

Table C.1-12. Facility-Level Overview of Human Health Risk Results for Air Pathway by Decharacterization Status

Facility Status	Below Risk Criteria		Environmental Release[a] All Values		Exceeds Risk Criteria[a] All Values		Total	
Never Characteristic	3,344 (75%)		136 (3%)		158* (4%*)		3,638 (82%)	
	92%	86%	4%	41%*	4%*	68%*	100%	82%
Decharacterized	547 (12%)		198 (4%)		73* (2%)		818 (18%)	
	67%	14%	24%	59%*	9%	32%*	100%	18%
All Facilities	3,892 (87%)		334 (8%)		231* (5%)		4,457 (100%)	
	87%	100%	8%	100%	5%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.
[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).
* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

Table C.1-13. Facility-Level Overview of Human Health Risk Results for the Air Pathway by Decharacterization Status - Reported Values and Surrogate/DL Values

Facility Status	Below Risk Criteria		Environmental Release Reported Values		Environmental Release Surrogate/ DL Values		Exceeds Risk Criteria[a] Reported Values		Exceeds Risk Criteria[a] Surrogate/ DL Values		Total	
Never Characteristic[b]	3,344 (75%)		105* (2%)		31* (0.7%)		158* (4%*)		0 (0%)		3,638 (82%)	
	92%	86%	3%	62%*	0.9%	19%*	4%*	92%*	0%	0%	100%	82%
Decharacterized[c]	547 (12%)		64* (1%)		134 (3%)		13* (0.3%*)		60* (1%)		818 (18%)	
	67%	14%	8%*	38%*	16%	81%*	2%*	8%*	7%*	100%	100%	18%
All Facilities	3,892 (87%)		169 (4%)		165 (4%)		171* (4%*)		60* (1%)		4,457 (100%)	
	87%	100%	4%	100%	4%	100%	4%*	100%*	1%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.
DL = Detection limit.
[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).
* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

C.1.5.2 Discussion of Uncertainty. In its assessment of the air pathway, EPA relied on modeling tools that have been peer-reviewed and used in previous analyses, as much site-specific data as possible from the surveys, and standard EPA sources for important data such as exposure factors and health benchmarks. All of these factors contribute to a relatively robust analysis that met the study objectives of protective screening at earlier stages of the many impoundments and constituents and more robust modeling at the final stages of analysis. However, there are several key uncertainties that should be considered in interpreting the results of the air analysis. These are grouped under parameter uncertainties, modeling uncertainties, and results uncertainties. This section identifies these sources of uncertainty and qualitatively describes how each may influence the results.

Parameter Uncertainties. The key parameters required for the air pathway modeling included impoundment characteristics, receptor location, and exposure parameters.

- *Impoundment Characteristics*. To the extent possible, impoundment characteristics needed for the modeling were taken from the survey responses. However, some parameter values such as oxygen transfer rate, were not available from the survey responses for some or all impoundments. In these cases, assumptions or estimates were made, and these introduce uncertainty into the results. These assumptions and defaults could result in either under- or overprediction of risk, depending on the actual impoundment characteristics; however, they were generally chosen to be somewhat conservative (i.e., to overpredict risk), in keeping with the screening nature of this assessment.

- *Receptor Location*. The predicted risks were derived using actual receptor locations at each site. To the extent that some of these locations were based on old maps, there is some uncertainty introduced in the risk estimates, which could be either over- or underestimated, depending on whether the actual nearest receptor is nearer or farther from the site than the receptor location used. However, the conclusions regarding whether or not the risk may exceed the risk criteria are more robust, because in cases where this conclusion was sensitive to receptor location, the location was verified using recent aerial photos. Therefore, the uncertainties in the final results based on receptor location are small. It is important to note, however, that the air risks represent the nearest receptor to a given impoundment and do not necessarily reflect the "typical" risks to other receptors living within a 2-km radius of the facility; those "typical" risks are likely to be lower than the predicted risks for the closest receptor.

- *Exposure Parameters*. IWAIR uses standard EPA exposure factors, such as inhalation rate, body weight, and exposure duration. These parameters are based on the assumption of a receptor who ages from childhood to adulthood during the course of exposure. There is uncertainty in the risk results to the extent that actual receptors do not match these "typical" factors or this age profile. Exposure factors have been chosen to be somewhat conservative; therefore, this uncertainty will typically result in an overestimate of risk.

Modeling Uncertainties. The modeling for the air pathway simplifies the fate and transport of chemicals from an impoundment through air to a receptor. Many of these simplifications could result in either over- or underprediction of risk.

- *Volatile Emissions.* Emissions were modeled using CHEMDAT8. The level of peer review to which this model has been subjected supports confidence in the modeling construct to provide a solid basis for predicting inhalation risks. To the extent that this model is uncertain, it is unknown whether it would over- or underpredict emissions.

- *Hydrolysis*. The version of CHEMDAT8 incorporated in IWAIR cannot model hydrolysis. Hydrolysis rates are also not readily available for many chemicals. To the extent that constituents modeled with IWAIR do hydrolyze, IWAIR will overpredict emissions and therefore risks. For some constituents that hydrolyze quickly, this could be significant. For others, it will be less significant or insignificant, depending on the rate at which the constituent actually hydrolyzes in a particular impoundment.

- *Biodegradation Losses*. IWAIR does model biodegradation losses in the impoundment, using conservative (i.e., lowest available) biodegradation rate constants. The lower the level of biodegradation, the more constituent is available to volatilize, and the greater the emissions and risks. However, biodegradation is heavily influenced by such site-specific factors as temperature, pH, and other constituents present. Therefore, the emissions estimates are uncertain to the extent that actual biodegradation at a particular impoundment differs from the rate assumed. This uncertainty could result in either over- or underprediction of emissions and risks.

- *Dispersion Factors.* Dispersion factors were generated using the Industrial Source Complex model (ISC). ISC has been thoroughly peer-reviewed, which provides confidence in the modeling construct to provide a solid basis for predicting inhalation risks. To the extent that this model is uncertain, it is unknown whether it would over- or underpredict emissions.

- *Receptor Location Relative to Plume*. The receptor is assumed to be located at the centerline of the plume of constituent as it disperses around the site. Air concentrations are highest at the centerline of the plume, and decrease with distance from the centerline. Depending on the site-specific meteorology, particularly prevailing wind directions, the nearest receptor may not be located in the centerline of the plume. This uncertainty tends to overpredict air concentration at the nearest receptor, and thus risk.

- *Coverage of Meteorological Data in IWAIR*. IWAIR uses dispersion factors for a pre-determined set of 29 meteorological stations. Peer review of IWAIR suggested that additional meteorological stations would reduce uncertainty in the air concentration estimates; therefore, dispersion factors for 12 additional meteorological stations were generated and added to IWAIR for this study. There remains some uncertainty in the risk estimates to the extent that the 41 available meteorological stations do not fully

represent all possible locations where there are impoundments. However, this uncertainty, with the addition of new meteorological stations for IWAIR, is believed to be small. The direction of this uncertainty is not known—depending on the impoundment location, the air concentration (and thus risk) could be over- or underpredicted.

- *Interpolation of Dispersion Factors in IWAIR Based on Impoundment Area.* IWAIR uses dispersion factors generated for a fixed set of 14 impoundment areas. For impoundment areas that fall between the impoundment areas in IWAIR, there is some uncertainty based on this interpolation. The interpolation will result in the underprediction of air concentration, and therefore risk. This underprediction is expected to be modest; it will be greatest for small areas that fall close to half way between 2 of the 14 modeled areas. It will be less for areas that fall near 1 of the 14 modeled areas, and less for large areas regardless of closeness to one of the modeled areas (because the dispersion factor curve flattens out at large areas and is less sensitive to area).

- *Interpolation of Risk by Distance.* The IWAIR model can only be run at 7 preset distances. Therefore, risk results were interpolated to the actual distance of the nearest receptor. This interpolation is likely to slightly overpredict risk.

Results Uncertainties. As with any risk assessment, there is uncertainty in the risk results associated with simplifying assumptions and data limitations such as chemical-physical properties and health benchmarks. Several key uncertainties to consider in interpreting the risk results are presented below.

- *Standard Error*. The large standard error for the national estimate of potential risk exceedances for facilities with reported chemical concentrations indicates that there is considerable uncertainty in this estimate. Given the available data, it is not possible to quantify the magnitude or direction of this uncertainty with respect to protectiveness. Indeed, only two facilities in the sample population had potential exceedances for reported concentrations. The impact of our assumption that the receptor is located along the centerline of the air plume suggests that the risk estimates may be overprotective.

- *Multiple Constituent Exposures*. The risk of each constituent is considered separately in this analysis, and this may overlook additive or possible synergistic effects. This is a potential underestimation of adverse effects.

- *Chemical-Physical Properties*. IWAIR did not include all of the constituents of interest in this study that had inhalation benchmarks. Therefore, 25 additional constituents were added to IWAIR. However, adequate chemical-physical properties to run IWAIR were not available for 12 of these constituents. To the extent that these constituents may pose risks, this results in an underestimate of risk.

- *Health Benchmarks*. Many constituents in the scope of this study do not have health benchmarks for inhalation. This limited the number of constituents and facilities for which it was possible to assess inhalation risks. The absence of an inhalation health benchmark is generally taken as an indication that the constituent is not of great concern by the inhalation pathway; however, there is some uncertainty in this assumption. If health benchmarks were available for inhalation, a few more constituents might be found to pose risks; therefore, this uncertainty tends to result in an underestimate of risk.

C.1.6 Phase IC/II: Risk Modeling— Groundwater Pathway

C.1.6.1 Methods Summary and Key Results. In the risk modeling of the groundwater pathway, EPA evaluated the risk to a person drinking contaminated groundwater from the well located nearest to an impoundment that exceeded the risk criteria during the release assessment. Chemicals may reach a receptor well by leaching through the bottom of the impoundment into groundwater and migrating downgradient to residences that rely on drinking water wells. The potential for direct exposure to constituents via the groundwater pathway was assessed in three phases, each designed to be more protective than the previous phase. The first phase, direct exposure pathway screening, compared estimated leachate concentrations to screening factors for drinking water ingestion. The second phase, screening-level modeling, calculated risks and hazard quotients using EPA's IWEM. The third phase, site-based risk modeling, identified facility and impoundment combinations that have the greatest potential to impact receptor wells, and performed a Monte Carlo simulation to derive a site-specific distribution of risk for the nearest receptor well at each facility that was determined to be high priority for modeling.

The facilities were chosen for risk modeling using three basic decision rules:

- EPA evaluated the 71 facilities that exceeded risk criteria based on the IWEM Tier 1 screening analysis to determine if the potential exists for direct exposure to contamination via the groundwater pathway.

- EPA assumed the potential for exposure by determining if drinking water wells were present in the downgradient direction of groundwater flow.

- If receptor wells were not present, or if the receptor wells were determined not to be downgradient of the surface impoundment, EPA presumed the pathway to be incomplete and excluded the site from further evaluation.

For those facilities that were not excluded, two sets of criteria were developed and used to identify which facilities required site-based modeling. The first set of criteria focused on environmental setting characteristics (e.g., distance to receptor well), and the second set of criteria relied on professional judgment (e.g., conductivity of aquifer material). Each set of criteria and the method in which they were applied are described in Attachment C-8. Application of the two sets of ranking criteria resulted in the selection of 10 facilities that were considered the highest priority for site-based groundwater modeling. Site-based modeling involved assessing the fate and transport of chemical constituents present in surface impoundments by performing a

Monte Carlo simulation using EPACMTP and feeding the groundwater concentrations into a Monte Carlo exposure/risk simulation that varied human health exposure factors.

Table C.1-14 presents the results for the groundwater pathway with facilities classified according to waste characterization categories. Table C.1-15 presents this same information according to whether the source concentration data were based on reported values or surrogate/DL values. The complete risk results, standard errors, and additional descriptors on regulatory status (direct vs. zero dischargers) and impoundment characteristics (e.g., liner vs. no liner) are presented in Attachment C-12.

Table C.1-14. Facility-Level Overview of Human Health Risk Results for Groundwater Pathway by Decharacterization Status

Facility Status	Below Risk Criteria		Environmental Release[a] All Values		Exceeds Risk Criteria[a] All Values		Total	
Never Characteristic	2,574 (58%)		1,055 (24%)		9* (0.2%*)		3,638 (82%)	
	71%	88%	29%	71%	0.3%*	18%*	100%	82%
Decharacterized	345 (8%)		432 (10%)		41* (0.9%)		818 (18%)	
	42%*	12%	53%	29%	5%*	82%*	100%	18%
All Facilities	2,919 (65%)		1,488 (33%)		50* (1%)		4,457 (100%)	
	65%	100%	33%	100%	1%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

The results of the groundwater pathway analysis indicate that less than one percent of the facilities nationally that manage chemical constituents with reported values may exceed risk criteria for groundwater ingestion. Both tables suggest that facilities that manage decharacterized waste may potentially pose two to five times the risk of facilities that manage only waste that has never been characteristic.

C.1.6.2 Discussion of Uncertainty. In its assessment of the groundwater pathway, EPA relied on modeling tools that have been peer-reviewed and used in previous analyses, as much site-specific data as possible from the surveys, and standard EPA sources for important data such as exposure factors and health benchmarks. All of these factors contributed to a relatively robust analysis that met the study objectives of the Surface Impoundment Study. This section identifies the primary sources of uncertainty and qualitatively describes how each may influence the results of the risk assessment.

Table C.1-15. Facility-Level Overview of Human Health Risk Results for Groundwater Pathway by Decharacterization Status—Reported Values and Surrogate/DL Values

Facility Status	Below Risk Criteria		Environmental Release [a]				Exceeds Risk Criteria[a]				Total	
			Reported Values		Surrogate/ DL Values		Reported Values		Surrogate/ DL Values			
Never Characteristic	2,574 (58%)		341* (8%)		714 (16%)		9* (0.2%*)		0 (0%)		3,638 (82%)	
	71%	88%	9%	53%*	20%	84%*	0.3%*	33%*	0%	0%	100%	82%
Decharacterized	345 (8%)		300 (7%)		132* (3%)		18* (0.4%)		23* (0.5%)		818 (18%)	
	42%*	12%	37%	47%*	16%	16%*	2%*	67%*	3%*	100%	100%	18%
All Facilities	2,919 (65%)		641 (14%)		846 (19%)		27* (0.6%)		23* (0.5%)		4,457 (100%)	
	65%	100%	14%	100%	19%	100%	0.6%	100%	0.5%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.
DL = Detection limit.
[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).
* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

Parameter Uncertainties. The sources of parameter uncertainty include measurement errors, sampling errors, variability, and use of generic or surrogate data. Parameter uncertainty was incorporated in the Surface Impoundment Study by (1) executing a Monte Carlo analysis to capture the natural variability present in nature, and (2) using a regional site-based modeling approach that relied on data compiled at actual waste sites around the country. The critical parameters required for the screening of groundwater pathway included the distribution coefficients (K_d) and model parameter inputs.

- *Distribution Coefficients*. Empirical data were used to characterize partitioning of chemical contaminants between the aqueous phase and soil and aquifer materials. The K_d values used in the Surface Impoundment Study are based on values compiled from the literature. The values for all constituents are assumed to range over at least 3 orders of magnitude. For values with five or fewer literature values available for establishing a distribution of K_d values, a lognormal distribution was assumed centered on the mean value of the available log K_ds and extending for 1.5 log units on each side of the log mean. This uncertainty could result in either an underestimation or an overestimation of risk.

- *Model Input Parameters*. Application of the EPACMTP model requires input values for the source-specific, chemical-specific, unsaturated zone-specific, and saturated zone-specific model parameters. For this analysis, facility-specific values for impoundment location and waste, soil, and aquifer characteristics were used to the extent possible. Where facility-specific data were not available, regional databases were used to obtain the parameter values for soil and aquifer conditions. The use of facility-specific data reduces, but does not eliminate,

uncertainty. Use of regional databases may result in a greater spread of risks in Monte Carlo analyses.

- *Toxicological Endpoint for Fluoride*. The chemical that exceeds the risk criterion most often in the groundwater pathway assessment is fluoride. This is one of the two chemicals for which risk modeling indicates exceedances that are based on reported chemical concentrations. However, the endpoint of interest is currently dental fluorosis, an endpoint that is not considered to be an adverse effect by EPA. Although safe levels for fluoride of skeletal fluorosis are within a factor of 2 of the RfD for fluoride, there is considerable uncertainty in this value because there has been no formal workgroup process to derive a health benchmark.

Model Uncertainties. Model uncertainty is associated with all models used in all phases of a risk assessment because models and their mathematical expressions are simplifications of reality that are used to approximate real-world conditions, processes, and their relationships. Models used in the Surface Impoundment Study were selected based on science, policy, and professional judgment. These models were selected because they provide the information needed for this analysis and because they are generally considered to be state-of-the-science. Even though the models used in the risk analyses are used widely and have been accepted for numerous applications, they each retain significant sources of uncertainty. Evaluated as a whole, the sources of model uncertainty in this analysis could result in either an overestimation or underestimation of risk. Specific areas of modeling uncertainty in this analysis are as follows:

- *Channel Flow*. In modeling the fate and transport of chemicals in groundwater, complex hydrogeology such as karst or highly fractured aquifers was not assessed. Some fraction of the groundwater settings in this analysis are located in hydrogeologic environments where fracturing is likely. In general, fractured flow in groundwater can channel the contaminant plume, thus allowing it to move faster and in a more concentrated state than in a nonfractured flow environment. As a result, the modeling may under- or overestimate the concentrations in the groundwater.

- *Model Simplifications*. EPACMTP does not model colloidal transport nor does it model possible geochemical interactions among different contaminants in the leachate and the subsurface environment. The EPACMTP modeling incorporates the following assumptions: (1) transverse dispersion is negligible in the unsaturated zone, potentially resulting in an overestimation of risks; (2) receptors use the uppermost aquifer rather than a deeper aquifer as a domestic source of drinking water, which overestimates risks where the uppermost aquifer is not used;[8] and (3) hydrogeologic conditions that influence contaminant fate and

[8] Note that, for some facilities, EPA used technical materials supplied by the survey respondents to confirm that the uppermost aquifer was not used as a drinking water source. This information was entered in the numeric ranking scheme and used to identify facilities that were not considered to be a high priority with respect to potential groundwater risks.

transport are uniform spatially (i.e., no heterogeneity or fractured flow) as well as uniform temporally (i.e., over the 10,000-year time frame modeled). The use of these simplifications may result in a greater estimated spread of concentrations in the groundwater.

- *Groundwater Mounding*. Groundwater flow in the saturated zone is based on the assumption that the contribution of recharge from the unsaturated zone is small relative to the regional flow in the aquifer and the saturated aquifer thickness is large relative the rise due to infiltration. This assumption allows for the saturated zone to be modeled as having a uniform thickness (i.e., in the absence of mounding). The use of this simplification may result in a greater estimates spread of concentrations in the groundwater.

- *Recharge Rate*. The recharge rates used in this analysis were developed based on analyses that rely on regionalized climatic data and generalized soils types. These are not site-specific data but are intended to represent the range of conditions expected in the area. Although the model accounts for uncertainty using a probabilistic simulation, the recharge rates are not site-specific and may over- or underpredict the contaminant flux to groundwater.

- *Timeframe of Exposure*. There is uncertainty in predicting the movement of contaminants over long periods of time. The risk to receptors for the groundwater pathway was evaluated over a time period of 10,000 years. Depending on the constituent properties and rate as which it moves in groundwater, the time to peak concentration may be relatively long, on the order of hundreds or thousands of years. There are significant uncertainties concerning how exposure and environmental assumptions will change over time, and the modeling methodology does not change these assumptions over this 10,000-year period. As a result, groundwater concentrations may be under- or overestimated.

Results Uncertainties. It is important to consider several key uncertainties in interpreting the significance of the groundwater pathway results. The greatest uncertainty is focused around assumptions made in defining the geometric configuration of the modeled system, specifically, with regard to the groundwater flow direction and well construction. In addition, the risk results for reported values are based entirely on two chemical constituents: fluoride and acetone. As discussed above, the fluoride hazard is based on an effect that is not considered adverse by EPA, and the recommended safe value by EPA is approximately two times the health benchmark. Given the fact that fluoride is the risk driver for the entire groundwater pathway assessment and that the 90th percentile hazard quotient for acetone is 13 (50th percentile hazard quotient is 0.02), the groundwater hazard estimates may tend to be overprotective of actual adverse effects. Other uncertainties are discussed below.

- *Groundwater Flow Direction*. The direction of groundwater flow was not provided in the survey responses. Because the exact direction of the groundwater flow was unknown, the actual receptor well locations in the general the direction of the groundwater flow, as well as the physiography of the site were used to

define the angle "THETA." For each surface impoundment, THETA sets the bounds for the true direction of groundwater flow and, therefore, captures the uncertainty in centerline for groundwater flow and contaminant movement relative to the nearest receptor well to the impoundment. The error margin for THETA was based on professional judgment and was set to 5 degrees for all facilities evaluated in the risk modeling. The impact of this geometrical inexactitude is considered to be much smaller than the impact of several other uncertainties in the groundwater pathway analysis.

- *Well Construction*. The aquifer from which receptor wells drew water was not consistently reported in survey results. In the absence of technical information from the survey respondents indicating a site-specific well depth, it was assumed that the receptor wells considered in this analysis drew water from the uppermost unconfined saturated zone. This is a protective assumption and would tend to overestimate risk.

- *Volatilization*. The evaluation of the groundwater pathway was focused only on the ingestion of contaminated groundwater. EPA did not address volatilization of chemical constituents in groundwater that may result in inhalation exposures during showering. Because the inhalation pathway associated with shower exposure was not modeled, the groundwater pathway risk results may underestimate the total risk from leaching to groundwater. This contributes to the uncertainty in the risk estimates in the direction of underprotectiveness.

C.1.7 Phase IC/II: Risk Modeling—Groundwater to Surface Water Pathway Screening

C.1.7.1 Methods Summary and Key Results. In the risk modeling of the groundwater to surface water pathway, EPA evaluated the potential for degradation of surface water quality with respect to human usage. The basic approach to evaluating the potential for risks by this pathway was first to identify high-priority sites through a screening process (that considered groundwater concentrations, proximity to surface waterbodies, and the magnitude of potential dilution). For high-priority sites, modeling was conducted to generate flux rates from the surface impoundments, estimate groundwater concentrations that might contaminate the surface waterbody, and model the ensuing dilution. This analysis was conducted on all facilities that reported the presence of in-scope constituents. The basic steps in the assessment of this pathway were to

- Identify sites near (within 1 km) one or more fishable waterbodies

- Eliminate facilities from consideration based on a comparison of leachate concentrations to the ambient water quality criteria for the ingestion of surface water and aquatic organisms (HH-AWQC)

- For those that were not eliminated, estimate groundwater concentrations (from DAFs) and compare these to the HH-AWQC. The DAFs used were intended to

provide estimates of groundwater concentrations toward the high end of the possible distribution

- Using site-specific data (such as surface impoundment area) and reviewing topographical maps, identify sites with a high potential to impact surface water. Typically, this was based on a low probability of dilution by the surface waterbody based on flow data for the closest waterbody

- Conduct screening-level risk modeling using site-generated infiltration rates and flow rates for receiving waterbodies to estimate of chemical concentrations in surface water, and compare the resulting values to the HH-AWQC.

Table C.1-16 presents the results for the groundwater pathway with facilities classified according to waste characterization categories. Table C.1-17 presents this same information according to whether the source concentration data were based on reported values or surrogate/DL values. The complete risk results, standard errors, and additional descriptors on regulatory status (direct vs. zero dischargers) and impoundment characteristics (e.g., liner vs. no liner) are presented in Attachment C-15.

Table C.1-16. Facility-Level Overview of Human Health Risk Results for Groundwater to Surface Water Pathway by Decharacterization Status

Facility Status	Below Risk Criteria		Environmental Release[a] All Values		Exceed Risk Criteria[a] All Values		Total	
Never Characteristic	2,203 (49%)		1,397 (31%)		38* (0.9%)		3,638 (82%)	
	61%	88%	38%	75%	1%	52%*	100%	82%
Decharacterized	310 (7%)		472 (11%)		36* (0.8%)		818 (18%)	
	38%	12%	58%	25%	4%*	48%*	100%	18%
All Facilities	2,513 (56%)		1,869 (42%)		75* (2%)		4,457 (100%)	
	56%	100%	42%	100%	2%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

The results of the groundwater to surface water pathway analysis indicate that approximately 1 percent of the facilities nationally that manage chemical constituents with reported values may exceed risk criteria for adverse surface water impacts. The results are similar for risk exceedances predicted using surrogate/DL-based chemical concentrations. The overall trend using both types of concentration data does not indicate that decharacterized facilities are associated with higher potential risks than facilities that manage only never characteristic waste.

Table C.1-17. Facility-Level Overview of Human Health Risk Results for the Surface Water Pathway by Decharacterization Status - Reported Values and Surrogate/DL Values

Facility Status	Below Risk Criteria	Environmental Release[a]		Exceed Risk Criteria[a]		Total
		Reported Values	Surrogate/ DL Values	Reported Values	Surrogate/ DL Values	
Never Characteristic	2,203 (49%)	479 (11%)	918 (21%)	29* (0.7%)	9* (0.2%*)	3,638 (82%)
	61% 88%	13% 61%*	25% 85%	0.8% 67%*	0.3%* 30%*	100% 82%
Decharacterized	310 (7%)	311 (7%)	161 (4%)	14* (0.3%)	22* (0.5%)	818 (18%)
	38% 12%	38% 39%*	20% 15%	2%* 33%*	3%* 70%*	100% 18%
All Facilities	2,513 (56%)	790 (18%)	1,079 (24%)	44* (1.0%)	31* (0.7%)	4,457 (100%)
	56% 100%	18% 100%	24% 100%	1.0% 100%	0.7% 100%	100% 100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.
DL = Detection limit.
[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).
* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

C.1.7.2 *Discussion of Uncertainty*. There are several key uncertainties that should be considered in interpreting the results of the surface water quality screening assessment. These are grouped under parameter uncertainties, modeling uncertainties, and results uncertainties. This section identifies these sources of uncertainty and qualitatively describes how each may influence the results.

Parameter Uncertainties. The critical parameters required for the screening modeling of surface waterbodies included flow rates and DAFs.

- *Flow Rates*. Flow rates were a potentially significant source of uncertainty; the low flow rate (7Q10) was often greater than the average flow rate, suggesting that the data sources were highly variable. In addition, many flow rate estimates are based on end-of-stream locations, which could be a substantial distance from the point at which the groundwater could reasonably be expected to intersect with the surface waterbody. Consequently, the river dilution factor calculated from the flow rate may be highly uncertain.

- *Dilution Attenuation Factors*. For surface waterbodies within 150 meters, a default DAF of 1.0 was chosen. This value tends to overestimate the contaminant flux in groundwater that reaches the surface waterbody. The DAFs in IWEM were used for waterbodies beyond 150 meters and, as with the default DAF, these were developed for a protective groundwater screening tool. The resulting groundwater concentrations will generally lead to an overprediction of the contaminant concentration in the surface waterbody.

Modeling Uncertainties. The screening modeling for the groundwater to surface water pathway simplifies the fate and transport of chemicals from groundwater to surface water and is based on several protective assumptions. These simplifications generally rely on protective assumptions and, as a result, the modeling approach tends to overpredict the potential effects on water quality.

- *Groundwater Flow Direction*. For the surface water screening, groundwater flow direction was inferred from the topography, and a plausible groundwater flow direction was established perpendicular to the receiving waterbody—either a flowing waterbody or a quiescent system such as a small pond. In addition, the plume was assumed to completely intersect with the waterbody so that the groundwater would exert the maximum impact on the surface waterbody. The combination of these assumptions creates a bias toward higher surface water concentrations.

- *Designation of Fishable Waterbody*. The closest fishable waterbody was identified for each impoundment based on both survey responses and simple decision rules (e.g., a reach order of 3 or above is presumed to be fishable). However, there may be substantial uncertainty in this selection because, in many instances, survey responses were not useful in identifying the closest fishable waterbody.

- *Infiltration Rates*. The infiltration rates used in this analysis were developed using the HELP model using regionalized climatic data and generalized soils data. These are not site-specific data but are intended to represent the range of conditions expected in the area. Although the model accounts for uncertainty using a probabilistic simulation, the infiltration rates are not site-specific and may over- or underpredict the contaminant flux to groundwater.

Results Uncertainties. It is important to consider several key uncertainties in interpreting the significance of the surface water pathway results. The modeling approach is based on the assumption of instantaneous and thorough dilution throughout the surface waterbody, which would create a constant exposure profile for human usage throughout the entire receiving waterbody. In reality, contaminant release into the surface waterbody through this pathway would likely be associated with a concentration gradient that would vary the exposure pattern throughout the length of the waterbody. In many instances, only a small portion of the receiving waters may actually maintain chemical concentrations above the HH-AWQC. For the highest area of contamination (perhaps a "favorite" fishing spot), the dilution may mask a potentially adverse impact on surface water quality. It should be noted that the HH-AWQC used in this analysis are based on the consumption of aquatic organisms *and* surface water. In reality, the percentage of the population that consumes untreated surface water on a regular basis is very small. Therefore, the selection of the HH-AWQC for the ingestion of both aquatic organisms and surface will tend to produce an overestimate of the potential risks to surface water quality (relative to the actual usage of receiving waterbodies). The results of this analysis suggest that, despite the proximity of receiving waterbodies to surface impoundments, the risks from adverse effects to surface water quality are generally low nationwide.

A second potentially important source of uncertainty in the national risk estimates is based on the fact that HH-AWQC exceedances greater than a factor of 10 were observed for only one facility, and the only constituent with reported concentrations was arsenic. This finding in no way mitigates that risk potential at that particular facility. However, given the generally protective design of the screening risk modeling for this pathway, it is conceivable that this is the only facility (182) for which surface water impacts are of potential significance. Two other key uncertainties are worth considering when interpreting these results:

- *Data Gaps*. The screening criteria (HH-AWQC) selected for this analysis were identified in EPA's compilation of national recommended water quality criteria developed pursuant to section 304(a) of the Clean Water Act. An HH-AWQC was not available for all of the constituents that failed the preliminary screen and, therefore, the results may not capture impacts from all chemicals that may be released through this pathway.

- *Additive/Synergistic Effects*. The screening modeling does not address the possibility that other contaminant sources may be releasing the similar chemical constituents into the same waterbody. For waterbodies that are already receiving significant contaminant loads of the similar chemicals (or synergistic chemicals), the chemical release from an impoundment may be a significant contributor to water quality degradation.

C.1.8 Phase IC/II: Indirect Exposure Pathway Assessment

C.1.8.1 Methods Summary and Key Results. To characterize the potential for indirect exposures at facilities that manage bioaccumulative chemicals at in-scope surface impoundments, EPA conducted an indirect exposure pathway (IEP) screening analysis that used a combination of facility-specific and environmental setting criteria to assign each facility to one of three categories regarding the potential for indirect exposure pathway risk:

- **Potential concern** - The potential exists for indirect exposure pathway risk.

- **Lower concern** - There is a lower potential for indirect exposure pathway risk.

- Least concern - The analysis suggests that these facilities have the least potential for indirect exposure pathway risk.

In order for a facility to be placed in the category with the highest level of concern (i.e., the potential concern category), the IEP screening analysis had to suggest that the potential exists for indirect exposure pathway risk under current site conditions. Consequently, overall rankings for the facilities were assigned based on a current status scenario, which was designed to represent current conditions at the facilities. A future closure scenario was also included in the analysis to provide perspective on the number of facilities that had the potential to pose risk through an indirect exposure pathway after impoundment closure. This future closure scenario analysis was based on precautionary assumptions concerning postclosure actions and,

consequently, the results of the analysis were used only to qualify the results of the current status scenario (i.e., future closure results were not used in assigning overall rankings to the facilities).

The IEP analysis considered a set of exposure pathways, each linked to a specific release scenario and receptor population. For example, the analysis considered volatilization of chemicals from impoundments with subsequent transport to offsite residential home gardens (this represented a specific exposure pathway that was evaluated for the resident receptor population). Each of these exposure pathways was evaluated using a specific set of facility-specific and environmental setting criteria, which in turn, were used in a ranking algorithm to generate the overall ranking for that exposure pathway regarding the potential for indirect exposure pathway risk. Once all exposure pathways were evaluated for a given facility, those rankings were reviewed and an **overall ranking** was given to that facility for the IEP screening analysis. As noted above, these overall rankings were based only on the current status scenario.

Table C.1-18 presents the results for the indirect exposure pathway assessment with facilities classified according to waste characterization categories. Because the results of this assessment do not include quantified risk estimates that are chemical- and impoundment-specific, these results are not presented according to facilities with reported values or surrogate/DL values. The complete risk results, standard errors, and additional descriptors such as regulatory status are presented in Attachment C-18.

Table C.1-18. Facility-Level Overview of Human Health Risk Results for Indirect Exposure Pathway Assessment by Decharacterization Status

Facility Status	Least Concern[a]		Lower Concern[a]		Potential Concern[a]		Total	
Never characteristic	1,369 (31%)		2,153 (48%)		116* (3%)		3,638 (82%)	
	38%*	88%	59%*	82%	3%	41%*	100%	82%
Decharacterized	183 (4%)		466 (10%)		169 (4%)		818 (18%)	
	22%	12%	57%	18%	21%	59%*	100%	18%
All facilities	1,552 (35%)		2,620 (59%)		285 (6%)		4,457 (100%)	
	35%	100%	59%	100%	6%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

The results of the IEP screening analysis indicate that approximately 6 percent of the facilities nationally that manage bioaccumulative chemical constituents may present potential concern via indirect exposures. The overall results do not indicate that decharacterized facilities are associated with higher potential risks than facilities that manage only never characteristic waste.

C.1.8.2 Discussion of Uncertainty. The qualitative character of the indirect exposure pathway analysis leads to several major areas of uncertainty that affect interpretation of the results. These are grouped under parameter uncertainties, modeling uncertainties, and results uncertainties.

Parameter Uncertainties. Key parameters required for this analysis fall into one of two broad categories: facility performance parameters and environmental setting parameters. Various sources of uncertainty can impact each of these parameters. Those parameter uncertainties that are believed to have the greatest potential impact on the indirect exposure pathway screening assessment are discussed below.

- *Distance to nearest receptor*: The distance between specific impoundments and the nearest receptor (i.e., residential areas, farms, or fishable waterbodies) was estimated using a combination of aerial photos and topographic maps. Although these measurements were made using the most up to-date photos and maps available, some of the photos and maps were somewhat dated. This introduces uncertainty in the distance to nearest receptor measurements since land use change could result in a receptor either being added to or removed from a given study area (note, this is less of an issue in identifying fishable waterbodies).

- *Assessment of potential for erosion/runoff*: Topographic maps used to assess slope and the potential for sheet versus channel flow may not be current, in which case significant changes in land use (which would not show up on older maps) could introduce error into the characterization of this parameter.

Modeling Uncertainties. The indirect exposure pathway screening assessment is a facility-level evaluation intended to rank facilities according to their potential for complete indirect exposure pathways. This analysis uses a ranking algorithm together with facility-specific and environmental setting criteria to generate overall ranking scores for individual exposure pathways. The criteria used in this analysis were selected as surrogates for key factors related to human health risk (e.g., impoundment surface area was used as a surrogate for level of chemical emissions, distance to receptor was used as a surrogate for level of dispersion following source release). The use of these surrogate parameters as criteria in the ranking algorithms for individual exposure pathways, while appropriate given the screening-nature of the analysis, does introduce modeling uncertainty into the analysis. In addition, there are uncertainties associated with the ranking algorithms used in the anlaysis.

- *Use of ranking algorithms*: The ranking algorithm used in this analysis assumes an additive relationship between the criteria that are considered. However, in relation to actual risk, these criteria may have multiplicative or even nonlinear relationships to each other, in which case the overall importance of individual criteria could be misrepresented in the ranking algorithm.

- *Use of surface area as a surrogate parameter*. Total aggregated impoundment surface area for a given facility was used as a surrogate for the level of constituent emissions from that facility. However, a wide range of factors can influence the

degree of source emissions from an impoundment including chemical composition of the wastewater/sludge and other environmental setting/impoundment characteristics. Consequently, use of surface area as a surrogate for emissions levels does introduce uncertainty into the analysis.

- *Use of distance to receptor as a surrogate parameter*: The shortest distance from any of the impoundments at a facility to the nearest offsite receptor (i.e., resident, farmer, or fisher) was used as a surrogate for the degree of chemical dispersion that would occur following release. However, a wide range of factors in addition to distance to receptor can impact dispersion including meteorology, topography, and the specific characteristics of the source release.

Results Uncertainties. The indirect exposure pathway screening analysis is designed to identify which facilities have the potential to pose an indirect exposure pathway risk to surrounding populations. Given this scope, the analytical framework for the indirect exposure pathway screening analysis uses a combination of surrogate criteria and simple additive ranking algorithms in place of a formal site-specific risk assessment framework to generate ranking results. While this semiquantitative approach does support ranking of facilities with regard to the potential for indirect exposure pathway risk, care should be taken not to overextend conclusions drawn from the analysis. A similar issue applies to results produced for the current status scenario versus future closure scenario.

- *Drawing conclusions from the analysis*: Because the IEP screening analysis uses surrogate criteria combined with simple additive algorithms to rank facilities, there is significant uncertainty associated with the overall analysis that should be considered in interpreting results. While, this degree of uncertainty is considered acceptable for a first-pass assessment as to whether individual facilities have the potential for indirect exposure pathway risk, it precludes drawing any conclusions regarding the potential *level* of risk that these facilities could pose.

- *Current status scenario vs. future closure scenario results*: There is significantly greater uncertainty associated with results generated for the future closure scenario than for the current status scenario. This discrepancy results from the fact that the current status scenario is based on best available data regarding the current status of modeled facilities, while the future closure scenario is not intended as a "best guess" of future closure conditions at sites, but rather as a protective analysis of the potential for indirect exposure pathway risk should impoundments close without sufficient postclosure actions being taken to limit constituent mobility. Reflecting this discrepancy in uncertainty, overall rankings for the indirect exposure pathway screening analysis are based only on results for current status scenario—results from the future closure scenario are not considered in assigning these rankings. However, the results of the future closure scenario could be used to qualify the results of the current status scenario since they provide perspective on how many facilities could pose an indirect exposure pathway risk should impoundment closure occur without remediation.

C.1.9 Phase I: Preliminary Screen—Ecological Risk

C.1.9.1 Methods Summary and Key Results. The ecological risk screening is somewhat different from the human health screening in that a single comparison of screening factors and constituent concentrations was conducted. The screening ecological risk assessment focused on a subset of 43 constituents for which toxicological and exposure factor data were readily available. The habitats and receptors considered in this study are consistent with the national assessment strategy developed to support HWIR, proposed in November 1999. Because the HWIR risk assessment framework was intended to support national studies of waste management practices, the SIS has adopted this framework as the basis for selecting receptors and habitats. Depending on the ecological receptor of concern, the analysis estimated risks from either the ingestion of contaminated plants, prey, and media or from direct contact with a contaminated medium such as sediment or soil. The ecological risk estimates were compared to risk criteria to characterize the potential for adverse ecological effects at facilities of interest.

As with the preliminary screening of noncancer hazard for human health, the ecological screening analysis calculates risks to individual ecological receptors (e.g., red fox, aquatic biota) based on the ratio between risk screening factors and the concentrations of constituents in surface impoundments reported in the survey questionnaire. Consequently, ecological risk screening factors are given in units of concentration (e.g., mg/kg or mg/L). The use of screening factors is considered to be precautionary because the factors are

- Derived using established EPA protocols for use in evaluating ecological risk (e.g., sediment quality criteria)
- Based on highly protective assumptions regarding the toxicological potency of a constituent (e.g., no adverse effects levels and low adverse effects levels)
- Calculated assuming that all media and food items originate from a contaminated source.

In addition, the application of the screening factors assumes that ecological receptors are exposed directly to chemical concentrations in the sludge and wastewater found in the surface impoundment. For mammals, birds, and selected herpetofauna, these screening factors reflect ingestion of contaminated media, plants, and prey. For other receptor groups, such as soil fauna, these screening factors reflect both the direct contact and ingestion routes of exposure.

Table C.1-19 presents the results for the indirect exposure pathway assessment with facilities classified according to waste characterization categories. The categories for risk, although similar to those used in the IEP screening analysis, have a specific meaning in the context of the ecological risk assessment. The metric chosen to distinguish potential concern from lower concern was the number of receptors for which chemical concentrations exceeded ecological screening factors. The precautionary nature of the screening assessment resulted in a high percentage of "failures," that is, facilities and impoundments for which the predicted hazard quotient was greater than 1. Therefore, EPA used the median number of receptor of exceedances (38) across all facilities evaluated to discriminate between potential concern and lower concern.

Consequently, the national percentages shown in Table C.1-19 for potential concern reflect the potential for screening ecological risks to exceed the target criterion of 1 for more than 38 ecological receptors across various taxa. However, because the results of this assessment are considered screening-level, they are not presented according to facilities with reported values or surrogate/DL values. Table C.1-19 suggests that the majority of facilities have some potential for adverse ecological effects, and somewhat less than one third of the facilities have a relatively high level of potential concern based on the number of receptors for which risk exceedances were predicted. There is an apparent trend with regard to decharacterization status in that almost four times the number of facilities listed as of potential concern manage never characteristic waste.

Table C.1-20 provides insight into the ecological risks at facilities located near sensitive habitats such as wetlands and/or managed areas (e.g., national wildlife refuges). This table indicates that less than 10 percent of the facilities classified of potential concern are located within 1 km of a wetland or 3 km of a managed area. This figure trebles (roughly 30 percent) if the facilities classified as of lower concern are considered. Naturally, the "least concern" category refers to facilities for which ecological risks were not predicted at levels of potential concern. The complete risk results, standard errors, and additional descriptors such as regulatory status are presented in Attachment C-23.

Table C.1-19. Facility-Level Overview of Human Health Risk Results for Indirect Exposure Pathway Assessment by Decharacterization Status

Facility Status	Least Concern[a]		Lower Concern[a]		Potential Concern[a]		Total	
Never Characteristic	594* (13%)		2,007 (45%)		1,037 (23%)		3,638 (82%)	
	16%*	75%*	55%*	85%	28%	79%	100%	82%
Decharacterized	194 (4%)		352 (8%)		273 (6%)		818 (18%)	
	24%	25%*	43%*	15%	33%	21%	100%	18%
All Facilities	788 (18%)		2,359 (53%)		1,310 (29%)		4,457 (100%)	
	18%	100%	53%	100%	29%	100%	100%	100%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

C.1.9.2 Discussion of Uncertainty. The screening nature of the analysis leads to several major areas of uncertainty that affect interpretation of the results. These are grouped under parameter uncertainties, modeling uncertainties, and results uncertainties.

Table C.1-20. Facility-Level Results for Ecological Risk by Proximity to Wetlands and Managed Areas

Facility Status	Least Concern[a]		Lower Concern[a]		Potential Concern[a]		Total	
Wetland Within 1 km	105* (2%)		460* (10%*)		263 (6%)		828 (19%)	
	13%*	17%*	56%*	19%*	32%*	19%	100%	19%
Managed Area Within 3 km	58* (1%)		326* (7%)		92 (2%)		476 (11%)	
	12%*	8%*	69%*	14%	19%*	7%	100%	11%
Wetland Within 1 km and Managed Area Within 3 km	9* (0.2%*)		5* (0.1%*)		40* (0.9%)		54* (1%)	
	17%*	1%*	9%*	0.2%*	75%*	3%	100%	1%

Table key: Number of facilities (% of all facilities).
Row %, Column %.

[a] Number of facilities (percentages are of the total number of facilities, approximately 4,500).

* This estimate may not be reliable because of a large relative standard error. See Appendix A.5 for details.

Parameter Uncertainties. The key parameters required for the ecological risk screening include the list of ecological receptors assigned to each facility, dietary assumptions, and ecological screening factors. As appropriate for screening-level analyses, the selection of parameter values tends to support a protective assessment.

- *Ecological Receptor Assignments*. Ecological receptors were assigned at each facility as a function of the land use patterns and presence of wetlands and/or fishable waterbodies. This adds to the protective nature of the screening assessment because not all facilities are located in areas of sufficient ecological quality to sustain those receptors.

- *Assumptions on Dietary Exposure*. Screening-level assessments typically assume exclusive intake of contaminated prey in the diets of primary and secondary consumers (i.e., 100 percent of the diet originates from the contaminated area), providing a very conservative estimate of potential risks.

- *Conservatism of Screening Factors*. Because the screening factors were generally based on benchmarks for very low levels of effect for sensitive endpoints, these factors tend to be very protective of wildlife species and natural communties.

Modeling Uncertainties. The screening ecological risk assessment did not involve fate and transport modeling of chemical movement and uptake into plants and prey items. Consequently, this direct exposure approach is protective in the sense that it implies actual usage of the impoundment as habitat.

- *Spatial Scale of Exposure*. The screening level of resolution does not provide insight into the scope/size of ecological impacts. The size of the contaminated

area is a critical determinant of the risk results because larger areas dilute chemical concentrations. Restricting the area to the impoundment tends to bias the results toward an overestimate of risk.

- *Temporal Scale of Exposure*. The timing is assumed to include the entire life stage of the wildlife species evaluated or, in the case of community-type receptors (e.g., soil biota), a period that is relevant to the structure and function of the community. The chronic, low-level exposure that this implies may be underprotective of some species during sensitive lifestages or of short-lived species.

- *Constant Chemical Concentration*. The chemical concentration was assumed to be constant for the screening analysis when, in reality, the chemical concentrations in plants, prey, and media will vary over time and space. A constant chemical concentration will tend to overpredict the potential risks to wildlife.

- *Chemical Behavior*. For screening purposes, all forms of a constituent are assumed to be equally bioavailable and toxic. This assumption may either overestimate or underestimate the actual exposures, depending on the environmental characteristics. For example, the form of arsenic (i.e., elemental, ionic, and methylated) has been shown to influence toxicity profoundly.

- *Single Chemical Exposures*. The risk of each constituent is considered separately in this analysis, and this may overlook possible synergistic effects. This is one example of a potential underestimation of adverse effects.

Results Uncertainties. As with any screening ecological risk assessment, there is considerable uncertainty in the risk results associated with simplifying assumptions and data limitations such as ecological benchmarks. Moreover, the screening analysis does not address the potential significance of predicted ecological impacts. Although the ecological risk results indicate that the potential for adverse ecological effects exists at these facilities, it is not possible to quantify that potential within the broader context of ecological health and sustainability. Several key uncertainties to consider in interpreting the risk results are presented below.

- *Concentration Data Source*. A portion of the risk findings are based on surrogate data and detection limits, rather than on reported concentrations, and this contributes to the overall uncertainty in the results.

- *Data Gaps*. Protective ecological screening factors were developed for constituents when sufficient data were available which, for this analysis, included 41 chemicals. The absence of benchmarks may lead to the underestimation of risks associated with stressors for those chemicals that could not be evaluated.

- *No Additional Stressors*. The only stressor assumed in the screening analysis is the introduction of chemicals into the environment. In the field, wildlife may be

exposed to a variety of stressors (e.g., habitat alteration); therefore, the risk results may underestimate the potential for adverse effects.

- *Threatened/Endangered Species*. Only common species were evaluated in this analysis. The sensitivity of endangered species that are already under substantial stress is not accounted for explicitly. Although the selection of screening approach and parameters is inherently protective, it is possible that the results do not capture the risks to sensitive species and habitats.

C.2 Direct Exposure Pathway–Air

The air pathway considers the risk to a person (or receptor) inhaling air contaminated with the chemicals present in surface impoundments. These chemicals reach the air by volatilizing from the surface impoundment. They may then be transported some distance from the impoundment before a person inhales them. The farther the person is from the impoundment, the lower the concentration of the chemical in the air and the lower the risk.

C.2.1 Methods

C.2.1.1 Overview. The air pathway was assessed using several screening steps, each less conservative than the previous. The first two steps, direct exposure pathway screening and screening level modeling, are summarized in Section C.1.1; additional details are provided in the *Technical Plan* (where they are referred to as Phase IA and IB, respectively). The third step, Site-based Modeling, was not covered by the *Technical Plan* but is discussed here.

Although each of the screening steps is similar, for each successive step, the person inhaling the air was placed farther from the impoundment and more site-specific data from the SIS survey were used.

In the direct exposure pathway screening, data from the SIS survey on air concentration of chemicals of concern in the air over the impoundment were used. A receptor was assumed to inhale that concentration from childhood through adulthood. The air concentration data needed for this step were not available from the survey for many impoundments and chemicals. If data were not available or the risk calculated by this step for an impoundment and chemical exceeded the risk criteria, which were 1E-5 for risk or 1 for HQ, they passed on to the next step.

In the screening level modeling, an air risk model called IWAIR (Industrial Waste Air Model) was used. This model uses emissions data from the survey or, if no data are available, estimates emissions from concentration and other site-specific data from the SIS survey. IWAIR then estimates the concentration in air at some distance from the impoundment. The farther from the impoundment, the lower the air concentration. In this step, a distance of 25 m was used. The person inhaling the chemicals was assumed to do so for 30 years, starting in childhood. Site-specific data from the survey were used for the model inputs that most affect the results, including the size of the impoundment, where it is located, and whether it is aerated.

In the site-based modeling, IWAIR was used again, with the same site-specific data as before, but with the receptor placed at the actual distance to the nearest residence for each impoundment (taken from the survey). This was typically more than the 25 m used in the previous step, so the risk was typically lower than in the screening level modeling step.

Because the data on distance to nearest residence were sometimes incomplete or based on old maps, census data and aerial photos that were acquired from the United States Geological Survey (USGS) were used as a check on the distance to the nearest residence. The distance to the nearest populated census block was used to identify sites that might change from being below risk criteria to exceeding risk criteria if there were residences nearer than the survey data

suggested. For those sites, aerial photos were examined. In most cases, the aerial photos confirmed the nearest residence location reported in the survey. When they did not, the receptor distance was updated based on the aerial photo, and the risk was recalculated.

C.2.1.2 IWAIR. IWAIR is an interactive computer program with three main components: an emissions model, a dispersion model to estimate fate and transport of constituents through the atmosphere and determine ambient air concentrations at specified receptor locations, and a risk model to calculate the risk to exposed individuals. IWAIR can model four types of waste management unit, but only the surface impoundment component was used for this study. IWAIR requires only a limited amount of site-specific information, including facility location, impoundment characteristics, waste characteristics, and receptor information. IWAIR was modified for this study to bypass the interactive user interface and read data compiled from the surface impoundment survey directly from a database.

A brief description of each component and other modifications made to IWAIR for this study follows. The *IWAIR Technical Background Document* (U.S. EPA, 1998b) contains a more detailed explanation of the IWAIR model.

Emissions Model. The emission model uses waste characterization, impoundment, and facility information to estimate emissions for 95 constituents identified in Table C.2-1. The emission model incorporated into IWAIR is EPA's CHEMDAT8 model. This model has undergone extensive review by both EPA and industry representatives and is publicly available from EPA's web page. For this study, data on 13 additional chemicals, identified in Table C.2-2, were added to IWAIR. These chemicals represent the chemicals reported in the survey that were not already in IWAIR and that have inhalation health benchmarks and sufficient chemical-physical properties data to be modeled using IWAIR.

Table C.2-1. Constituents Included in IWAIR

CAS No.	Chemical Name
75070	Acetaldehyde
67641	Acetone
75058	Acetonitrile
107028	Acrolein
79061	Acrylamide
79107	Acrylic acid
107131	Acrylonitrile
107051	Allyl chloride
62533	Aniline
71432	Benzene
92875	Benzidine
50328	Benzo(a)pyrene
75274	Bromodichloromethane
106990	Butadiene, 1,3-
75150	Carbon disulfide

(continued)

Table C.2-1. (continued)

CAS No.	Chemical Name
56235	Carbon tetrachloride
108907	Chlorobenzene
124481	Chlorodibromomethane
67663	Chloroform
95578	Chlorophenol, 2-
126998	Chloroprene
10061015	cis-1,3-Dichloropropylene
1319773	Cresols (total)
98828	Cumene
108930	Cyclohexanol
96128	Dibromo-3-chloropropane, 1,2-
75718	Dichlorodifluoromethane
107062	Dichloroethane, 1,2-
75354	Dichloroethylene, 1,1-
78875	Dichloropropane, 1,2 -
57976	Dimethylbenz[a,h]anthracene, 7, 12-
95658	Dimethylphenol, 3,4-
121142	Dinitrotoluene, 2,4-
123911	Dioxane, 1,4-
122667	Diphenylhydrazine, 1,2-
106898	Epichlorohydrin
106887	Epoxybutane, 1,2-
111159	Ethoxyethanol acetate, 2-
110805	Ethoxyethanol, 2-
100414	Ethylbenzene
106934	Ethylene dibromide
107211	Ethylene glycol
75218	Ethylene oxide
50000	Formaldehyde
98011	Furfural
87683	Hexachloro-1,3-butadiene
118741	Hexachlorobenzene
77474	Hexachlorocyclopentadiene
67721	Hexachloroethane
78591	Isophorone
7439976	Mercury
67561	Methanol
110496	Methoxyethanol acetate, 2-
109864	Methoxyethanol, 2-
74839	Methyl bromide
74873	Methyl chloride
78933	Methyl ethyl ketone
108101	Methyl isobutyl ketone
80626	Methyl methacrylate
1634044	Methyl tert-butyl ether
56495	Methylcholanthrene, 3-

(continued)

Table C.2-1. (continued)

CAS No.	Chemical Name
75092	Methylene chloride
68122	N,N-Dimethyl formamide
91203	Naphthalene
110543	n-Hexane
98953	Nitrobenzene
79469	Nitropropane, 2-
55185	N-Nitrosodiethylamine
924163	N-Nitrosodi-n-butylamine
930552	N-Nitrosopyrrolidine
95501	o-Dichlorobenzene
95534	o-Toluidine
106467	p-Dichlorobenzene
108952	Phenol
85449	Phthalic anhydride
75569	Propylene oxide
110861	Pyridine
100425	Styrene
1746016	TCDD, 2,3,7,8 -
630206	Tetrachloroethane, 1,1,1,2-
79345	Tetrachloroethane, 1,1,2,2-
127184	Tetrachloroethylene
108883	Toluene
10061026	trans-1,3-Dichloropropylene
75252	Tribromomethane
76131	Trichloro-1,2,2-trifluoroethane, 1,1,2-
120821	Trichlorobenzene, 1,2,4-
71556	Trichloroethane, 1,1,1-
79005	Trichloroethane, 1,1,2-
79016	Trichloroethylene
75694	Trichlorofluoromethane
121448	Triethylamine
108054	Vinyl acetate
75014	Vinyl chloride
1330207	Xylenes

Table C.2-2. Constituents Added to IWAIR for Surface Impoundment Study

CAS No.	Chemical Name
542881	Bis(chloromethyl)ether
75343	Dichloroethane, 1,1-
76448	Heptachlor
319846	Hexachlorocyclohexane, alpha-
319857	Hexachlorocyclohexane, beta-
55684941	Hexachlorodibenzofurans [HxCDFs]
34465468	Hexachlorodibenzo-p-dioxins [HxCDDs]
30402154	Pentachlorodibenzofurans [PeCDFs]
1336363	Polychlorinated biphenyls
55722275	Tetrachlorodibenzofurans [TCDFs]
41903575	Tetrachlorodibenzo-p-dioxins [TCDDs]
8001352	Toxaphene
88062	Trichlorophenol, 2,4,6-

Dispersion Model. IWAIR's second modeling component estimates dispersion of volatilized contaminants and determines air concentrations at specified receptor locations, using default dispersion factors developed with EPA's Industrial Source Complex, Short-Term Model, version 3. ISCST3 was run to calculate dispersion for a standardized unit emission rate (1 $\mu g/m^2$-s) to obtain a unitized air concentration (UAC), also called a dispersion factor, which is measured in μ/m^3 per $\mu g/m^2$-s. The total air concentration estimates are then developed by multiplying the constituent-specific emission rates derived from CHEMDAT8 with a site-specific dispersion factor. Running ISCST3 to develop a new dispersion factor for each location and impoundment is very time consuming and requires extensive meteorological data and technical expertise. Therefore, IWAIR incorporates default dispersion factors developed by ISCST3 for many separate scenarios designed to cover a broad range of unit characteristics, including

- 29 meteorological stations, chosen to represent the nine general climate regions of the continental United States
- 14 surface area sizes for surface impoundments
- 7 receptor distances from the unit (0, 25, 50, 75, 150, 500, 1000 meters)
- 16 directions in relation to the edge of the unit.

The default dispersion factors were derived by modeling each of these scenarios, then choosing as the default the maximum dispersion factor for each impoundment/surface area/meteorological station/receptor distance combination.

Peer review comments on IWAIR received before this study was completed suggested that the 29 meteorological stations were not sufficient to be fully representative of the United States. Therefore, 12 additional meteorological stations were selected to be added to IWAIR for

this study. These additional meteorological stations were selected to better represent the locations of surface impoundments, based on data from the surface impoundment survey. The appropriate dispersion factors for these new meteorological stations were developed and added to the IWAIR dispersion factor database. Table C.2-3 lists the original 29 meteorological stations included in IWAIR and the 12 new stations added to IWAIR for this study.

Table C.2-3. Meteorological Stations Included in and Added to IWAIR for Surface Impoundment Study

Original Met Stations		Added for SIS	
Met Station ID	**City**	**Met Station ID**	**City**
23050	Albuquerque, NM	3812	Asheville, NC
13874	Atlanta, GA	12842	Tampa, FL
24011	Bismarck, ND	12916	New Orleans, LA
24131	Boise, ID	13737	Norfolk, VA
24089	Casper, WY	13865	Meridian, MS
13880	Charleston, SC	13957	Shreveport, LA
94846	Chicago, IL	14742	Burlington, VT
14820	Cleveland, OH	14840	Muskegon, MI
23062	Denver, CO	24033	Billings, MT
93193	Fresno, CA	13897	Nashville, TN
14751	Harrisburg, PA	13968	Tulsa, OK
14740	Hartford, CT	14778	Williamsport, PA
12960	Houston, TX		
3860	Huntington, WV		
23169	Las Vegas, NV		
14939	Lincoln, NE		
13963	Little Rock, AR		
23174	Los Angeles, CA		
12839	Miami, FL		
14922	Minneapolis, MN		
13739	Philadelphia, PA		
23183	Phoenix, AZ		
14764	Portland, ME		
13722	Raleigh-Durham, NC		
24232	Salem, OR		

(continued)

Table C.2-3. (continued)

Original Met Stations		Added for SIS	
Met Station ID	**City**	**Met Station ID**	**City**
24127	Salt Lake City, UT		
23234	San Francisco, CA		
24233	Seattle, WA		
24128	Winnemucca, NV		

Based on the size and location of a unit, IWAIR selects an appropriate dispersion factor from the default dispersion factors in the model. If the impoundment surface area that falls between two of the sizes that have already been modeled, a linear interpolation method then estimates dispersion in relation to the two closest unit sizes.

Risk Model. The third component of IWAIR combines the constituent's air concentration with receptor exposure factors and toxicity benchmarks to calculate the risk from concentrations managed in the impoundment. The model applies default values for exposure factors, including inhalation rate, body weight, exposure duration, and exposure frequency. These default values are based on data presented in EPA's *Exposure Factors Handbook* (U.S. EPA, 1997c, d, e) and represent average exposure conditions. IWAIR maintains standard health benchmarks (cancer slope factors for carcinogens and reference concentrations for noncarcinogens) for 95 constituents. These health benchmarks are from the Integrated Risk Information System (IRIS) (U.S. EPA, 2000f) and the Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1997h). As noted earlier, data on 13 additional chemicals reported in the surface impoundment survey were added to IWAIR.

C.2.1.3 Additional Methodology Details for Site-Based Modeling. The basic approach used for the site-based modeling step was to identify the location of the nearest receptor, interpolate the risk or HQ at that receptor, and evaluate that risk or HQ with respect to the risk criteria, which were 1E-5 for risk or 1 for HQ.

Calculating Risk at Nearest Receptor. IWAIR can only be run at seven preset distances: 0, 25, 50, 75, 150, 500, and 1,000 m. IWAIR had already been run at 25 m for the screening-level modeling. To conduct the site-based modeling, an interpolation approach was taken: IWAIR was run at all six remaining distances for the impoundment/chemical combinations that had risks in the screening level modeling that exceeded the risk criteria. EPA then interpolated the risk at the nearest receptor using standard interpolation techniques. Due to the overall shape of the risk-distance curve, which is not strictly linear but approaches zero risk asymptotically as distance increases, EPA did a log-log interpolation, as shown in Equation C-1.

$$\log(R) = \frac{(\log R2 - \log R1)}{(\log D2 - \log D1)} \times (\log D - \log D1) + \log R1 \qquad \text{(C-1)}$$

where

R_2 = upper-bound risk or HQ modeled by IWAIR
R_1 = lower-bound risk or HQ modeled by IWAIR
D_2 = upper-bound distance modeled by IWAIR (m)
D_1 = lower-bound distance modeled by IWAIR (m)
D = nearest receptor distance (m)
R = interpolated risk or HQ at nearest receptor distance.

The lower and upper bound distances are the distances at which IWAIR can be run that bracket the actual distance to the nearest receptor. For example, if the nearest receptor were at 100 m, the lower bound distance would be 75 m and the upper bound distance would be 150 m. The lower and upper bound risk or HQ is the modeled risk or HQ at the lower or upper bound distance. When the actual receptor distance is beyond the data modeled, the last two points modeled can be used to extrapolate using this same equation; for example, for a receptor distance of 1,200 m, the data for 500 m and 1,000 m can be used to extrapolate.

The interpolated risks were then compared to the risk or HQ criterion. If the risk exceeded the risk or HQ criterion (1E-5 for risk or 1 for HQ), the combination was retained for further analysis. If the risk or HQ was below the criterion, the combination was dropped from further analysis.

Identifying the Nearest Receptor. Based on the survey data, we identified the nearest residence for the impoundments for which the risk calculated in the screening-level modeling exceeded the risk criteria. The survey respondents were sent topographic maps of the area surrounding their facility. These maps show residences present at the time the map was last updated. Some maps had been updated recently and others had not been updated for many years. Survey respondents were asked to mark any additional residences on the map, verify the map as provided, or provide their own map with residences shown. Some respondents did not annotate the provided map or verify the map as provided. These maps were considered unverified. The returned maps were digitized, and a computer program was used to calculate the distance to the nearest marked residence.

Because some of the returned maps were old and unverified, EPA also considered two alternative methods of locating residences as checks.

One alternative method of locating residences is to assume that the nearest edge of the nearest populated census block edge is a reasonable minimum distance to the nearest residence. However, there may not be residences in that part of the census block, so this approach introduces a high degree of uncertainty. This distance can be determined by computer based on publicly available census data.

A more accurate method of locating the nearest residence is by examination of aerial photos of the area surrounding each facility. EPA acquired aerial photos from USGS for most sites in the survey at the time the survey was conducted. However, examination of aerial photos is very time consuming, so it could not realistically be done for all sites.

To make the most efficient use of resources, EPA used map date, verification status, and census block distance to identify facilities with the most uncertainty in residence location and most likely to change from having a risk below the risk criterion to having a risk that exceeds the risk criterion if there were residences closer than indicated by the survey. EPA examined aerial photos only for those facilities. Specifically, EPA performed the following steps:

- EPA calculated risk based on digitized (survey) residence location. If this risk exceeded the criterion, then that result was taken as final. Because the risk already exceeds the risk criterion, there is little to be gained by locating the nearest residence more precisely even if there is a closer residence.

- If the risk at the nearest digitized receptor was below the risk criterion, EPA considered whether the map was verified and the map date. If the map was verified, or if the map date was more recent than the most recent census data (1990), EPA considered the nearest digitized residence to be reliable, and the result stood.

- If the map was unverified and older than 1990, EPA calculated the risk based on the nearest edge of the nearest populated census block. This is a realistic worst case for residence distance; therefore, if the risk was below the risk criterion even at this distance, then the result based on the digitized receptor stood.

- If the risk at the census block edge exceeded the risk criterion, EPA examined the aerial photo to identify the actual nearest residence. If this was different than the digitized residence location, EPA updated that location and recalculated the risk at the new location. The risk at the updated location was then the final result, whether it exceeded or fell below the risk criterion.

Figure C.2-1 shows this same logic in a flow diagram.

In all cases, the final risk was that calculated at the digitized residence location or the location determined by examination of the aerial photo, if that was different. In most cases, the aerial photos confirmed the digitized residence location. In the few cases that they did not, the nearest residence was still considerably farther away than the nearest edge of the nearest populated census block. Therefore, risk at the edge of the census block was never used as the final risk.

Figures C.2-2 and C.2-3 show the digitized maps and aerial photos of two of the sites examined. The aerial photo of the site in Figure C.2-3 clearly shows residences closer to some of the impoundments than those shown on the digitized map from the survey.

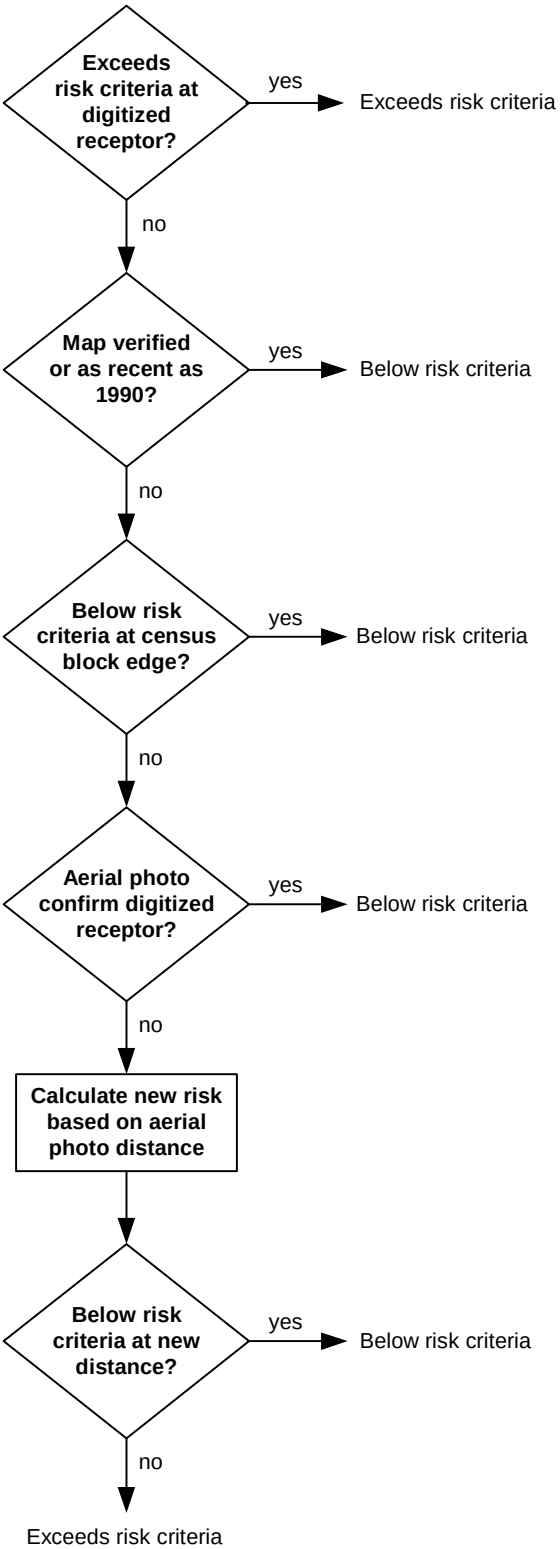


Figure C.2-1. Decision tree for performing air risk screening.

Figure C.2-2. Examples of nearest receptor: Example 1.

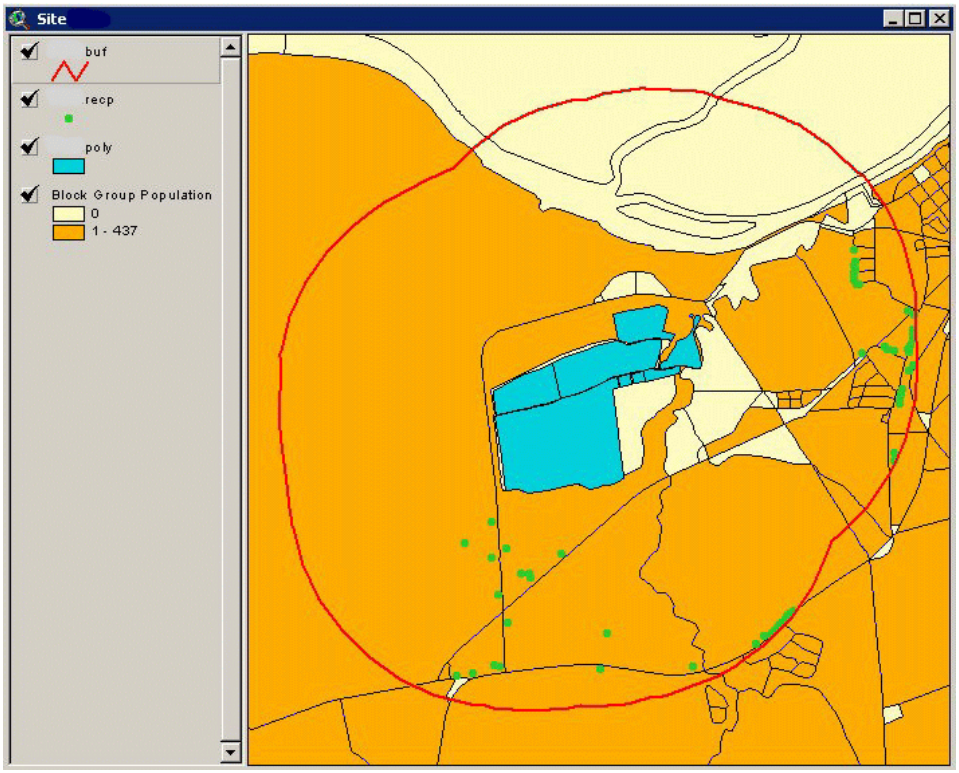


Figure C.2.3. Examples of nearest receptor: Example 2.

C.2.2 Results from Air Pathway Analysis

C.2.2.1 Direct Exposure Pathway Screening Results. A total of 39 constituents present in 84 surface impoundments at 19 facilities were considered in the initial screening step. When constituent air concentrations reported in the surface impoundments (or estimated from reported emissions rates) were compared to human health screening factors based on toxicity benchmarks for inhalation, 17 constituents in 28 surface impoundments at 11 facilities exceeded the risk criteria for the direct exposure pathway screening. The constituent counts reflect only those chemicals for which at least one human health benchmark was available. Many of the facilities and impoundments did not have the emissions or air concentration data needed for the direct exposure pathway screening for air; those impoundments were passed on for consideration in the screening-level modeling step.

C.2.2.2 Screening-Level Modeling Results. For those constituents, impoundments, and facilities that exceeded the risk criteria for the direct exposure pathway screening, plus those for which the direct exposure pathway screening could not be performed due to lack of data, a more realistic assessment of air risk was calculated using IWAIR. In this case, 90 constituents in 290 surface impoundments at 85 facilities were modeled. Forty-two constituents in 75 impoundments at 33 facilities exceeded the risk criteria at this step and were retained for site-based modeling.

C.2.2.3 Site-Based Modeling. Site-based modeling was conducted for the constituents, impoundments, and facilities that exceeded the risk criteria for screening-level modeling. After the site-based modeling, 12 constituents in 17 impoundments at 12 facilities exceeded the risk criteria. A summary of exceedances is presented in Table C.2-4. Attachment C-6 presents the full set of site-based air modeling results for the sample population. Attachment C-7 presents the national estimates for the air pathway results.

Table C.2-4. Summary of Hazard and Risk Exceedances for the Air Pathway

Facility	SI	Summary of HQ Exceedance	Summary of Risk Exceedance
Risk Exceedances Based on Reported Concentrations			
85	1		**Chlorodibromomethane** - 1e-05
151	1		**alpha-Hexachlorocyclohexane** -2.62e-05
Risk Exceedances Based on Surogate/DL Chemical Concentrations			
23	1	Chloroform - 2.2	
23	1	Acetonitrile -57.2	
23	4	Chloroform -1.82	
23	4	Acetonitrile - 47.7	
45	2	Acrolein -7.96	
			(continued)

Table C.2-4. (continued)

Facility	SI	Summary of Risk Exceedance	
45	4	Acrolein - 4.52	
45	5	Acrolein - 3.63	
46	3	Acrolein[b] -2.64	
46	3		Bis(chloromethyl) ether [b] - 4.84e-04
46	3		N-Nitrosodiethylamine [b] - 4.64e-05
46	3		N-Nitrosodi-n-butylamine [b]- 1.55e-05
46	4		Bis(chloromethyl) ether [b]- 1.05e-04
46	5		Bis(chloromethyl) ether [b]- 2.44e-04
77	1		Bis(chloromethyl) ether - 3.61e-01
84	4		Bis(chloromethyl) ether - 1.62e-04
84	5	Acrolein - 8.73	
84	5		Bis(chloromethyl) ether - 8.73e-03
84	5	Hexachlorocyclopentadiene - 1.5	
103	3		Tetrachlorodibenzofurans - 3.22e-05
175	3	Acrolein[b] - 11.5	
184	2		Toxaphene - 4.00e-03
Risk Exceedances Based on Summed Risks for the Facility			
156			Facility level sum - 1.5e-05
156	5		**Acetaldehyde** [a] - 6.00e-06
156	7		Tetrachlorodibenzodioxins - 9.00e-06

[a] This constituent and the other bolded ones are based on reported values.

[b] Industry representatives, subsequent to completion of the survey, have indicated that this constituent is not expected to be present at the facility. These constituents were reported to EPA in response to the Survey of Surface Impoundments in November 1999 as less than a specified limit of detection. When this constituent was evaluated in the risk analysis at the reported detection limit, the concentrations were high enough to predict the indicated risk/hazard of concern. EPA included the results in this table because of the methodology used throughout the study to evaluate less than detection limit data.

C.3 Direct Exposure Pathway—Groundwater

People may be exposed to constituents originating in surface impoundments if the constituents leach through the bottom of the impoundment into groundwater and migrate to downgradient receptor wells. The potential for direct exposure to constituents via the groundwater pathway was assessed in three phases, each less conservative than the previous phase. The first phase, direct exposure pathway screening, compared estimated leachate concentrations to screening factors for drinking water ingestion. The second phase, screening-level modeling, calculated risks and hazard quotients using EPA's Industrial Waste Evaluation Model. The third phase, site-based modeling, identified facility and impoundment combinations that have the greatest potential to impact receptor wells and provided quantitative risk estimates for the nearest receptor well at each site of interest.

Site-based modeling was accomplished in three basic steps:

- EPA evaluated the 71 facilities that exceeded risk criteria based on the IWEM Tier 1 screening analysis to determine if the potential exists for direct exposure to contamination via the groundwater pathway.

- EPA assumed the potential for exposure by determining if drinking water wells were present in the downgradient direction of groundwater flow.

- If receptor wells were not present, or if the receptor wells were determined not to be downgradient of the surface impoundment, EPA presumed the pathway to be incomplete and excluded the site from further evaluation.

For those facilities that were not excluded, two sets of criteria were developed and used to prioritize which facilities required site-based modeling. The first set of criteria focused on environmental setting characteristics (e.g., distance to receptor well) and the second set of criteria relied on professional judgment (e.g., conductivity of aquifer material). Each set of criteria and the method in which they were applied are detailed in Attachment C-8. Application of the two sets of screening criteria produced 10 facilities that were considered the highest priority for site-based groundwater modeling. The 10 facilities are identified in Attachment C-8 and summaries of pertinent site and risk characteristics are presented in Attachment C-9.

Characterization and data selection for the 10 modeled facilities are presented in Attachment C-10. Risk results and modeling for the groundwater pathway are presented in Attachments C-11 and C-12, respectively.

Site-based modeling was conducted following identification of the highest priority facilities. Modeling involved assessing the fate and transport of chemical constituents present in surface impoundments using Monte Carlo simulations executed using EPACMTP. Site-specific, regional, and national data, as appropriate, were used in model simulations.

These groundwater concentrations were then coupled with Monte Carlo-generated exposure parameters to generate individual cancer risk and noncancer hazard quotients for the 10 highest priority facilities. The results of this analysis are presented in Attachment C-12.

C.3.1 Numeric Ranking System for Facilities, Impoundments, and Constituents

The direct exposure pathway screening analysis compared constituent concentrations reported in surface impoundments to human health screening factors protective of residential exposure. Specifically, the risks posed to an individual receptor based on concentrations of constituents in surface impoundments were compared to human health risk screening factors based on toxicity benchmarks for direct ingestion of drinking water. These screening risks are highly protective of human health because the underlying assumption is that the resident drinks impoundment water. Those constituents, impoundments, and facilities that posed negligible risk (i.e., cancer risk less than 1E-5 or HQ less than 1.0) were below risk criteria for the analysis. This human health risk screening calculation was performed for each constituent in each surface impoundment for each of the 133 facilities. Of the 133 facilities, 106 facilities exceeded risk criteria.

For those constituents, impoundments, and facilities that exceeded risk criteria, a more refined assessment of groundwater risk was performed by evaluating fate and transport processes in the environment using EPA's IWEM Tier 1 screening model (U.S. EPA, 1999b, c). This phase of the screening process also used protective assumptions, such as assessing risks for receptor wells located 150 meters from the surface impoundment.

The IWEM Tier 1 screening model consists of tabulated leachate concentration threshold values for specific chemicals based on a dilution attenuation factor and the toxicity reference levels for 191 constituents. The toxicity reference level is based on toxicological benchmarks or the maximum contaminant level. The DAFs were generated by modeling the migration of waste constituents from an impoundment through the underlying soil to a monitoring point in the aquifer using EPACMTP in a national Monte Carlo probabilistic analysis. The DAFs are multiplied by the toxicity benchmark to provide the leachate concentration threshold value for each constituent.

To maintain consistency with the initial phase of risk screening, only the DAFs from IWEM were used. DAFs and leachate concentration threshold values were evaluated for three impoundment liner scenarios: no liner, single liner, and a composite liner. The no liner scenario represented an impoundment relying on location-specific conditions such as low-permeability native soils beneath the unit or low annual precipitation rates to mitigate the release of contaminants to the groundwater. The single liner scenario represented a 3-foot-thick clay liner with low hydraulic conductivity (10^{-7} cm/s) beneath the impoundment, and the composite liner scenario consisted of a 3-foot-thick clay liner beneath a 40-mil-thick high-density polyethylene (HDPE) flexible membrane liner. The DAFs for each constituent for each of the three liner scenarios are presented in Table C.3-1.

Table C.3-1. Constituent Dilution Attenuation Factors for Liner Scenarios

Constituent	CAS_NO	Scenario[a]	DAF
1,1,2,2-Tetrachloroethane	79345	1	3.9
1,1,2,2-Tetrachloroethane	79345	2	34000
1,1,2,2-Tetrachloroethane	79345	3	34000
1,1-Dichloroethylene [Vinylidene chloride]	75354	1	1.8
1,1-Dichloroethylene [Vinylidene chloride]	75354	2	7
1,1-Dichloroethylene [Vinylidene chloride]	75354	3	730000
1,2,3-Trichloropropane	96184	3	1.00E+06
1,2,3-Trichloropropane	96184	1	1.2
1,2,3-Trichloropropane	96184	2	10
1,2,4,5-Tetrachlorobenzene	95943	2	170
1,2,4,5-Tetrachlorobenzene	95943	3	170
1,2,4,5-Tetrachlorobenzene	95943	1	5.2
1,2-Dibromo-3-chloropropane	96128	1	1.8
1,2-Dibromo-3-chloropropane	96128	3	110000000
1,2-Dibromo-3-chloropropane	96128	2	13
1,2-Dichloroethane [Ethylene dichloride]	107062	3	1.00E+06
1,2-Dichloroethane [Ethylene dichloride]	107062	1	1.8
1,2-Dichloroethane [Ethylene dichloride]	107062	2	8.4
1,2-Dichloropropane [Propylene dichloride]	78875	1	1.9
1,2-Dichloropropane [Propylene dichloride]	78875	2	19
1,2-Dichloropropane [Propylene dichloride]	78875	3	19
1,2-Diphenylhydrazine	122667	1	1.8
1,2-Diphenylhydrazine	122667	3	130000
1,2-Diphenylhydrazine	122667	2	6.6
1,3-Dinitrobenzene [m-Dinitrobenzene]	99650	1	1.1

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
1,3-Dinitrobenzene [m-Dinitrobenzene]	99650	3	310000
1,3-Dinitrobenzene [m-dinitrobenzene]	99650	2	5
1,4-Dichlorobenzene [p-dichlorobenzene]	106467	3	11000000
1,4-Dichlorobenzene [p-dichlorobenzene]	106467	2	15
1,4-Dichlorobenzene [p-dichlorobenzene]	106467	1	2
1,4-Dioxane [1,4-diethyleneoxide]	123911	1	1.8
1,4-Dioxane [1,4-diethyleneoxide]	123911	3	130000
1,4-Dioxane [1,4-diethyleneoxide]	123911	2	6.6
2,3,7,8-TCDD [2,3,7,8-tetrachlorodibenzo-p-dioxin]	1746016	1	300
2,3,7,8-TCDD [2,3,7,8-tetrachlorodibenzo-p-dioxin]	1746016	2	7900000000
2,3,7,8-TCDD [2,3,7,8-tetrachlorodibenzo-p-dioxin]	1746016	3	7900000000
2,4,6-Trichlorophenol	88062	1	1.8
2,4,6-Trichlorophenol	88062	3	1900000
2,4,6-Trichlorophenol	88062	2	7.9
2,4-Dichlorophenol	120832	1	1.2
2,4-Dichlorophenol	120832	3	3100000
2,4-Dichlorophenol	120832	2	7.2
2,4-Dinitrophenol	51285	1	1.1
2,4-Dinitrophenol	51285	3	130000
2,4-Dinitrophenol	51285	2	4.8
2,4-Dinitrotoluene	121142	1	1.1
2,4-Dinitrotoluene	121142	2	5.2
2,4-Dinitrotoluene	121142	3	600000
2,6-Dinitrotoluene	606202	1	1.1
2,6-Dinitrotoluene	606202	3	380000

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
2,6-Dinitrotoluene	606202	2	5
2-Chlorophenol [o-chlorophenol]	95578	1	1.1
2-Chlorophenol [o-chlorophenol]	95578	2	5.4
2-Chlorophenol [o-chlorophenol]	95578	3	790000
3,3'-Dichlorobenzidine	91941	1	2.1
3,3'-Dichlorobenzidine	91941	3	21000000
3,3'-Dichlorobenzidine	91941	2	22
4,4'-Methylene bis(2-chloroaniline)	101144	3	1.00E+06
4,4'-Methylene bis(2-chloroaniline)	101144	1	1.8
4,4'-Methylene bis(2-chloroaniline)	101144	2	8
Acetone [2-Propanone]	67641	1	1.1
Acetone [2-Propanone]	67641	3	130000
Acetone [2-Propanone]	67641	2	4.8
Acrylic acid [propenoic acid]	79107	1	1.1
Acrylic acid [propenoic acid]	79107	3	130000
Acrylic acid [propenoic acid]	79107	2	4.8
Acrylonitrile	107131	1	1.8
Acrylonitrile	107131	3	190000
Acrylonitrile	107131	2	6.6
Aldrin	309002	1	360
Aldrin	309002	2	9800000000
Aldrin	309002	3	9800000000
Allyl alcohol	107186	1	1.1
Allyl alcohol	107186	3	130000
Allyl alcohol	107186	2	4.8

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
alpha-Hexachlorocyclohexane [α-BHC]	319846	2	230000000
alpha-Hexachlorocyclohexane [α-BHC]	319846	3	230000000
alpha-Hexachlorocyclohexane [α-BHC]	319846	1	59
Aniline	62533	2	6.6
Antimony	7440360	2	1360
Antimony	7440360	3	1360
Antimony	7440360	1	45
Arsenic	7440382	1	33
Arsenic	7440382	2	969
Arsenic	7440382	3	969
Barium	7440393	1	2.6585
Barium	7440393	3	232269.81
Barium	7440393	2	47.4
Benzene	71432	1	1.8
Benzene	71432	2	7.1
Benzene	71432	3	770000
Benzidine	92875	1	1.8
Benzidine	92875	3	320000
Benzidine	92875	2	6.7
Benzo(a)pyrene	50328	1	150
Benzo(a)pyrene	50328	2	3300000000
Benzo(a)pyrene	50328	3	3300000000
Benzo(b)fluoranthene	205992	1	150
Benzo(b)fluoranthene	205992	2	2100000000
Benzo(b)fluoranthene	205992	3	2100000000

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
Benzo[a]anthracene	56553	2	230000000
Benzo[a]anthracene	56553	3	230000000
Benzo[a]anthracene	56553	1	50
Benzyl chloride	100447	2	1.00E+06
Benzyl chloride	100447	1	1.00E+06
Benzyl chloride	100447	3	1.00E+06
Beryllium	7440417	3	1.00E+06
Beryllium	7440417	1	4.6
Beryllium	7440417	2	70
beta-Hexachlorocyclohexane [β-BHC]	319857	1	2.2
beta-Hexachlorocyclohexane [β-BHC]	319857	2	26
beta-Hexachlorocyclohexane [β-BHC]	319857	3	27000000
Bis(2-chloroethyl) ether [sym-dichloroethyl ether]	111444	1	2.3
Bis(2-chloroethyl) ether [sym-dichloroethyl ether]	111444	2	40
Bis(2-chloroethyl) ether [sym-dichloroethyl ether]	111444	3	40
Bis(2-chloroisopropyl) ether [2,2'-dichloroisopropyl ether]	39638329	1	1.8
Bis(2-chloroisopropyl) ether [2,2'-dichloroisopropyl ether]	39638329	3	2600000
Bis(2-chloroisopropyl) ether [2,2'-dichloroisopropyl ether]	39638329	2	8.4
Bis(chloromethyl) ether [sym-dichloromethyl ether]	542881	2	1.00E+06
Bis(chloromethyl) ether [sym-dichloromethyl ether]	542881	1	1.00E+06
Bis(chloromethyl) ether [sym-dichloromethyl ether]	542881	3	1.00E+06
Bromodichloromethane [dichlorobromomethane]	75274	1	1.8
Bromodichloromethane [dichlorobromomethane]	75274	3	1400000
Bromodichloromethane [dichlorobromomethane]	75274	2	8.1
Cadmium	7440439	3	1.00E+06

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
Cadmium	7440439	1	15.4
Cadmium	7440439	2	325.6
Carbon tetrachloride	56235	1	1.9
Carbon tetrachloride	56235	2	36
Carbon tetrachloride	56235	3	36
Chlordane, α & γ isomers	57749	2	130000
Chlordane, α & γ isomers	57749	3	130000
Chlordane, α & γ isomers	57749	1	176
Chlorobenzilate	510156	2	16000
Chlorobenzilate	510156	3	16000
Chlorobenzilate	510156	1	4.1
Chloroform [trichloromethane]	67663	1	1.8
Chloroform [trichloromethane]	67663	2	6.9
Chloroform [trichloromethane]	67663	3	930000
Chloromethane [methyl chloride]	74873	1	1.8
Chloromethane [methyl chloride]	74873	3	200000
Chloromethane [methyl chloride]	74873	2	6.6
Chromium	7440473	1	23
Chromium	7440473	2	645
Chromium	7440473	3	645
Chromium VI [hexavalent chromium]	18540299	3	1.00E+06
Chromium VI [hexavalent chromium]	18540299	1	23
Chromium VI [hexavalent chromium]	18540299	2	645
cis-1,3-Dichloropropylene	10061015	2	21000
cis-1,3-Dichloropropylene	10061015	1	21000

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
cis-1,3-Dichloropropylene	10061015	3	21000
Copper	7440508	2	164
Copper	7440508	3	313372.81
Copper	7440508	1	7.139
Cyanide	57125	2	1.00E+06
Cyanide	57125	3	1.00E+06
Cyanide	57125	1	28
Diallate	2303164	1	13
Diallate	2303164	2	830000
Diallate	2303164	3	830000
Dibenz[a,h]anthracene	53703	1	1059
Dibenz[a,h]anthracene	53703	2	2.9e+015
Dibenz[a,h]anthracene	53703	3	2.9e+015
Dieldrin	60571	2	2992
Dieldrin	60571	1	2992
Dieldrin	60571	3	2992
Ethyl acetate	141786	1	1.4
Ethyl acetate	141786	2	21
Ethyl acetate	141786	3	21
Ethylene dibromide [1,2-dibromoethane]	106934	2	1200
Ethylene dibromide [1,2-dibromoethane]	106934	3	1200
Ethylene dibromide [1,2-dibromoethane]	106934	1	3.1
Ethylene glycol	107211	1	1.1
Ethylene glycol	107211	3	130000
Ethylene glycol	107211	2	4.8

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
Ethylene oxide	75218	2	1.00E+06
Ethylene oxide	75218	3	1.00E+06
Ethylene oxide	75218	1	28
Fluoride	16984488	1	1.1
Fluoride	16984488	3	130000
Fluoride	16984488	2	4.8
Formaldehyde	50000	1	1.1
Formaldehyde	50000	3	130000
Formaldehyde	50000	2	4.8
Furfural	98011	1	1.1
Furfural	98011	3	130000
Furfural	98011	2	4.8
Heptachlor	76448	2	1.00E+06
Heptachlor	76448	1	1.00E+06
Heptachlor	76448	3	1.00E+06
Heptachlor epoxide, α, β, and γ isomers	1024573	2	557
Heptachlor epoxide, α, β, and γ isomers	1024573	1	557
Heptachlor epoxide, α, β, and γ isomers	1024573	3	557
Hexachloro-1,3-butadiene [hexachlorobutadiene]	87683	2	250
Hexachloro-1,3-butadiene [hexachlorobutadiene]	87683	3	250
Hexachloro-1,3-butadiene [hexachlorobutadiene]	87683	1	7.9
Hexachlorobenzene	118741	2	520000000
Hexachlorobenzene	118741	3	520000000
Hexachlorobenzene	118741	1	59
Hexachloroethane	67721	1	2.5

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
Hexachloroethane	67721	2	37
Hexachloroethane	67721	3	41000000
Hexachlorophene	70304	1	23
Hexachlorophene	70304	2	860
Hexachlorophene	70304	3	860
Indeno(1,2,3-cd) pyrene	193395	2	12000000000
Indeno(1,2,3-cd) pyrene	193395	3	12000000000
Indeno(1,2,3-cd) pyrene	193395	1	440
Kepone	143500	2	120
Kepone	143500	3	1e+030
Kepone	143500	1	4.7
Lead	7439921	3	1.00E+06
Lead	7439921	2	46290.666667
Lead	7439921	1	490.66666667
Manganese	7439965	3	1.00E+06
Manganese	7439965	1	11
Manganese	7439965	2	283.9
Mercury	7439976	1	15
Mercury	7439976	2	545
Mercury	7439976	3	545
Methanol [methyl alcohol]	67561	1	1.1
Methanol [methyl alcohol]	67561	3	130000
Methanol [methyl alcohol]	67561	2	4.8
Methyl ethyl ketone [2-butanone][MEK]	78933	1	1.1
Methyl ethyl ketone [2-butanone][MEK]	78933	3	130000

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
Methyl ethyl ketone [2-butanone][MEK]	78933	2	4.8
Methylene chloride [dichloromethane]	75092	1	1.8
Methylene chloride [dichloromethane]	75092	3	350000
Methylene chloride [dichloromethane]	75092	2	6.8
Molybdenum	7439987	3	1.00E+06
Molybdenum	7439987	1	23
Molybdenum	7439987	2	645
Naphthalene	91203	1	1.4
Naphthalene	91203	3	13000000
Naphthalene	91203	2	15
n-Butyl alcohol [n-butanol]	71363	1	1.1
n-Butyl alcohol [n-butanol]	71363	3	170000
n-Butyl alcohol [n-butanol]	71363	2	4.9
Nickel	7440020	3	1.00E+06
Nickel	7440020	1	11
Nickel	7440020	2	283.9
Nitrobenzene	98953	1	1.1
Nitrobenzene	98953	3	460000
Nitrobenzene	98953	2	5.1
N-Nitrosodiethylamine	55185	1	1.8
N-Nitrosodiethylamine	55185	3	130000
N-Nitrosodiethylamine	55185	2	6.6
N-Nitrosodimethylamine	62759	1	1.8
N-Nitrosodimethylamine	62759	3	170000
N-Nitrosodimethylamine	62759	2	6.6

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
N-Nitrosodi-n-butylamine	924163	1	1.8
N-Nitrosodi-n-butylamine	924163	3	1400000
N-Nitrosodi-n-butylamine	924163	2	7.5
N-Nitrosodi-n-propylamine [di-n-propylnitrosamine]	621647	1	1.8
N-Nitrosodi-n-propylamine [di-n-propylnitrosamine]	621647	3	240000
N-Nitrosodi-n-propylamine [di-n-propylnitrosamine]	621647	2	6.7
N-Nitroso-N-methylethylamine	10595956	1	1.8
N-Nitroso-N-methylethylamine	10595956	3	240000
N-Nitroso-N-methylethylamine	10595956	2	6.7
N-Nitrosopyrrolidine	930552	1	1.8
N-Nitrosopyrrolidine	930552	3	130000
N-Nitrosopyrrolidine	930552	2	6.6
o-Cresol [2-methyl phenol]	95487	1	1.1
o-Cresol [2-methyl phenol]	95487	2	5.3
o-Cresol [2-methyl phenol]	95487	3	680000
p-Cresol [4-methyl phenol]	106445	1	1.1
p-Cresol [4-methyl phenol]	106445	2	5.3
p-Cresol [4-methyl phenol]	106445	3	680000
Pentachlorobenzene	608935	2	280000000
Pentachlorobenzene	608935	3	280000000
Pentachlorobenzene	608935	1	56
Pentachlorophenol [PCP]	87865	3	12000000
Pentachlorophenol [PCP]	87865	2	15
Pentachlorophenol [PCP]	87865	1	2
Polychlorinated biphenyls [aroclors]	1336363	2	10000000000

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
Polychlorinated biphenyls [aroclors]	1336363	3	10000000000
Polychlorinated biphenyls [aroclors]	1336363	1	370
Pyridine	110861	1	1.1
Pyridine	110861	3	170000
Pyridine	110861	2	4.9
Selenium	7782492	2	166
Selenium	7782492	3	166
Selenium	7782492	1	6.7
Silver	7440224	3	388554.45
Silver	7440224	1	4.05
Silver	7440224	2	52.9
Tetrachlorodibenzofurans [TCDFs]	55722275	2	1.00E+06
Tetrachlorodibenzofurans [TCDFs]	55722275	3	1.00E+06
Tetrachlorodibenzofurans [TCDFs]	55722275	1	1059
Tetrachloroethylene [perchloroethylene]	127184	1	1.2
Tetrachloroethylene [perchloroethylene]	127184	3	1700000
Tetrachloroethylene [perchloroethylene]	127184	2	6.1
Thallium	7440280	2	2380
Thallium	7440280	3	2380
Thallium	7440280	1	73
Toluene	108883	1	1.2
Toluene	108883	3	2800000
Toluene	108883	2	6.9
Toxaphene [chlorinated camphene]	8001352	1	12
Toxaphene [chlorinated camphene]	8001352	2	640000

(continued)

Table C.3-1. (continued)

Constituent	CAS_NO	Scenario[a]	DAF
Toxaphene [chlorinated camphene]	8001352	3	640000
trans-1,3-Dichloropropylene	10061026	2	21000
trans-1,3-Dichloropropylene	10061026	1	21000
trans-1,3-Dichloropropylene	10061026	3	21000
Trichloroethylene [TCE]	79016	1	1.8
Trichloroethylene [TCE]	79016	3	1400000
Trichloroethylene [TCE]	79016	2	7.5
Vanadium	7440622	3	1000022.3
Vanadium	7440622	1	11.933333333
Vanadium	7440622	2	397.56666667
Vinyl chloride [chloroethylene]	75014	1	1.1
Vinyl chloride [chloroethylene]	75014	3	240000
Vinyl chloride [chloroethylene]	75014	2	4.9
Zinc	7440666	3	100000
Zinc	7440666	2	118.971
Zinc	7440666	1	6.328

[a] Liner scenario key:
1 = No liner.
2 = Single liner.
3= Composite liner.

For each constituent, the DAF from each liner scenario was multiplied by the carcinogenic or noncarcinogenic risk screening factor from the initial phase of risk screening to develop a new SI-modified IWEM Tier 1 table containing the leachate concentration threshold values. This approach ensured that receptors were evaluated with the same exposure factors (e.g., groundwater ingestion rate) used in the initial phase of risk screening.

There were a number of SIS constituents that were not included in the IWEM Tier 1 table. For those constituents, a leachate concentration threshold value was calculated using a DAF from a surrogate chemical. The leachate concentration threshold value was calculated by

using the IWEM procedure for estimating DAFs of chemicals for which EPACMTP was not simulated, as follows: the DAF was determined by interpolating between the DAFs of chemicals whose hydrolysis rate and retardation factor are in the same range as the hydrolysis rate and retardation factor of the new chemical.

Leachate concentration threshold values were exceeded for chemicals at 71 facilities in the IWEM Tier 1 screening model. Each of the 71 facilities was then evaluated to determine if the potential exists for direct exposure to contamination via the groundwater pathway.

Specifically, the topographic maps supplied by the facilities as part of their survey responses were evaluated to determine (1) whether drinking water wells were located within 2 km of any impoundment, (2) if the groundwater flow direction could be determined based on review of the topographic maps, and, if so, (3) if receptor wells were present in the downgradient direction.

The map review considered the location of the surface impoundments relative to surface waterbodies in the area. Surface waterbodies included bays, estuaries, rivers, lakes, streams, creeks, canals, harbors, and wetlands. The purpose of evaluating the relative location of impoundments to surface waterbodies was to determine the likely direction of groundwater flow. If the surface impoundment was situated proximate to the surface waterbody, it was assumed that leachate originating from the surface impoundment discharged in the direction of the nearby surface waterbody.

Survey respondents were also asked to identify the type and location of wells within a 2-km radius of the facility. Each of the topographic maps was reviewed to determine the location of receptor wells relative to the groundwater flow direction. To ensure that the assessment was conservative, all wells that might potentially be used for drinking water purposes, as identified by the facilities in their survey responses, were included in the assessment. The wells selected for consideration included the following categories:

- Private drinking water wells (residential)
- Public drinking water wells
- Industrial drinking water wells
- Business/commercial wells
- Church wells
- Drinking water services
- Wells designated as “don’t know”
- Wells designated as “other”
- Wells for which no designation was provided.

If no drinking water wells were present, or the groundwater flow was determined not to be in the downgradient direction of any receptor well, the potential for exposure via the groundwater pathway was presumed to be nonexistent and the site was excluded from further assessment. The facilities that were excluded from further assessment are presented in Attachment C-8. A numeric ranking of either 1 or 2 was assigned to the facilities for which

groundwater exposures could not definitively be ruled out. Table C.3-2 presents the ranking system used.

Table C.3-2. Ranking System for Groundwater Receptors

Score	Criteria
2	Groundwater direction can be determined **and** there are receptor wells located downgradient of the failed surface impoundments
1	Groundwater direction cannot be determined with certainty **but** the presence of potential receptor wells cannot be definitively ruled out
Exclude	Groundwater direction can be determined **and** there are no potential receptor wells located downgradient of the failed surface impoundments

Thirty-three of the 71 facilities were excluded from further assessment based on evidence that the groundwater pathway would not result in exposure. The remaining 38 facilities were evaluated using two sets of criteria developed to assign a numeric score that could be used to rank the facilities at greatest risk for groundwater exposures.

Two sets of criteria were developed for the groundwater analysis. The first set of criteria focused on easily quantifiable environmental setting characteristics such as distance to the nearest receptor well. The second set was based on professional judgment and involved detailed review of survey data and, in many cases, geotechnical reports submitted by the respondents. Each of the criteria was assigned a numeric score to rank facilities for additional site-based fate and transport modeling. The criteria and scoring methodology are discussed below.

C.3.1.1 Criteria Based on Environmental Setting Characteristics. Four criteria were selected to prioritize facilities and impoundments having potential for direct exposure to contaminants via the groundwater pathway. Each of the four criteria was selected to permit quantification of parameters that support the probability that the groundwater pathway may result in exposure. Hence, the criteria focus on the source of potential groundwater contamination (i.e., the chemicals present in the surface impoundment and their risk factors) and the point of exposure (i.e., the presence of wells used for drinking water consumption). Criteria were assigned a numeric score ranging from 1 to 3, with 3 having the highest potential for exposure. The four criteria were applied to the 38 facilities that exceeded the IWEM Tier 1 screening criteria. The four environmental setting criteria are

- Distance to the nearest receptor well
- Maximum cancer risk or HQ as determined using IWEM Tier 1
- Number of chemicals
- Surface area.

Distance to Nearest Receptor Well. The distance to the nearest receptor is an important indicator of the likelihood that exposure will occur as a result of consumption of contaminated drinking water. Receptor wells that are close to sources of contamination have a greater potential of being impacted than those located at great distances from the source of contamination. Hence, facilities that were characterized by receptor wells located at distances of less than 500 meters were given a higher ranking for modeling than facilities with receptor wells located at distances greater than 1,000 meters.

As noted above, survey respondents were asked to identify the type and location of wells within a 2-km radius of the facility. Distances from the surface impoundments to each of the wells identified as having the potential to be used for drinking water purposes were measured using the topographic maps. The minimum distance measured from the surface impoundment to a drinking water well was recorded and assigned a numeric scoring in accordance with Table C.3-3.

Although each of the facilities was asked to provide well information, not all respondents were able to supply this information. In the absence of survey data, the distance to the nearest populated census block within a census block group with residential wells was calculated. The minimum distance to the nearest populated census block was used in assessing well distances for facilities that did not supply well data. Table C.3-4 presents the distance value that was assigned and the associated scores.

Table C.3-3. Distance to Nearest Drinking Water Well (As Marked on Topographic Map)

Score	Criteria
3	0 < Distance ≤ 150 m
2	150 < Distance ≤ 500 m
1	500 < Distance ≤ 2,000 m

Table C.3-4. Distance to Populated Census Block

Score	Criteria	Assigned distance (m)
3	0 m < Residential well < 150 m	75
2	150 m < Residential well < 500 m	150
1	500 m < Residential well < 2000 m	500

Each facility received a single score based on well distance. Data supplied by the facility was the preferred source of data. Census data were only used as a default in the absence of facility-supplied well data. Scoring is presented in Attachment C-8.

Maximum Cancer Risk or HQ. Cancer risks and HQs were estimated during the IWEM screening analysis. The maximum cancer risk and the maximum HQ for each surface impoundment were compared and the risk or HQ that resulted in the highest overall score in accordance with Table C.3-5 was used in prioritization.

Table C.3-5. Maximum Cancer Risk or HQ

Score	Cancer Risk	Hazard Quotient
3	Cancer risk >10E-4	HQ >100
2	10E-6 ≤ Cancer risk ≤ 10E-4	10 < HQ ≤ 100
1	Cancer risk < 10E-6	1 ≥ HQ ≤ 10

Number of Chemicals. The total number of chemicals present at a facility was also scored. The larger the number of chemicals, the higher the score. Table C.3-6 presents the scores.

Table C.3-6. Total Number of Chemicals

Score	Criteria
3	Chemicals > 15
2	5 ≤ Chemicals ≤ 15
1	Chemicals < 5

Surface Area. The last criterion used was the surface area of the largest surface impoundment containing chemicals that exceeded the IWEM screening criteria. The scores were applied as presented in Table C.3-7.

Table C.3-7. Surface Area of Largest Surface Impoundment that Exceeded Risk Criteria

Score	Criteria (m^2)
3	Area > 75,000
2	10,000 < area ≤ 75,000
1	Area ≤ 10,000

Overall scores for the environmental setting criteria were calculated by summing each of the individual scores. A maximum of 14 points was possible.

C.3.1.2 Criteria Based on Professional Judgment. A second set of criteria were applied to refine the evaluation further. The second set of criteria were based on professional judgment and depended on detailed review of the survey responses and any supplemental geotechnical reports submitted with the surveys. These criteria were important because they added yet another dimension to assessing whether groundwater exposures were viable. These criteria depended on geometric considerations such as whether receptor wells are drawing water from a contaminated aquifer as opposed to drawing water from an aquifer situated hundreds of feet below the contaminated zone. The presence of low-conductivity layers that impede the downward migration of contaminants was also considered. These criteria were scored similarly to the environmental setting criteria in that scores ranged from 1 to 3, with 3 having the greatest potential for viable groundwater exposures.

Presence of Aquifers That Support Drinking Water Use. An aquifer is best defined as a saturated permeable layer that yields significant or economic quantities of groundwater. Ninety-six percent of the world's available fresh water reserve is groundwater and the U.S. Geologic Survey reports that groundwater supplies 51 percent of our nation's population with drinking water (U.S. EPA, 1998c). This water reaches the population through private water wells or through municipal systems that use groundwater as a source. The focus of this assessment is on private wells that supply drinking water.

Survey respondents were asked to provide information on whether the aquifers beneath the facility were suitable for drinking water purposes. If the aquifers were not suitable for use as a source of drinking water, the potential for exposure via the groundwater pathway was limited. A score of 1 to 3 was awarded to each facility based on the survey results (Table C.3-8).

Table C.3-8. Aquifers Support Domestic Supply

Score	Criteria
3	Facility indicates that aquifers are used for domestic supply
2	Facility does not know if aquifers are used for domestic supply
1	Facility indicates that aquifers are not used for domestic supply

Twelve facilities indicated that the aquifers beneath the site were used to supply drinking water (Attachment C-8). Two facilities indicated that the groundwater beneath their sites was not suitable for drinking water; however, a score of "3" was assigned to both of these sites. One of the facilities received a score of "3" because the existence of groundwater contamination confirmed the possibility of exposure via the groundwater pathway. The presence of an onsite potable well at the second facility showed that the groundwater was used for drinking water

purposes and, hence, could support drinking water purposes. Therefore, 14 facilities or 38 percent of the facilities were characterized by aquifers that support drinking water use.

Presence of Wells Screened in Aquifer. If the aquifer beneath the site was suitable to supply drinking water, the next step was to assess whether wells were drawing water from the aquifer for human consumption. Table C.3-9 illustrates the scoring system used.

Table C.3-9. Domestic Wells Screened in Aquifer

Score	Criteria
3	Facility indicates that wells draw water from an at-risk drinking water aquifer
2	Facility does not know if there are wells screened in the drinking water aquifer
1	Facility indicates that there are no wells screened in the drinking water aquifer at risk

Survey respondents were asked to indicate which subsurface saturated zone (or aquifer) supplied water to wells shown on the topographic map. This information was cross-referenced against aquifer information supplied in the survey and a judgment was made as to whether receptor wells draw drinking water from the aquifers of interest. Eleven facilities (or 38 percent) indicated that wells were screened in the drinking water aquifers (Attachment C-8).

Presence of a Continuous Confining Layer. Aquifers are defined as layers that yield significant quantities of water. Layers that do not produce or yield significant quantities of water are defined as aquitards. The most common aquitards are clays, chalk, shales, and dense crystalline rock. Definitions of aquifers and aquitards are imprecise because the terms are relative. For example, in an interlayered sand-silt sequence, the silts may be considered aquitards, whereas in a silt-clay system, the same silts may be described as aquifers. For purposes of this assessment, thick continuous layers (in excess of 20 feet) of clay or chalk were defined as aquitards.

Aquitards are characterized by low conductivity (10^{-4} m/d to 10^{-7} m/d). The low conductivity retards the downward migration of contamination. If an aquitard is present, contamination is unlikely to reach the underlying aquifer, and the groundwater pathway is considered incomplete. A score of either 1 or 2 was assigned (Table C.3-10).

Table C.3-10. Presence of a Low Conductivity Confining Layer

Score	Criteria
2	Thin, discontinuous, or absent confining layer
1	Well-defined confining layer > 20 feet thick

A score of 1 indicates that the potential for vertical migration of contaminants is negligible and the facility is excluded from further scoring. Eight facilities (22 percent) were characterized by the presence of a thick, continuous confining layer that made the groundwater pathway not viable (Attachment C-8).

Aquifer Conductivity. Aquifers are commonly characterized by hydraulic conductivities that range from 10^6 m/d to 10 m/d. The higher hydraulic conductivities are associated with well-sorted sands and gravels. If an aquifer is characterized by higher hydraulic conductivity, contaminants have the potential to migrate at a faster rate and impact receptor wells. Scoring was based on survey responses (Table C.3-11).

Eleven facilities were characterized by aquifer stratigraphy that was conducive to rapid migration of contaminants (Attachment C-8).

Table C.3-11. Aquifer Conductivity

Score	Criteria
3	Highly conductive stratigraphy (sand, sand and gravel)
2	Variable conductivity (silty sands)
1	Low conductive stratigraphy (clay, chalk)

Having scored each of the professional judgment criteria, both the environmental setting scores and the professional judgment scores were summed into a total score. The facilities that received the highest scores were prioritized for additional characterization using groundwater modeling. The methods and results for groundwater modeling are presented in Attachments C-11 and C-12.

C.3.2 Modeling Groundwater Exposure Concentrations

Groundwater fate and transport modeling was conducted for constituents that did not pass the screening analyses described in Section C.3.1. The modeling was conducted for wastewaters managed in onsite surface impoundments and was directed toward estimating groundwater concentrations in residential drinking water wells downgradient from the surface impoundment. Surface impoundment characteristics and constituent concentrations were obtained from data provided by operators in the Survey of Surface Impoundments.

The analysis used EPACMTP, a state-of-the-science vadose zone and groundwater fate and transport model designed specifically for regulatory applications. The model can be applied in either a probabilistic (Monte Carlo) or a deterministic mode. The version of EPACMTP used resulted from modifications made specifically for the Inorganics Listing Determination (U.S. EPA, 2000b) with two additional modifications. These modifications removed constraints on the depth of the receptor well location and the angle of the receptor well off plume centerline that were implemented specifically for the Inorganics Listing Determination. Additional details are

provided in Section C.3.2.2. Monte Carlo model runs were conducted in this analysis. Site-specific modeling data were used when available and supplemented by regional and national data sources. Distributions were used to characterize potential site variability and uncertainty in model input parameters.

Section C.3.2.1 presents a brief technical summary of the simulation model chosen for this analysis, the EPACMTP. The general modeling methodology and assumptions for this analysis are described in Section C.3.2.2, in addition to code modifications made specifically for this analysis. Data sources and assumptions for the modeling of conservative and non-conservative organic constituents are described in Section C.3.2.3. Data sources for site-specific characteristics and subsurface modeling parameters are described in Section C.3.2.4. Section C.3.2.5 presents the facility-specific modeling approach adopted for this analysis. The results of the Monte Carlo simulations are presented in Attachment C-11 of this Appendix.

C.3.2.1 EPACMTP Background. Only releases to groundwater were considered in this portion of the risk assessment. The EPACMTP groundwater model was used to estimate the fate and transport of constituents through the subsurface environment, as described here.

Description of EPACMTP. The groundwater pathway modeling conducted for this Monte Carlo analysis was performed to determine the residential groundwater well exposure concentrations resulting from the release of waste constituents from surface impoundments. Liquid that percolates through the surface impoundment generates leachate, which can infiltrate from the bottom of the impoundment into the subsurface. For surface impoundments, the liquid is the wastewater managed in the impoundments. The waste constituents dissolved in the leachate are then transported via aqueous phase migration through the vadose zone (unsaturated zone that lies below the bottom of the surface impoundment and above the water table) to the underlying aquifer (or saturated zone) and then downgradient to a groundwater receptor well. 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 surface impoundment. This well is referred to hereafter as the "receptor well." This conceptual model of the groundwater fate and transport of contaminant releases from the surface impoundment is illustrated in Figure C.3-1.

The conceptual procedure described here is quantitatively evaluated with a groundwater model developed by EPA, EPACMTP (U.S. EPA, 1996d,e, 1997b). EPACMTP is a tool that has been widely peer reviewed and is used by EPA to assess wastes managed in land disposal units (landfills, surface impoundments, wastepiles, or land application units). EPACMTP simulates flow and transport of contaminants in the unsaturated zone and aquifer beneath a waste disposal unit to predict the maximum concentration arriving at a specified receptor well location. For use in risk assessments, the receptor well concentration can be reported as the peak concentration or as the highest average concentration over an appropriate exposure time interval.

Fate and transport processes accounted for in the model are advection, hydrodynamic dispersion, linear and nonlinear sorption at equilibrium, and chemical hydrolysis. The composite

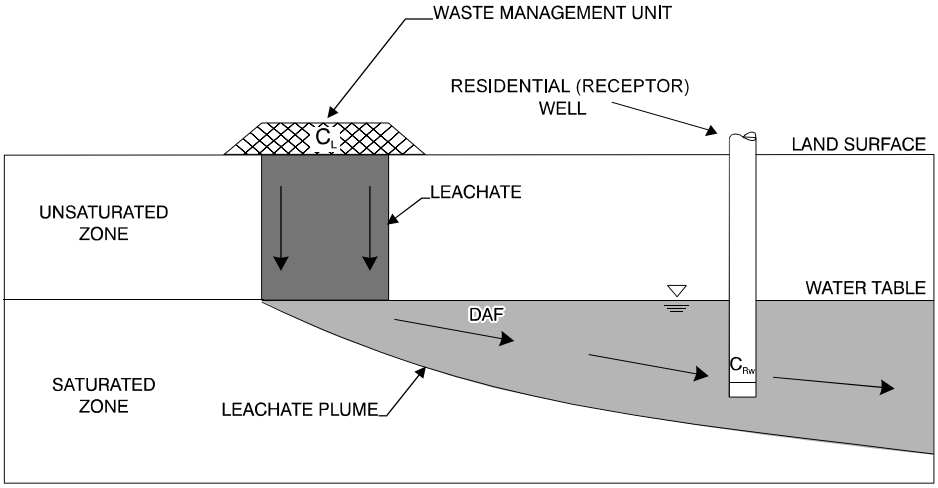


Figure C.3-1. Schematic diagram of groundwater modeling scenario.

model consists of two coupled modules: a one-dimensional (1-D) module that simulates infiltration and dissolved contaminant transport through the unsaturated zone and a saturated zone flow and transport module that can be run in either a fully 3-D or quasi-3-D mode. Quasi-3-D mode simplifies the fully 3-D flow and transport solutions to one of two 2-D conditions. For conditions where the saturated zone is thin and the contaminant mass flux into the saturated zone is large, fully mixed conditions are assumed and an areal (x-y) planar approximation is implemented. For conditions in which flow in the horizontal transverse (y) direction is of minor significance, such as when infiltration through the surface impoundment area is relatively low compared to the groundwater flow rate, a vertical 2-D cross-sectional solution is employed where a numerical solution is achieved in the x-z plane and an analytical solution is used to expand this in the transverse (y) direction. EPACMTP uses an automatic criterion for determining which of these quasi-3-D scenarios to apply based on the combination of aquifer parameters. The principal benefit of this quasi-3-D approach is that it provides substantial savings in computational effort, making large-scale Monte Carlo simulations feasible. It is for this reason that the quasi-3-D approach was used for all of the Monte Carlo runs in this analysis.

It is assumed that the soil and aquifer are uniform porous media and that flow and transport are described by the flow equation and the advection-dispersion equation, respectively. The flow equation is based on Darcy's law, which states that the flow per unit area of groundwater through porous media is the product of hydraulic conductivity and hydraulic gradient. The advection-dispersion equation describes solute transport by flowing groundwater (advection) and hydrodynamic dispersion resulting from mechanical mixing and molecular diffusion.

Flow and Transport Equations Used in EPACMTP. The groundwater flow simulation is based on the following simplifying assumptions:

- The aquifer is homogeneous.
- Groundwater flow is steady-state.
- Flow is isothermal and governed by Darcy's law.
- The fluid is slightly compressible and homogeneous.
- The principal directions of the hydraulic conductivity tensor are aligned with the Cartesian coordinate system.

According to Freeze and Cherry (1979), the governing equation for steady-state flow in three dimensions may be written:

$$k_r K_x \frac{\partial^2 H}{\partial x^2} + k_r K_y \frac{\partial^2 H}{\partial y^2} + k_r K_z \frac{\partial^2 H}{\partial z^2} = 0 \qquad \text{(C.3-1)}$$

where

H = hydraulic head (m)

k_r = relative permeability (dimensionless)

K_x, K_y, and K_z = hydraulic conductivities (m/yr) in the longitudinal (x), horizontal transverse (y), and vertical (z) directions, respectively.

Further details about these parameters may be found in Freeze and Cherry (1979). Equation (C.3-1) is solved subject to the boundary conditions given in U.S. EPA (1996e).

Flow in the vadose zone is modeled as steady-state, one-dimensional, and vertically downward from underneath the source surface impoundment toward the water table. The lower boundary of the vadose zone is the water table. The flow in the vadose zone is predominantly gravity-driven; therefore, the vertical flow component accounts for most of the fluid flux between the source and the water table. The flow rate is determined by the long-term average infiltration rate through the surface impoundment.

For the saturated zone, relative permeability k_r is equal to unity. Flow in the saturated zone is based on the assumption that the contribution of recharge from the unsaturated zone is small relative to the regional flow in the aquifer and the saturated aquifer thickness is large relative to the rise due to infiltration from the surface impoundment and recharge outside the surface impoundment so that the saturated zone can be modeled as having a uniform thickness.

The governing equation for transport in three dimensions is given by (Bear, 1979):

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C_l}{\partial x_j}\right) - V_i\frac{\partial C_l}{\partial x_i} = \theta R_l\frac{\partial C_l}{\partial t} + \theta\, Q_l\lambda_l C_l + \sum_{m=1}^{M}\xi_{lm}Q_m\lambda_m C_m \qquad \text{(C.3-2)}$$

where

x_1, x_2, and x_3	=	x, y, and z Cartesian coordinates, respectively
t	=	time
C_l	=	concentration of the l-th component species in the n_c member decay chain, λ_l
R_l	=	first-order decay coefficient and retardation coefficient, both for species l
Q_l and Q_m	=	correction factors to account for sorbed phase decay of species l and parent m, respectively
θ	=	water content

and Einstein summation conventions are used to simplify the notation. For computation of the longitudinal, horizontal transverse, and vertical dispersion coefficients (D_{xx}, D_{yy}, and D_{zz}), the conventional dispersion tensor for isotropic porous media is modified to allow the use of different horizontal transverse and vertical dispersivities (U.S. EPA 1996e). The dispersion coefficients are given by:

$$\begin{aligned}
D_{xx} &= \alpha_L\frac{V_x^2}{|V|} + \alpha_T\frac{V_y^2}{|V|} + \alpha_V\frac{V_z^2}{|V|} + \theta D^*\\
D_{yy} &= \alpha_L\frac{V_y^2}{|V|} + \alpha_T\frac{V_x^2}{|V|} + \alpha_V\frac{V_z^2}{|V|} + \theta D^*\\
D_{zz} &= \alpha_L\frac{V_z^2}{|V|} + \alpha_V\frac{V_y^2}{|V|} + \alpha_V\frac{V_x^2}{|V|} + \theta D^*\\
D_{xy} &= D_{yx} = (\alpha_L - \alpha_T)\frac{V_xV_y}{|V|}\\
D_{xz} &= D_{zx} = (\alpha_L - \alpha_V)\frac{V_xV_z}{|V|}\\
D_{yz} &= D_{zy} = (\alpha_L - \alpha_V)\frac{V_yV_z}{|V|}
\end{aligned} \qquad \text{(C.3-3)}$$

where α_L, α_T, and α_V are the longitudinal, horizontal transverse, and vertical dispersivity (m), respectively, and D^* is the effective molecular diffusion coefficient (m^2/yr).

The water content, θ, and Darcy velocity V_i, are defined as follows:

$$\theta = \varphi S_w \tag{C.3-4}$$

$$\begin{aligned} V_x &= - k_r K_x \frac{\partial H}{\partial x} \\ V_y &= k_r K_y \frac{\partial H}{\partial y} \\ V_z &= k_r K_z \frac{\partial H}{\partial z} \end{aligned} \tag{C.3-5}$$

where

φ = effective porosity
S_W = degree of water saturation.

In the saturated zone, $S_W = 1$. Equation (C.3-2) is solved separately for the vadose and saturated zones. Details of boundary conditions and solution methods are given in U.S. EPA (1996e).

The retardation factor for each of the member species is given by

$$R = 1 + \frac{\rho_b \, ds}{\theta \, dC} \tag{C.3-6}$$

where

ρ_b = bulk density (g/m^3)
s = adsorbed concentration (g/g)

and

$$S = k_1 C^{\eta} , \tag{C.3-7}$$

where

k_1 = Freundlich coefficient
η = Freundlich exponent.

The subscript *l* has been dropped for convenience. Assuming the adsorption isotherm follows the equilibrium Freundlich equation, the retardation coefficient can be written as

$$R = 1 + \frac{\rho_b}{\theta} k_1 \eta C^{\eta-1} \quad . \qquad \text{(C.3-8)}$$

The coefficient Q is given by

$$Q = 1 + \frac{\rho_b}{\theta} k_1 \eta C^{\eta-1}. \qquad \text{(C.3-9)}$$

Note that, in general, the retardation factor is a nonlinear function of concentration. The Freundlich isotherm becomes linear when the exponent $\eta = 1$. The Freundlich coefficient, k_1 in this case, is the same as the familiar solid-liquid phase partition coefficient, K_d. When sorption is linear, the coefficients R and Q also become identical. For all the inorganic chemicals reported herein, $\eta = 1$, $\lambda_l = 0$, and $n_c = 1$.

EPACMTP does not account for heterogeneity, preferential pathways such as fractures and macropores, or colloidal transport, which may affect migration of strongly sorbing constituents such as metals. However, sites located in karstic terrain may be accommodated by using the associated solution limestone hydrogeologic environment provided in the HydroGeologic DataBase (Newell et al., 1990, U.S. EPA, 1997b) used by EPACMTP. The database is described in more detail in Section C.3.2.2.

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. The output from EPACMTP is a prediction of the contaminant concentration arriving at a downgradient groundwater receptor well. This can be either a steady-state concentration value, corresponding to a continuous source scenario, or a time-dependent concentration, corresponding to a finite source scenario. In the latter case, the model can calculate the peak concentration arriving at the well or a time-averaged concentration corresponding to a specified exposure duration (e.g., a 9-year average residence time). For this analysis, either the peak or the average concentrations were calculated to determine the risks associated with noncarcinogenic or carcinogenic constituents, respectively. For all modeled constituents, the groundwater averaging time and exposure duration are assumed to follow a prespecified probability distribution instead of being input as constant values. For each given realization, however, the groundwater averaging time and exposure duration are identical.

For the probabilistic analysis, 10,000 realizations[1] were conducted for each modeling scenario, with the inputs specified as constant values, derived values, or statistical or empirical distribution of values. Each realization comprises a complete and distinct set of model input parameters and the flow and transport solution derived from those inputs. The input parameters for each realization are chosen by EPACMTP from the user-specified values or distributions based on a sequence of randomly generated numbers.

Source Terms and Release Mechanisms. The release of contaminants into the subsurface constitutes the source term for the groundwater fate and transport model. Because the modeled subsurface fate and transport processes are the same for each waste management scenario, the conceptual differences between different waste management scenarios are reflected solely in how the model source term is characterized. 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 (infiltration rate), (3) constituent-specific leachate concentration, and (4) duration of the constituent leaching. Leachate flux rate and leaching duration are determined as a function of both the design and operational characteristics of the waste management unit and the waste stream characteristics (waste quantities and waste constituent concentrations).

C.3.2.2 Modeling Methodology. The general modeling methodology and assumption for this analysis are described in this section, in addition to code modifications made specifically for this analysis, the Monte Carlo modeling approach, and a summary of modeling data sources.

Modeling Infiltration and Recharge Rates. EPACMTP requires inputs for both infiltration and recharge rates. Infiltration is defined as water percolating through the surface impoundment to the underlying soil, while recharge is water percolating through the soil to the aquifer outside of the surface impoundment. For recharge, EPACMTP uses estimates from the

[1] The Monte-Carlo groundwater pathway analysis was performed with 10,000 realizations based on the results of a previous bootstrap analysis to maintain consistency with previous analyses, such as the Petroleum Refining and Lead Based Paint Analyses. Bootstrap analysis is a technique of replicated resampling (usually by a computer) of an original data set for estimating standard errors, biases, confidence intervals, or other measures of statistical accuracy. It can automatically produce accuracy estimates in almost any situation without requiring subjective statistical assumptions about the original distribution.

In this case, the bootstrap analysis upon which this decision was based was documented in *EPACMTP Sensitivity Analyses* (U.S. EPA, 1996d). This report presents a bootstrap analysis conducted in response to public comments regarding the number of realizations used for the 1995 proposed Hazardous Waste Identification Rule. In using a Monte Carlo modeling approach, a higher number of realizations usually leads to a more convergent and more accurate result. However, it is not generally possible to determine beforehand how many realizations are needed to achieve a specified degree of convergence since the value can be highly dependent on parameter distributions. Therefore, EPA conducted a bootstrap analysis for the EPACMTP model to evaluate how convergence improves with increasing numbers of realizations. The analysis was based on a continuous source, landfill disposal scenario in which the 90th percentile DAF was 10. The bootstrap analysis results suggested that, with 10,000 realizations, the expected value of the 90th percentile DAF was 10 with a 95 percent confidence interval of 10 ± 0.7. The 95 percent confidence interval was near asymptotic. Because the parameter distributions used in the analyses for HWIR and this analysis are similar, the HWIR-related bootstrap analysis results were considered applicable.

HELP model, a hydrologic model for conducting water balance analysis of landfills, cover systems, and soil systems (U.S. EPA, 1994a, b). In the context of EPACMTP, HELP has been run for three soil textures (sandy loam, silt loam, silty clay loam) and 97 climatic centers across the country to represent nationwide variability in soil properties, cover characteristics, and climatic data (e.g., precipitation and evapotranspiration) that affect recharge and infiltration rates. For this risk assessment, recharge rates were selected from this set of data to represent site conditions of each facility.

Infiltration rates for this analysis were calculated using the semi-analytical solution defined below. Impoundment-specific data were used where available. In cases where the base of the impoundment is at or below the water table, the leachate flux to the aquifer was calculated outside of EPACMTP (using the method described in Bear, 1979), and this flux was directly applied to the saturated zone; that is, the vadose zone was not modeled.

A semi-analytical solution technique used in EPACMTP allows a very efficient and accurate solution of the vertical steady-state flow resulting from a surface impoundment unit. The surface impoundment scenario consists of a surface impoundment unit overlying a liner overlying the soil in the vadose zone. Ideally, an accurate method of determining the infiltration rate through the liner is to solve the variably saturated flow equation in a composite domain consisting of the liner and the vadose zone. However, this method requires a fine discretization to describe a relatively sharp pressure profile above the interface between the liner and the underlying soil. A simpler but conservative approach was, therefore, adopted by EPA. Infiltration rate through the liner is obtained by solving the non-linear variably saturated flow equation for the one-dimensional vertical flow domain encompassing the liner and the vadose zone soil (U.S. EPA, 1996e). For computational efficiency, the liner is assumed to be saturated at all times, and the gradient across the liner is uniform and may be approximated using the ponding depth (i.e., the height of wastwaters above the liner) and the thickness of the liner. The method tends to overestimate infiltration rate when the ponding depth is relatively small. When the ponding depth is relatively large, the infiltration rates estimated using the current method in EPACMTP approach the respective rates determined by the variably saturated flow equation.

An independent computational model has recently been developed to assist in estimating infiltration from surface impoundment units by solving the variably saturated flow equation in the whole flow domain (U.S. EPA, 1999e). This module allows the sediments at the bottom of the unit to settle and be consolidated by the overlying hydrostatic and loose sediment loads. In this case, the hydraulic function of the consolidated sediment layer is equivalent to that of a liner. In the module, the flow domain encompasses the compacted sediment and the native material in the vadose zone.

In the simulations described here, the EPACMTP *effective liner* layer consists of two components: a layer of in-unit compacted sediment derived from sludge solids in the waste water, underlain by a liner reported by the owner of the surface impoundment unit. The effective hydraulic conductivity of the effective liner layer is determined using the harmonic mean of the hydraulic conductivity of the liner (reported by the owner/ operator) and the consolidated sediment hydraulic conductivity using the constitutive relationship between the hydrostatic loads

above the consolidated sediment and hydraulic conductivity of the consolidated sediment (U.S. EPA, 1999e). When no liner information is reported, only the in-unit sediments contribute to the determination of the liner conductivity. The thickness of the compacted sediment is assumed to be one-half the total thickness of the sediment. If the total thickness of the sediment is not reported, a default value of 15 cm is used for the compacted sediment thickness. If the liner conductivity is not available, a value of 1.0×10^{-7} cm/s is assumed. The compacted sediment conductivity is given by the constitutive relationship between hydraulic conductivity and water-and-loose-sediment load as given in the HWIR99 background document for the surface impoundment source module (U.S. EPA, 1999e).

Infiltration rates for the composite-liner scenario, consisting of a clay liner with a flexible membrane liner (FML) on top of the clay layer, were computed using a liner leakage equation developed by Bonaparte et al. (1989) to estimate leakage through pinholes in a geomembrane for good contact conditions:

$$Q_L = 0.21 \cdot a^{0.1} \cdot h_W^{0.9} \cdot k_S^{0.74} \qquad \text{(C.3-10)}$$

where

Q_L = rate of leakage through a circular hole in the geomembrane component of the composite liner (m^3/s)

a = geomembrane hole area (m^2)

h_W = head of liquid on top of the geomembrane (m)

k_S = hydraulic conductivity of the low-permeability soil component of the composite liner (m/s).

A geomembrane hole was assumed to have an area of 3×10^{-6} m^2 and a hole density of 1 hole per acre of membrane. These assumptions are consistent with those in IWEM (U.S. EPA 1999b, c).

Location and Time of Exposure. The selected receptors for the groundwater pathway were hypothetical adult and child residents who obtained drinking water from a groundwater well. The exposure point was determined as the nearest drinking water well likely to be exposed to constituent releases migrating through the groundwater from a surface impoundment at a facility. The nearest drinking water well was identified by an examination of each facility's topographic map and selecting wells in the probable direction of groundwater flow. Based on survey responses, these are well locations in potential use by residents.

The location of the receptor well is confined for each surface impoundment to a circular arc defined by an angle "THETA." The angle THETA is defined as the angle of the well off the plume centerline (based on the best estimate of the local groundwater flow direction) plus a small

amount as an additional margin of safety. For a fixed groundwater flow direction, THETA may be viewed as uncertainty associated with the well location. Conversely, for a fixed receptor well location, THETA implies uncertainty with respect to the groundwater flow direction. Since site maps were furnished with defined well locations, THETA is considered to be a measure of the uncertainty in the groundwater flow direction.

A potential problem arises in the event that multiple surface impoundments are present at a given facility. For consistency in calculating risks, it is imperative that all impoundments at a given facility have the same degree of uncertainty associated with the inferred average groundwater flow direction. This can be done by using a common angle THETA for all units at a given facility. Thus, THETA, the average uncertainty with respect to the groundwater flow direction at a given site, is defined as the sum of two angles:

- The average of the impoundment-specific values for THETA at that facility
- A small angle to account for an error margin.

The error margin is subjective and has been set to 5 degrees for all facilities for this analysis based on professional judgment. In the Monte Carlo EPACMTP modeling conducted for this project, THETA is enforced by assigning a minimum and a maximum value whose difference is THETA. Geometrically, the corresponding well locations for respective surface impoundments are located near one another; however, these locations are not quite identical. Effects due to this geometrical inexactitude are considered insignificant when compared with those due to other uncertainties in the modeling scenario.

A distribution of 10,000 exposure durations was selected from a Weibull distribution corresponding to all nonfarming residents and applied to all Monte Carlo simulations. The selection of the shape and scaling parameter for the Weibull distribution are described in Table C.3-15.

Description of Required Code Modifications. For the Surface Impoundment Study, only two modifications were made to EPACMTP to facilitate the groundwater analysis. EPACMTP Version 1.2.2 was created specifically for the Inorganics Listing Determination (U.S. EPA, 2000b) and subsequently tested (U.S. EPA, 2000e). In addition to the main input data file, an extra input file may be specified in EPACMTP version 1.2.2, also referred to as the source data file. The source data file contains values of parameters whose distribution types are set to "88" in the main input data file. The source data file permits output from source models or previous simulations of EPACMTP to be used as input to EPACMTP and provides the means to correlate parameters, such as leachate concentration, infiltration rate, and soil and aquifer type, to facility location. Version 1.2.2 limited the depth of the receptor location to vary uniformly throughout the aquifer thickness or throughout the upper 10 m of the aquifer thickness, whichever is less. That is, the well depth is never allowed to exceed 10 m below the water table. For this study, the 10-m depth restriction was removed.

In addition, logic was added to version 1.2.2 to override the existing receptor well location algorithm to permit the user to specify a constant value for the angle between the well

location and the plume centerline. This constraint was relaxed to allow the user to specify a range for the angle. The resulting EPACMTP version is version 1.2.3.

Monte Carlo Analysis. Application of the EPACMTP model requires input values for the source-specific, chemical-specific, unsaturated zone-specific, and saturated zone-specific model parameters. Each of these input parameters can be represented by a probability distribution reflecting the range of variation that may be encountered at the modeled waste site(s). The fate and transport simulation modules in EPACMTP are linked to a Monte Carlo module to allow quantitative estimation of the uncertainty in the downgradient receptor well concentration due to uncertainty and variability in the model input parameters.

Following is a brief description of the general Monte Carlo methodology used in EPACMTP. Additional information about Monte Carlo modeling using EPACMTP can be found in EPACMTP documents (U.S. EPA, 1996c, 1996e, 1997b).

The Monte Carlo option in EPACMTP is based on the module incorporated in EPA's Composite Model for Landfills (EPACML) (U.S. EPA, 1990). This module has been enhanced in three ways: (1) to account more directly for dependencies between various model parameters by using data from actual waste sites across the United States (2) to include a site-based methodology to directly associate the appropriate regional climatic and hydrogeologic conditions to the location of a waste site, and (3) to account for statistical correlations between two or more model parameters (e.g., hydraulic conductivity and gradient) when missing parameter values are generated.

The EPACMTP input parameters considered in the groundwater Monte Carlo modeling are presented in Table C.3-12. For modeling the surface impoundment, the depth of the sludge layer and the ponding depth were set to a constant value based on facility information; the hydraulic conductivity of the sediment layer at the base of impoundment and the underlying unsaturated zone were derived as described in the surface impoundment module documentation (U.S. EPA, 1999a).

Modified Regional Site-Based Methodology. The regional site-based approach offers several advantages over a strictly nationwide methodology. This methodology relies on data compiled at actual waste sites around the country, which can be linked to databases of climatic and hydrogeologic parameters through the use of climate and hydrogeologic indices. Thus, the regional site-based approach attempts to approximate the ideal situation where a complete set of the required site-specific values is available for each Monte Carlo realization without requiring the extensive sampling that would be required to actually gather these data.

Table C.3-12. EPACMTP Input Parameters for Monte Carlo Modeling

Impoundment Scenario/Parameter	Input Data Source
Surface impoundment scenario	
WMU area (m^2)	Site-specific data from SI Survey
Leachate concentration	Site-specific data from SI Survey
Regional recharge rate (m/yr)	Location-specific from national distribution based on proximity of facility to climate station (U.S. EPA, 1997b)
Infiltration rate (m/yr)	Derived using EPACMTP model or Darcy's law if liner is below water table
Pulse duration (yr)	Site-specific data from SI Survey or 50 years if impoundment is still operational and has operational life less than 50 years
Depth of wastewater (m)	Site-specific data from SI Survey or schematic drawings, if available
Liner thickness (m)	Site-specific data from SI Survey or schematic drawings, if available
Liner conductivity (m/yr)	Site-specific data from SI Survey or schematic drawings, if available, else assumed to be 1.0e-7 cm/s [3.15e-02 m/yr]
Chemical-specific parameters	
Organics	
Hydrolysis rate (yr^{-1})	Constituent-specific (Kollig et al., 1993)
K_{OC} (L/kg)	Constituent-specific (Kollig et al., 1993)
Inorganics	
K_d (L/kg)	Empirical or statistical distribution of values from the scientific literature (U.S. EPA, 2000b)
Both organics and inorganics	
Exposure duration (yr)	Weibull-based distribution; same for all Monte Carlo simulations
Unsaturated zone parameters	
Sat. hydraulic cond (cm/h)	Distribution based on soil type (Carsel and Parrish, 1988)
Hydraulic parameter, α (cm^{-1})	Distribution based on soil type (Carsel and Parrish, 1988)
Hydraulic parameter, β	Distribution based on soil type (Carsel and Parrish, 1988)
Residual water content	Distribution based on soil type (Carsel and Parrish, 1988)
Saturated water content	Distribution based on soil type (Carsel and Parrish, 1988)
Depth to groundwater (m)	Site-specific data from SI Survey or schematic drawings, if available, else distribution on HG region [a] (Newell et al., 1990)
Organic matter content (%)	Distribution based on soil type (Carsel et al., 1988)
Bulk density (g/cm^3)	Distribution based on soil type (Carsel et al., 1988)

(continued)

Table C.3-12 (continued)

Impoundment Scenario/Parameter	Input Data Source
Saturated zone parameters	
Particle diameter (cm)	National distribution (U.S. EPA, 1997b)
Saturated thickness (m)	Site-specific data from SI Survey or schematic drawings, if available, else distribution based on HG region [a] (Newell et al., 1989)
Hydraulic conductivity (m/yr)	Site-specific data from SI survey if available, else distribution based on HG region [a] (Newell et al., 1989)
Hydraulic gradient (m/m)	Site-specific data from SI survey if available, else distribution based on HG region [a] (Newell et al., 1989)
Longitudinal dispersivity (α_L)	Derived from distance to well (Gelhar et al., 1992; U.S.EPA, 1997b)
Transverse dispersivity (α_T)	Derived from distance to well (Gelhar et al., 1992; U.S.EPA, 1997b)
Vertical dispersivity (α_V)	Derived from distance to well (Gelhar et al., 1992; U.S.EPA, 1997b)
Groundwater temperature (°C)	Location-specific
Groundwater pH	Value based on soil type
Fraction organic carbon	National distribution (U.S. EPA, 1997a)
Receptor well location	
Radial well distance (m)	Site-specific data from topographic maps
Angle off plume centerline (°)	Site-specific data from topographic maps
X-well distance (m)	Derived from radial distance to well and angle off the plume centerline
Y-well location (m)	Derived from radial distance to well and angle off the plume centerline
Z-well depth (m)	Uniformly distributed throughout saturated thickness

[a] HG is the HydroGeologic database for modeling (Newell et al., 1990; U.S. EPA, 1997b).

The specific methodology for data gathering employed for this risk assessment can be summarized as follows:

- For sites where adequate site-specific data on soil and aquifer parameters were not available: (1) the site's geographic location was correlated with available GIS data and aquifer maps to classify the underlying aquifer as 1 of 13 types and to classify the soil as 1 of 3 types; (2) the site's geographic location was used to place the site within 1 of 97 climatic regions in the continental United States; and (3) the hydrogeologic and climatic indices were then used to define the site-specific distributions of hydrogeologic and climatic parameter values, respectively.

- For sites where adequate site-specific data on soil and aquifer parameters were available: (1) site-specific data were used to define the percentage of the three soil types present at the site and their associated pH, and values (or distribution of values) for aquifer parameters; and (2) the site's geographic location was used to place the site within 1 of 97 climatic regions in the continental United States, and

this climatic index and the soil type(s) present at the site were then used to define the site-specific recharge rate.

Once the percentages of soil types were defined for a facility, an ensemble of 10,000 soil type identifiers (1, 2, or 3) was randomly generated respecting the distribution of soil type percentages. These identifiers were used in the Monte Carlo simulation for all impoundments at a facility to choose from the appropriate distribution of values appropriate for that soil type (Carsel et al., 1988). These distributions are specified within the EPACMTP code, as described in U.S. EPA (1997b).

Data sources for the modified regional site-based methodology that were used to conduct this analysis include: (1) the infiltration and recharge analysis performed for 97 U.S. climatic centers using the HELP model (U.S. EPA, 1997b); (2) the USGS inventory of the groundwater resources of each state (USGS, 1985); and (3) the HydroGeologic DataBase for Modeling (HGDB) (Newell et al., 1990; U.S. EPA, 1997b), developed from a survey of hydrogeologic parameters for actual hazardous waste sites in the United States.

For this analysis, facility-specific values for impoundment location and waste, soil, and aquifer characteristics were used to the extent possible. Where site-specific data were not available, the following parameters were available from the HGDB database (Newell et al., 1990; U.S. EPA, 1997b):

- Depth to groundwater (m)
- Aquifer thickness (m)
- Hydraulic conductivity (m/yr)
- Hydraulic gradient (m/m).

Given a hydrogeologic environment, 10,000 values for the above four parameters were selected as correlated parameters according to the methodology described in U.S. EPA (1997b). If reliable site-specific values for any of the four were available, that value was used instead of the generated values. In most cases, sufficient information existed to establish values for the depth to groundwater and the thickness of the saturated region. Information about the remaining hydrogeologic parameters, hydraulic gradient and hydraulic conductivity of the aquifer, were generally not available, therefore, these parameters were generated using the hydrogeologic environment classification. It was assumed that the loss in correlation by supplanting correlated parameters with site-specific parameters was more than equaled by the uncertainty in other parameters (i.e., groundwater flow direction).

For surface impoundments, the infiltration rate was calculated using EPACMTP; the ambient recharge rate was set equal to the HELP model recharge rate for the nearest climate center.

For facilities without adequate site-specific data, the USGS inventory of state groundwater resource maps (USGS, 1985) and available GIS data were used to identify the predominant hydrogeologic environment (or aquifer type) underlying each impoundment to be

modeled. Once the aquifer type was determined, the HGDB was then used to specify the probability distribution for each of the groundwater parameters. The HGDB provides data on depth to groundwater, aquifer thickness, hydraulic gradient, hydraulic conductivity, and hydrogeologic classification for approximately 400 hazardous waste sites nationwide. These site-specific data were then regrouped according to hydrogeologic classification, and 13 aquifer types were classified (12 specific environments and one category called "other"). Each aquifer type consists of a distribution of values for each of the four aquifer parameters.

For this analysis, each site to be modeled was located on the appropriate state groundwater map from USGS (1985), and available GIS data were compiled and evaluated. Then the primary aquifer type for that location was classified according to the 13 aquifer types. The aquifer types and the parameter values for each are provided in the *EPACMTP User's Guide* (U.S. EPA, 1997b).

C.3.2.3 Chemical Data. Chemical properties used in the analysis include hydrolysis rate constants and the organic carbon partition coefficient K_{OC} for the organic constituents and soil-water partition coefficients for metals. These were collected from measured literature values as available and are described in U.S. EPA (2000b, c).

Many of the chemical constituents present at facilities included in this phase of the analysis can be characterized as *conservative* in that they do not sorb (K_{oc}=0) nor hydrolyze (lambda = 0) in partially or fully saturated environments. Conservative chemicals behave *linearly* with respect to advective and dispersive contaminant transport: an increase or decrease in the source concentration results in a proportional increase or decrease in observed concentrations in the groundwater. This behavior permits the use of a single *surrogate* chemical to represent all conservative chemicals.

All conservative chemical constituent modeling at a unique facility/impoundment combination was represented by a surrogate constituent in a single Monte Carlo simulation. The resulting normalized peak and average concentrations for the surrogate were then scaled by the leachate concentration of the constituents escaping the impoundment to produce constituent-specific results. For organics, a conservative constituent is defined as one with K_{OC} value equal to or less than that of benzene (K_{OC} = 63.1 L/kg; since the values in the nationwide distribution of fraction organic carbon are generally small, the resulting average unsaturated zone retardation coefficient for benzene is 1.17) and with an average hydrolysis rate in the unsaturated zone equal to or less than 1.0E-4 1/yr (this criterion was used to define nondegraders in modeling conducted for the 1995 HWIR proposed rule). Fluoride was also considered to behave as a conservative constituent since it is an anion in solution under environmental conditions.

To test the above assumptions, a chemical-specific modeling run was conducted for each of two of the organic constituents assumed to be conservative to verify our assumption that they behave conservatively during subsurface transport: benzene (in the impoundment at Facility 174) and chloroform (in impoundment 1 at Facility 23). Benzene was chosen because it has the highest K_{OC} of the organic constituents assumed to be conservative. Chloroform was chosen

because it has the highest hydrolysis rate of the organic constituents assumed to be conservative. No toxic daughter products were simulated in this analysis.

Test results are presented in Table C.3-13 as percent differences for select percentiles of the dilution-attenuation factor between simulations using constituent-specific constants (K_{OC} and hydrolysis rates) and conservative surrogate assumptions (Note: the 10th percentile DAF

Table C.3-13. Percent Difference for Selected Percentile DAFs for Benzene and Chloroform

	Benzene	Chloroform
Select Percentiles for DAF	**% Difference for Average DAF[a]**	**% Difference for Average DAF[a]**
50	5.4%	1.6%
25	7.4%	2.4%
20	6.9%	5.8%
15	7.8%	5.2%
10	8.6%	6.1%
5	5.9%	5.8%
2.5	7.2%	7.5%
1	4.9%	1.9%

[a] Percent difference is calculated as (Conservative Constituent Average DAF - Surrogate Average DAF)/Conservative Constituent Average DAF.

corresponds to the 90th percentile concentrations, peak and average). The maximum difference in the lower half of the distribution is 8.6 percent and represents the worst case scenario under this assumption.

The metals-modeling methodology in EPACMTP incorporates two options to specify the K_d for a given metal: distributions of values or sorption isotherms. For this analysis, the K_d for metals was defined based on a comprehensive review of literature K_d values performed for the Inorganics Listing Determination (U.S. EPA, 2000b). Based on this review, K_d was defined as an empirical distribution when sufficient data are available or a log uniform distribution of values when fewer data are available from the scientific literature. The second option is the automated use of adsorption isotherms, which are expressions of the equilibrium relationship between the aqueous concentration and the sorbed concentration of a metal (or other constituent) at constant temperature. This second option was not used for this analysis because of current modeling limitations for generating metal sorption isotherms.

C.3.2.4 *Sources for Site and Hydrogeologic Parameter Values*. Data collected from the surveys and any supporting information, such as reports and diagrams, were examined to extract the maximum amount of reliable site-specific data for use in this analysis. The data included information on impoundment areas, volumetric flows of wastewater and sludge into impoundments, liner information, constituents present in wastewaters and their concentration, operation life, and maps that identify real and potential receptor wells and surface waterbodies. Survey data were also cross-referenced with other data sources to supplement the data collection effort. These sources include STATSGO (U.S. EPA, 1998d), HGDB (Newell et al., 1990), and meteorological databases.

C.3.2.5 *Facility-Specific Modeling Approach*. The groundwater modeling approach adopted for this analysis attempted to incorporate the maximum amount of facility-specific data available from the following primary sources: survey responses, topographic maps, and schematic drawings. Technical reports, when provided by respondents, were also used in extracting parameter values. Table C.3-12 identifies the sources for specific input modeling parameters.

The following general procedure was applied to all facilities modeled in this analysis:

- Groundwater Flow Direction - Assess topological details on provided maps to determine the most probable flow direction; decision may be supplemented by technical reports, when available.

- Receptor Location Selection - Using topological maps and the assumed flow direction, identify the downgradient receptor well screened in the surficial aquifer nearest to the impoundment most likely to be impacted by a migrating contaminant plume. If multiple impoundments are present at the facility, select the receptor location that is most likely to be impacted by the most impoundments; if no receptor wells are identified, use identified residences.

- Radial Receptor Well Distance and Angle Off Plume Centerline- Determine the radial distance as shortest distance from each impoundment to the selected receptor location. Measure the angle defined by the radius and the groundwater flow direction; these angles will be used to calculate the angle range used in the simulation to account for uncertainty in flow direction. The method for angle range calculation is

  - Determine average angle, THETA and for each impoundment at the facility
  - Min Angle = maximum (0^o , THETA - Angle)
  - Max Angle = maximum (THETA, Angle) + 5^o

- Extract Impoundment-Specific Data - Collect the following parameters from the survey: impoundment area, operational life, liner thickness and conductivity, depth of wastewater and sludge in the impoundments, depth to groundwater,

saturated thickness, aquifer hydraulic conductivity, and regional groundwater gradient, if available. If multiple sources exist for parameter values, the most conservative value is used (e.g., survey indicates wastewater depth is 1m and schematic prescribes a 2-m depth, the value from the schematic is used).

- Calculate Effective Liner Parameters - Combine sludge and liner information to determine the effective liner conductivity and thickness. If bottom of impoundment is below the water table, calculate an infiltration rate using the gradient across the liner and compacted sludge (Darcy's law [Bear, 1979]).

- Chemical Parameters - Group constituents present in wastewater into conservative and nonconservative populations using the guidelines described in Section C.3.2.2. Select chemical constituent parameters/distributions needed for simulating sorption and decay processes. Extract the leachate concentration of each constituent from survey data.

- Compilation of Data - Combine and supplement the above parameters with region-based and location-based parameters/parameter distributions as described in Section C.3.2.2 with exposure duration distribution to create input files and source data files.

The results of the data extraction process are presented in Attachment C-10 of this Appendix.

C.3.3 Methods - Exposure/Risk Calculations

The purpose of exposure and risk assessment is to estimate a contaminant dose to each receptor by combining modeled groundwater concentrations with relevant intake rates for the individuals being modeled. The dose, coupled with the relevant human health benchmarks, allows an estimation of human health risk and/or hazard. This assessment focused on chronic cancer risk and noncancer hazard resulting from tap water ingestion. Consequently, for this analysis, exposure assessment involved combining modeled residential well concentrations with adult and child tap water ingestion rates and exposure durations to generate both average daily dose estimates for noncarcinogens and lifetime averaged daily dose estimates for carcinogens.

For all impoundments evaluated in this analysis, groundwater was assumed to be contaminated from contaminants leaching from the impoundment, through the vadose zone, into the underlying aquifer, and migrating to the offsite residential well location. It was further assumed that the groundwater well was used as the sole source of tap water for the adults and children living in that residence.

Both child and adult residents were modeled in this analysis. For noncancer risk, a child in the 1- to 6-year-old age range was modeled. Note: The use of the 1- to 6-year-old child cohort in this analysis excluded exposures in the first year of life. For carcinogenic risk, an adult resident between the ages of 20 and 64 was modeled.

C.3.3.1 Exposure Parameter Variability Distributions Used in Probabilistic Analysis. The probabilistic analysis requires exposure parameter variability distributions for exposure duration and tap water ingestion rates. Although water ingestion rates were required for both the adult and child, exposure duration is required only in cancer risk calculations; therefore, exposure duration variability data were needed only for the adult. See Section C.3.2 for a discussion of exposure duration.

Tap Water Intake Rates. Tap water ingestion rate data standardized for body weight (i.e., with units of mL/kg-d) were used in this analysis. Because intake data that were standardized for body weight were used, body weight was not a variable in the analysis.

The statistical parameters used to derive the distributions for tap water ingestion rates are presented in Table C.3-15. A critical issue in using continuous variability distributions in probabilistic risk analysis is the truncation of these distributions to avoid inclusion of exposure parameter estimates that are unreasonable (truncation is typically not an issue with discrete distributions since the upper-bound values in these distributions are generally defined as the highest percentile value for which data are available from the underlying study). In selecting the truncation strategy to develop continuous distributions, care must be taken to avoid the inclusion of unrealistic values, while still allowing for consideration of individuals who could experience intake rates beyond the 99th percentile (i.e., high-end exposure). A number of different strategies have been used in previous analyses to truncate exposure parameter variability distributions, including (1) setting the upper bound between 2 and 3 standard deviations, and (2) setting the upper bound at twice the 99th percentile. For this analysis, exposure parameter variability distributions for tap water ingestion rates were truncated at 3 standard deviations. This approach produced upper-bound tap water ingestion rates that fell between the 99th percentile and twice the 99th percentile, which represents a reasonable approximation of high-end behavior without including unreasonably high intake rates, yet allows the possibility of exposures above the 99th percentile. The truncation values for each of the tap water ingestion rate variability distributions are also included in Table C.3-15. Tables C.3-16 and C.3-17 present the intake rate data from the lognormal distributions developed for this risk assessment and compare them with the empirical data presented in Tables 3-7 and 3-30 in the EFH.

Average Daily Dose for Children (Noncancer Endpoints). The average daily dose (ADD) estimates for the child resident receptor were generated by combining a daily intake rate that reflected variability in tap water ingestion rates with a residential well concentration. This produced a distribution of 10,000 ADD estimates. The ADD distribution was used, in turn, to generate a distribution of 10,000 noncancer HQs for each surface impoundment constituent combination for the child resident receptor.

The daily intake rate for the child resident was generated using a two-step procedure for determining tap water ingestion rate variability for the 1- to 6-yr-old cohort. The procedure involved: (1) random selection of either the 1- to 3- or 4- to 6-yr-old cohort for the child being modeled and (2) random sampling of a tap water ingestion rate from the tap water ingestion rate distribution for that age. This approach generated a daily intake rate for the child resident that

Table C.3-15. Variability Distributions for Exposure Parameters Used in Probabilistic Risk Analysis

Receptor Population/ Cohort Age Group	Percentile Values and Statistical Parameters Used to Define Discrete and Continuous Variability Distributions	References/Comments
Tap water ingestion rates (mL/kg-d)		
1- to 3-yr-old cohort	lognormal distribution: mean: 46.8 STD: 28.1 truncation value (3 standard deviations): 211.35	 1997 EFH Table 3-7 1997 EFH Table 3-7 derived
4- to 6-yr-old cohort	lognormal distribution: mean: 37.9 STD: 21.8 truncation value (3 standard deviations): 164.26	 1997 EFH Table 3-7 1997 EFH Table 3-7 derived

Table C.3-16. Comparison of Lognormal Distribution with Empirical Data for Percentiles of Tap Water Intake Rates for Adults

	Lognormal Distribution (based on Table 3-7)	Empirical Data Total Tap Water Intake (Table 3-7)	Recommended Drinking Water Intake Rates (Table 3-30)
Percentile	**mL/kg-d**	**mL/kg-d**	**mL/kg-d**
1%	5.40	2.2	
5%	7.50	5.9	
10%	9.10	8	
25%	12.50	12.4	
50%	17.50	18.2	19
75%	24.50	25.3	
90%	33.60	33.7	34
95%	40.40	40.0	
99%	57.50	54.8	

Table C.3-17. Comparison of Percentiles of Tap Water Intake Rates Between Lognormal Distribution and Empirical Data for Empirical Data for Child Age Groups (mL/kg-d)

	Lognormal Distribution[a]	Empirical Data for Total Tap Water Intake[a]	Lognormal Distribution[a]	Lognormal Distribution[a]
Percentiles	**1-to 3-yr-old**		**4-to 6-yr-old**	
1%	11.1	2.7	9.6	3.4
5%	15.8	11.8	13.7	10.3
10%	19.6	17.8	16.5	14.9
25%	27.4	27.2	22.9	21.9
50%	39.6	41.4	32.7	33.3
75%	75.7	60.4	47.1	48.7
90%	81.1	82.1	65.6	69.3
95%	99.4	101.6	78.6	81.1
99%	144.1	140.6	112.7	103.4

[a] Based on Table 3-7 of *Exposure Factors Handbook* (U.S.EPA, 1997c).

reflected the age-specific differences in tap water ingestion rates that occurs within the 1- to 6-yr-old cohort.

Cohort aging was not considered in characterizing noncancer risk for the child resident because emphasis was placed on capturing the highest chronic exposure level within this age group, which was expected to occur in children in the youngest cohort due to their higher intake rate to body weight ratio. The exposure parameter variability distributions for tap water ingestion for both the 1- to 3- and 4- to 6-year-old cohorts were normalized for body weight (intakes are expressed as L/kg-d), which eliminated the need to account for the correlation between body weight and tap water ingestion rate.

Once the daily intake rate data set was generated, it was combined with the residential well concentration data set to generate a discrete distribution of ADD estimates. The following equation was used to generate each ADD estimate for the child resident receptor:

$$ADD_{child} = IR \times C_{drinking\ water} \times \frac{1\ L}{1000\ mL} \qquad \text{(C.3-11)}$$

Parameter	Definition (units)
ADD_{child}	Modeled average daily dose for the child resident receptor (mg/kg-d)
IR	Tap water ingestion rate sampled from the 1- to 6-yr-old cohort variability distribution for tap water ingestion normalized for body weight (mL/kg-d)
$C_{drinking\ water}$	Peak modeled annual drinking water well constituent concentration (mg/L)

The generalized distribution of the child ADD without the residential well concentration component is the same as the child intake distribution converted to liters per kilogram per day. The ADD distribution percentiles are presented in Table C.3-18. The ADD is then divided by the non-cancer RfD to develop the hazard quotient (HQ).

Table C.3-18. Percentiles for Child ADD (L/kg-d)

	Lognormal Distribution[a]	Total Tap Water Intake[b]			Recommended Drinking Water Intake Rates[c]
Percentiles	1- to 6-yr-old	1- to 3-yr-old	4- to 6-yr-old	1- to 6-yr-old (average of 1- to 3-yr-old and 4- to 6-yr-old)	1- to 10-yr-old
1%	0.0101	0.0027	0.0034	0.0031	
5%	0.0144	0.0118	0.0103	0.0111	
10%	0.0178	0.0178	0.0149	0.0164	
25%	0.0249	0.0272	0.0219	0.0246	
50%	0.0359	0.0414	0.0333	0.0374	0.031
75%	0.0525	0.0604	0.0487	0.0546	
90%	0.0731	0.0821	0.0693	0.0757	0.064
95%	0.0893	0.1016	0.0811	0.0914	0.0794
99%	0.1296	0.1406	0.1034	0.122	

[a] Based on Table 3-11 of *Exposure Factors Handbook* (U.S. EPA, 1997c)
[b] Based on Table 3-7 of *Exposure Factors Handbook* (U.S. EPA, 1997c)
[c] Based on Table 3-30 of *Exposure Factors Handbook* (U.S. EPA, 1997c)

Lifetime Average Daily Dose (LADD) for Adult (Cancer Endpoints). The LADD for the adult resident were estimated by combining 10,000 Monte Carlo-generated lifetime averaged daily intake rates for the adult resident with 10,000 Monte Carlo-generated drinking water well

concentrations for a given surface impoundment/constituent. The groundwater averaging time used to estimate the residential well concentration was matched with the exposure duration for each iteration of the risk estimate. For the adult resident, an exposure duration and a single tap water ingestion rate were sampled. An averaging time of 70 years was also used in this calculation. The equation used to generate each LADD estimate for the adult resident is

$$LADD_{adult} = \frac{C_{drinking\ water} \times IR_{adult\ cohort} \times ED_{adult\ cohort} \times EF \times \frac{1\ L}{1{,}000\ mL}}{AT \times 365} \qquad \text{(C.3-12)}$$

Parameter	Definition (units)
$LADD_{adult}$	Modeled lifetime average daily dose for the adult resident receptor (mg/kg-d)
$C_{drinking\ water}$	Modeled drinking water well constituent concentration derived using an averaging time that corresponds to the exposure duration sampled for this LADD estimate (mg/L)
IR_{adult}	Tap water ingestion rate sampled from the adult variability distribution for tap water ingestion normalized for body weight (mL/kg-d)
ED_{adult}	Exposure duration value sampled for this modeled adult resident (yr)
EF	Exposure frequency (d/yr)
AT	Average lifetime used to generate a lifetime average intake rate (d).

Note: LADD estimates are generated using an exposure frequency of 350 d/yr and an average lifetime of 25,500 days (i.e., 365 d × 70 yr).

The generalized distribution of the adult LADD without the residential well concentration component is presented in Table C.3-19. The LADD is multiplied by the oral CSF to calculate the cancer risk.

C.3.4 Results from Groundwater Pathway Analysis

C.3.4.1 Direct Exposure Pathway Screening Results. A total of 186 constituents present in 435 surface impoundments at 127 facilities were considered in the preliminary screen. When constituent concentrations reported in the surface impoundments were compared to human health screening factors based on toxicity benchmarks for direct ingestion of drinking water, 109 constituents in 320 surface impoundments at 101 facilities exceeded the human health benchmark. The constituent counts reflect only those chemicals for which at least one human health benchmark was available. Complete results from the direct exposure pathway screening analysis are presented in this appendix.

C.3.4.2 Screening-Level Modeling Results. For those constituents, impoundments, and facilities that did not screen out in the preliminary screen, a more realistic assessment of groundwater risk was calculated using IWEM; in this case, 76 constituents in 214 surface impoundments at 71 facilities exceeded the criteria.

Table C.3-19. Percentiles of Generalized Adult LADD

Percentile	Adult LADD (L/kg-d)
1%	0.000573
5%	0.00089
10%	0.00116
25%	0.00187
50%	0.00335
75%	0.00587
90%	0.00953
95%	0.0125
99%	0.0201

C.3.4.3 Site-Based Modeling. Site-based modeling was conducted for 10 facilities and a total of 39 surface impoundments. There were a total of 30 HQ exceedances and 48 risk exceedances for all facilities, impoundments, and constituents for all risk/hazard estimation (i.e., for all central tendancy and high-end estimations. There were six 50^{th} percentile HQ exceedances and fifteen 50^{th} percentile risk exceedances. Also, there were four incidences where a chemical had an exceedance for both HQ and risk. Therefore, there were a total of 53 different facility/impoundment/chemical combinations that showed an exceedance of either HQ or risk out of a possible 202 facility/impoundment/chemical combinations.

Seven of the 10 facilities had at least one exceedance and 24 of the 39 impoundments had at least one exceedance. A summary of exceedances is presented in Table C.3-20. Each modeled facility/impoundment combination is presented in Table C.3-20. If an exceedance was observed, the chemical that exceeded the threshold is noted, followed by the HQ or cancer risk that was observed for that chemical. The central tendency value for that particular exceedance is then noted in parentheses. Attachment C-11, Tables C-11 through C-125, presents the full set of site-based modeling results.

Table C.3-20. Summary of Hazard and Risk Exceedances for the Groundwater Pathway

Facility	SI	Summary of HQ Exceedance	Summary of Risk Exceedance
Risk exceedances based on reported concentrations			
23	1	**Acetone** - 13 (0.02)	None
78	2	**Fluoride** - 1.2 (0.01)	None
182	1	**Fluoride** - 27 (1.5)	None
182	2	**Fluoride** - 59 (12)	None
182	3	**Fluoride** - 6.1 (0.4)	None
182	4	**Fluoride** - 38 (8.1)	None
182	6	**Fluoride** - 10 (3.1)	None
182	8	**Fluoride** - 3.1 (0.3)	None
Risk exceedances based on surrogate/DL concentrations			
23	1	Chloroform - 50 (0.09) Methylene chloride - 8.2 (0.01) Pyridine - 1.7 (0.003) Toluene - 1.8 (0.004)	Chloroform - 1.5E-4 (2.1E-7) Methylene chloride - 1.8E-4 (2.6E-7))
23	2	Methanol - 1.7 (0.004) Allyl alcohol - 26 (0.06)	None
23	3	Methanol - 1.3 (0.002) Allyl alcohol - 20 (0.03)	None
23	4	Chloroform - 23 (0.004) Methylene chloride - 4 (0.0006) Acetone - 6 (0.0009)	Chloroform - 7.0E-5 (9.3E-9) Methylene chloride - 8.3E-5 (1.1E-8)
175	3	Thallium - 4.5 (0.03)	N-Nitrosodimethylamine - 2.6E-4 (1.3E-5) Benzidine [a] - 1.2E-2 (5.7E-4) N-Nitrosodi-n-propylamine [a] - 3.5E-5 (1.7E-6) Acrylonitrile - 2.5E-5 (1.3E-6)
12	2	Fluoride - 1.3 (0.1)	None
173	1	Methanol - 1.7 (0.03)	None
45	2	None	Acrylonitrile - 1.4E-5 (3.1E-6) N-Nitrosodi-n-propylamine - 4.4E-5 (9.6E-6) N-Nitrosodimethylamine - 3.2E-4 (7.0E-5) Vinyl Chloride - 1.1E-5 (2.3E-6) Benzidine - 7.3E-3 (1.6E-3)

(continued)

Table C.3-20. (continued)

Facility	SI	Summary of HQ Exceedance	Summary of Risk Exceedance
45	4	None	Acrylonitrile - 1.5E-5 (3.2E-6) N-Nitrosodi-n-propylamine - 4.5E-5 (1.0E-5) N-Nitrosodimethylamine - 3.3E-4 (7.3E-5) Vinyl Chloride - 1.1E-5 (2.4E-6) Benzidine - 7.5-3 (1.6E-3)
45	6	None	N-Nitrosodi-n-propylamine - 7.1E-5 (1.2E-5) Benzidine - 1.6E-3 (2.8E-4)
45	7	None	N-Nitrosodi-n-propylamine - 1.4E-5 (2.3E-6) N-Nitrosodimethylamine - 1.0E-4 (1.7E-5) Benzidine - 2.3E-3 (3.7E-4)
45	8	None	N-Nitrosodi-n-propylamine - 1.5E-5 (2.3E-6) N-Nitrosodimethylamine - 1.1E-4 (1.7E-5) Benzidine - 2.4E-3 (3.9E-4)
45	9	None	N-Nitrosodimethylamine - 2.7E-5 (3.1E-6) Benzidine - 6.2E-4 (6.8E-5)
45	10	None	N-Nitrosodimethylamine - 1.9E-5 (1.7E-6) Benzidine - 4.2E-4 (3.8E-5)
45	11	None	N-Nitrosodimethylamine - 1.6E-5 (1.4E-6) Benzidine - 3.7E-4 (3.2E-5)
78	2		Arsenic - 1.6E-5 (8.1E-9)
182	7	Fluoride - 37 (1.2)	None
182	9	Fluoride - 35 (3.7)	None

[a] Industry representatives, subsequent to completion of the survey, have indicated that this constituent is not expected to be present at the facility. These constituents were reported to EPA in response to the Survey of Surface Impoundments in November 1999 as less than a specified limit of detection. When this constituent was evaluated in the risk analysis at the reported detection limit, the concentrations were high enough to predict the indicated risk/hazard of concern. EPA included the results in this table because of the methodology used throughout the study to evaluate less than detection limit data.

C.4 Indirect Exposure Pathway Analysis—Groundwater to Surface Water

By design, surface impoundments are often located near receiving waterbodies. As described in Section 2.0, impoundments designed for final treatment are intended to produce effluent that meets regulatory standards (e.g., the National Pollutant Discharge Elimination System, or NPDES and, therefore, the effluent can discharge directly into the waterbody. However, many impoundments are designed as part of a treatment train and are not intended to produce effluent of sufficient quality to meet regulatory standards. Although these impoundments do not discharge directly to surface water, chemicals may be released through the bottom of the impoundment, travel through the subsurface, and impact nearby waterbodies. The intersection of groundwater flow with surface water is often referred to as groundwater discharge to surface water. This is potentially a significant exposure pathway because 75 percent of RCRA and Superfund sites are located within a half mile of a surface waterbody, and almost half of all Superfund sites have impacted surface water (U.S. EPA, 2000a, *Proceedings of the Ground-Water/Surface-Water Interactions Workshop*). Of the 133 facilities considered in the Surface Impoundment Study, approximately 84 percent (112) have one or more fishable waterbodies located within 1 km of an impoundment.

For chemicals that are moderately mobile, contaminant fate and transport in the subsurface may result in a contaminant flux to the surface waterbody as the groundwater discharges into a pond or stream. Depending on the resulting surface water concentrations, the water quality may be adversely affected. For chemicals that are also bioaccumulative, chemical concentrations in fish may approach or exceed levels of concern for the segment of the population that fishes. For convenience, we refer to the release, transport, and accumulation of chemicals in fish and other aquatic organisms as the groundwater to surface water pathway, or gw-sw pathway.

C.4.1 Numeric Ranking of Facilities

EPA did a numeric ranking of facilities according to their potential to discharge to surface waterbodies at significant levels. This ranking was the basis for selecting facilities to model. The ranking was accomplished as follows.

The area surrounding each of the facilities was evaluated to determine if fishable waterbodies were present within a 1-km radius of the impoundments. Fishable waterbodies were defined as streams of reach order 3 and above, as well as bays, estuaries, lakes, canals, harbors, and wetlands. The name of the closest fishable waterbody was recorded and the distance from it to the impoundment was measured on the topographic map. Fishable waterbodies within a 1-km radius were identified for 112 facilities and 353 surface impoundments.

Wastewater (or leachate, when available) concentrations of the constituents present in the 353 surface impoundments were then compared to water quality benchmarks. The benchmark for this screen was the human health (HH) level associated with the ambient water quality criteria, or HH-AWQC. Table C.4-1 lists the HH-AWQC levels for the constituents of concern.

Most are based on aquatic organism and surface water ingestion. For facilities near estuarine or other unpotable surface waterbodies, the HH-AWQC was based on aquatic organism ingestion only.

The leachate concentration of at least one constituent exceeded the HH-AWQC in 240 surface impoundments across 79 facilities. The magnitude of the exceedances ranged from approximately 1 to 1,538,000. Exceedances were documented for 66 chemicals.

Having compared wastewater concentrations to the HH-AWQC, the next step of the surface water analysis was to compare constituent concentrations estimated to be in groundwater to the HH-AWQC. The constituent concentration in groundwater was calculated by dividing the constituent concentration in wastewater by the dilution attenuation factors generated as part of the groundwater screening analysis. If the surface waterbody was located within 150 meters of the surface impoundment, the DAF was set equal to 1 for consistency with the IWEM screening analysis. Hence, for impoundments located within 150 meters of a surface waterbody, the calculated groundwater concentration equaled the wastewater concentration. For 204 surface impoundments distributed among 70 facilities, calculated groundwater concentrations exceeded the AWQC-HH. Sixty-three constituents exceeded the benchmark.

A set of criteria was developed for use in prioritizing the 70 facilities having the greatest potential to impact surface water quality adversely. The criteria consisted of five easily quantifiable factors:

- Area of the surface impoundment
- Dilution factor
- Number of constituents that exceeded the water quality criteria
- Magnitude of the exceedance
- Distance to the nearest fishable waterbody.

Each of the criteria was assigned a numeric score, and these were used to rank facilities for site-based fate and transport modeling. Distance from surface impoundment to the nearest fishable waterbody, the area of the surface impoundment, and dilution factor are important determinants in assessing potential impacts to surface water quality and, as a consequence, these three criteria were each weighted by a factor of 2. The criteria and scoring methodology are detailed below. The resulting scores are presented in Attachment C-13.

C.4.1.1 Area of Surface Impoundment. The area of the largest surface impoundment that contained chemicals exceeding the HH-AWQC was determined and ranked in accordance with Table C.4-2.

Table C.4-1. Ambient Water Quality Criteria for Human Health (HH-AWQC)

Constituent	CAS No.	HH-AWQC (µg/L)
Antimony	7440360	1.40E+01
Arsenic	7440382	1.80E-02[a]
Copper	7440508	1.30E+03
Mercury	7439976	5.00E-02
Nickel	7440020	6.10E+02
Selenium	7782492	1.70E+02
Thallium	7440280	1.70E+00[b]
Zinc	7440666	9.10E+03
Cyanide	57125	7.00E+02
2,3,7,8-TCDD	1746016	1.30E-08
Acrolein	107028	3.20E+02
Acrylonitrile	107131	5.90E-02
Benzene	71432	1.20E+00
Bromoform	75252	4.30E+00
Carbon tetrachloride	56235	2.50E-01
Chlorobenzene	108907	6.80E+02
Chlorodibromomethane	124481	4.10E-01
Chloroform	67663	5.70E+00
Dichlorobromomethane	75274	5.60E-01
1,2-Dichloroethane	107062	3.80E-01
1,1-Dichloroethylene	75354	5.70E-02
1,2-Dichloropropane	78875	5.20E-01
1,3-Dichloropropene	542756	1.00E+01
Ethylbenzene	100414	3.10E+03
Methyl bromide	74839	4.80E+01

(continued)

Table C.4-1. (continued)

Constituent	CAS No.	HH-AWQC (µg/L)
Methylene chloride	75092	4.70E+00
1,1,2,2-Tetrachloroethane	79345	1.70E-01
Tetrachloroethylene	127184	8.00E-01
Toluene	108883	6.80E+03
1,2-trans-Dichloroethylene	156605	7.00E+02
1,1,2-Trichloroethane	79005	6.00E-01
Trichloroethylene	79016	2.70E+00
Vinyl chloride	75014	2.00E+00
2-Chlorophenol	95578	1.20E+02
2,4-Dichlorophenol	120832	9.30E+01
2,4-Dimethylphenol	105679	5.40E+02
2-Methyl-4,6-dinitrophenol	534521	1.34E+01
2,4-Dinitrophenol	51285	7.00E+01
Pentachlorophenol	87865	2.80E-01
Phenol	108952	2.10E+04
2,4,6-Trichlorophenol	88062	2.10E+00
Acenaphthene	83329	1.20E+03
Anthracene	120127	9.60E+03
Benzidine	92875	1.20E-04
Benzo(a)anthracene	56553	4.40E-03
Benzo(a)pyrene	50328	4.40E-03
Benzo(b)fluoranthene	205992	4.40E-03
Benzo(k)fluoranthene	207089	4.40E-03
Bis2-chloroethyl ether	111444	3.10E-02
Bis2-Chloroisopropyl ether	39638329	1.40E+03
Bis2-ethylhexyl phthalate	117817	1.80E+00

(continued)

Table C.4-1. (continued)

Constituent	CAS No.	HH-AWQC (µg/L)
Butylbenzl phthalate	85687	3.00E+03
2-Chloronaphthalene	91587	1.70E+03
Chrysene	218019	4.40E-03
Dibenzo(a, h)anthracene	53703	4.40E-03
1,2-Dichlorobenzene	95501	2.70E+03
1,3-Dichlorobenzene	541731	4.00E+02
1,4-Dichlorobenzene	106467	4.00E+02
3,3-Dichlorobenzidine	91941	4.00E-02
Diethyl pthalate	84662	2.30E+04
Dimethyl phthalate	131113	3.13E+05
Di-n-butyl phthalate	84742	2.70E+03
2,4-Dinitrotoluene	121142	1.10E-01
1,2-Diphenylhydrazine	122667	4.00E-02
Fluoranthene	206440	3.00E+02
Fluorene	86737	1.30E+03
Hexachlorobenzene	118741	7.50E-04
Hexachlorobutadiene	87683	4.40E-01
Hexachlorocyclopentadiene	77474	2.40E+02
Hexachloroethane	67721	1.90E+00
Ideno 1,2,3-cd pyrene	193395	4.40E-03
Isophorone	78591	3.60E+01
Nitrobenzene	98953	1.70E+01
n-Nitrosodimethylamine	62759	6.90E-04
n-Nitrosodi-n-propylamine	621647	5.00E-03
n-Nitrosodiphenylamine	86306	5.00E+00
Pyrene	129000	9.60E+02

(continued)

Table C.4-1. (continued)

Constituent	CAS No.	HH-AWQC (µg/L)
1,2,4-Trichlorobenzene	120821	2.60E+02
Aldrin	309002	1.30E-04
α-BHC	319846	3.90E-03
β-BHC	319857	1.40E-02
δ-BHC	58899	1.90E-02
Chlordane	57749	2.10E-03
4,4-DDT	50293	5.90E-04
4,4-DDE	72559	5.90E-04
4,4-DDD	72548	8.30E-04
Dieldrin	60571	1.40E-04
α-Endosulfan	959988	1.10E+02
β-Endosulfan	33213659	1.10E+02
Endosulfan sulfate	1031078	1.10E+02
Endrin	72208	7.60E-01
Endrin aldehyde	7421934	7.60E-01
Heptachlor	76448	2.10E-04
Heptachlor epoxide	1024573	1.00E-04
Toxaphene	8001352	7.30E-04
PCBs	1336363	1.70E-04

[a] For one facility near unpotable water, a value of 1.4E-7 was used, which reflects only aquatic organism ingestion.

[b] For one facility near unpotable water, a value of 6.3E-6 was used, which reflects only aquatic organism ingestion.

Table C.4-2. Scoring Criteria for Surface Area

Score	Criteria
3	Area > 100,000 m^2
2	10,000 ≤ Area ≤ 100,000 m^2
1	0 < Area < 10,000 m^2

C.4.1.2 Dilution Factor. The fishable waterbodies identified as nearest each surface impoundment were evaluated to determine whether they were quiescent or nonquiescent. It was assumed that groundwater discharging into a nonquiescent (i.e., flowing) waterbody would be diluted to a greater degree than groundwater discharging into a quiescent waterbody. Flow in nonquiescent waterbodies was compiled from three sources:

- U.S. EPA Office of Water, 1996 (U.S. EPA, 1996a), *Database for "Better Assessment Science Integrating Point and Nonpoint Sources*." EPA-823-R-96-001.
- Web pages: http://waterdata.usgs.gov/nwis-w/us/
- van der Leeden et al., 1990, *The Water Encyclopedia* - Second Edition, Table 3-6 Flowing Water Resources of the United States, Lewis Publishers, Inc., pp. 176.

Data from the EPA database were used when available. Streams not listed in the Basins database or that had a station located far from the site were researched using the USGS and associated state geological survey web pages. When data were not available on web sites, the table from van der Leeden et al. was used. No data were collected for ocean or bay areas.

The surface areas for lakes, ponds, and river inlets were measured on USGS 1:24,000 topographic maps using a planimeter. For waterbodies smaller than 5,760 m^2 (limit of planimeter for scale), the area was estimated by measuring the length and width and calculating the square area. Some inlet areas may be considered quiescent.

If the surface waterbody was nonquiescent, the score was assigned in accordance with Table C.4-3. If, however, the surface waterbody was quiescent, the score was assigned in accordance with Table C.4-4.

C.4.1.3 Number of Constituents That Potentially Exceeded Water Quality Criteria. The total number of chemicals potentially exceeding the HH-AWQC present at a facility was also scored. The larger the number of chemicals, the higher the score. Table C.4-5 presents the scores.

Table C.4-3. Median Annual Flow Rate (mfr) of Flowing Waterbody (e.g., River, Creek)

Score	Criteria
3	mfr < 1,250 ft^3/s
2	1,250 $\leq$ mfr $\leq$ 5,000 ft^3/s
1	mfr > 5,000 ft^3/s

Table C.4-4. Surface Area of Quiescent Waterbody (e.g., Lake, Pond)

Score	Criteria
3	Area < 10,000 m^2
2	10,000 $\leq$ Area $\leq$ 150,000 m^2
1	Area > 150,000 m^2

Table C-4-5. Number of Chemical Constituents Potentially Exceeding a Groundwater / HH-AWQC Ratio of 1

Score	Criteria
3	Chemicals > 21
2	2 < Chemicals $\leq$ 21
1	Chemicals $\leq$ 1

C.4.1.4 *Magnitude of Exceedance*. The magnitude of the exceedance was defined as the maximum ratio of the calculated groundwater concentration to the HH-AWQC at each impoundment. If the ratio exceeded 1, it was scored in accordance with Table C.4-6.

C.4.1.5 *Distance to Nearest Fishable Waterbody*. The distance to the nearest fishable waterbody was also scored. The method of scoring is reflected in Table C.4-7.

As noted above, the distance from surface impoundment to the nearest fishable waterbody, the area of the surface impoundment, and the dilution factor were each weighted by a factor of 2 and the five individual scores were summed. The final scores were ranked in descending order and every surface impoundment that was characterized by a total score equal to

Table C.4-6. Maximum Groundwater Concentration / HH-AWQC Ratio

Score	Criteria
3	Ratio $\geq$ 100
2	10 $\leq$ Ratio < 100
1	1 $\leq$ Ratio < 10

Table C.4-7. Distance to Nearest Surface Waterbody (as Marked on Topographic Map)

Score	Criteria
3	0 < Distance $\leq$ 333 m
2	333 < Distance $\leq$ 667 m
1	Distance > 667 m

or exceeding 20 was identified for site-based modeling. If a facility had multiple surface impoundments and only one surface impoundment was characterized by a score equal to or exceeding 20, all surface impoundments at the facility were modeled, regardless of their individual scores. In summary, 15 facilities and 69 surface impoundments were modeled.

C.4.2 Surface Water Screening Modeling

The surface water screening analysis was conducted to quantify the potential for degradation of surface water quality with respect to human usage. The pathway begins with infiltration of the constituent into soils beneath the surface impoundment and is completed with the subsequent transport in aquifers and discharge into the surface waterbodies.

Section C.4.2.1 describes the simplifying assumptions made to perform this analysis; Section C.4.2.2 states the basis for screening results; and Section C.4.2 presents the screening procedure, required input parameters, and their values. The results of the groundwater to surface water pathway screening are presented in Attachment C-14 of this Appendix.

C.4.2.1 Assumptions. To simplify the surface water screening methodology and to ensure conservative results, it was assumed that:

- The liquid in the surface impoundment leaks through the base of the unit and the underlying vadose zone to the aquifer

- Constituent concentrations are assumed to be decreased during subsurface transport by a factor equal to the groundwater DAF defined in the IWEM Tier 1 tables (see Table C.3-1) corresponding to the constituent and liner scenario.[1]

- All of the seepage from the aquifer discharges into the river immediately and is fully and instantaneously mixed with the river water

- The river is initially uncontaminated. The result of this screening calculation is an estimate of the final concentration of the constituent of concern in the river after the leachate from the surface impoundment has mixed with the water in the river.

C.4.2.2 Water Quality Screen. The surface water screening methodology compared constituent concentrations to the ambient water quality criteria for the ingestion of surface water and aquatic organisms (HH-AWQC). Attachment C-14 tabulates the results of the comparision. Specifically, constituent concentrations in wastewater, groundwater, and river water were compared to the HH-AWQC in the preliminary screening, the release assessment, and the risk modeling, respectively. If the constituent concentration exceeded the HH-AWQC, the constituent was said to have failed the screen. If the constituent concentration did not exceed the HH-AWQC, the constituent was said to have passed the screen. A pass/fail result is provided in Attachment C-14 for each facility-impoundment-constituent combination.

C.4.2.3 Screening Procedure. The first step of the analysis was to determine the infiltration rate from the surface impoundment. For surface impoundments, infiltration rates were calculated using EPACMTP. For impoundments where the water table was at or above the bottom of the impoundment, the infiltration rate was calculated according to the methodology presented in Bear (1979). Soil parameter values, liner characteristics, and liquid depth of the impoundment were chosen in a manner consistent with the methodology used for the groundwater modeling, as described in Section C.3.2.4 (see Table C.4-8).

After the appropriate infiltration rate I was obtained, an areal leakage rate Q_i from beneath the waste management unit was calculated as follows:

$$Q_i = A\ I \qquad \text{(C.4-1)}$$

where

A = area of the waste management unit (m^2)
I = infiltration rate (m/yr).

[1] A DAF of 1.0 was assigned if the waterbody was closer to the impoundent than the IWEM default distance of 150 meters.

Table C.4-8. Parameters for Infiltration Rate Calculation Used in Screening

Facility	Impoundment ID	Predominant Soil Type	Unsaturated Zone Thickness[a] (m)	Water Table Elevation[b] (m)	Ponding Depth of Surface Impoundment (m)	Effective Thickness of Liner (m)	Effective Hydraulic Conductivity of Liner (m/yr)
22	1	Silty clay loam	14.17	-	4.09	0.15	4.02E-02
	3	Silty clay loam[c]	14.17[c]	-	4.42	0.15	4.01E-02
38	1	Silty clay loam	0.00	0.00	3.64	0.92	4.41E-02
	2	Silty clay loam	4.27	-	1.28	0.99	5.34E-02
45	1	Silty loam	0.00	0.61	2.25	0.15	4.07E-02
	2	Silty loam	0.00	2.18	4.42	0.15	4.01E-02
	3	Silty loam	0.00	5.22	5.57	0.15	4.00E-02
	4	Silty loam	0.00	1.26	2.21	0.15	4.07E-02
	5	Silty loam	0.00	4.46	5.03	0.15	4.00E-02
	6	Silty loam	1.33	-	6.07	0.15	3.99E-02
	7	Silty loam	1.34	-	4.77	0.15	4.01E-02
	8	Silty loam	0.00	0.25	2.60	0.15	4.05E-02
	9	Silty loam	0.00	1.25	4.53	0.15	4.01E-02
	10	Silty loam	0.00	2.47	4.53	0.15	4.01E-02
	11	Silty loam	0.00	2.77	4.53	0.15	4.01E-02
50	1	Silty loam	63.25	-	1.52	0.15	4.13E-02
61	3	Silty clay loam	0.61	-	1.91	0.08	4.03E-02
	4	Silty clay loam	1.22	-	2.22	0.08	4.01E-02
	5	Silty clay loam	0.76	-	1.30	0.08	4.05E-02
	6	Silty clay loam	0.00	0.61	2.03	0.68	4.56E-02
	7	Silty clay loam	0.61	-	1.07	2.28	2.89E-03
78	1	Sandy clay loam	0.91	4.57	3.0	2.1	5.21E-02
	2	Sandy clay loam	1.37	3.048	3.2	2.6	5.41E-02
	3	Sandy clay loam	1.52	-	4.9	3.1	5.08E-02
84	4	Silty loam	0.00		0.30	0.15	4.21E-02
	5	Silty loam	0.00	1.83	2.90	0.15	4.17E-02

(continued)

Table C-4-8. (continued)

Facility	Impoundment ID	Predominant Soil Type	Unsaturated Zone Thickness[a] (m)	Water Table Elevation[b] (m)	Ponding Depth of Surface Impoundment (m)	Effective Thickness of Liner (m)	Effective Hydraulic Conductivity of Liner (m/yr)
103	1	Silty loam	2.00[d]	-	5.49	0.15	4.00E-02
	2	Silty loam	1.22	-	2.90	0.15	4.04E-02
	3	Sandy clay loam	2.74	-	1.21	0.15	4.18E-02
	4	Silty loam	2.00[d]	-	2.90	0.15	4.04E-02
	5	Silty loam	2.00[d]	-	2.90	0.15	4.04E-02
	6	Silty loam	NA[e]	-	NA[e]	NA[e]	NA[e]
105	1	Silty clay loam	1.52	-	1.96	0.15	4.09E-02
127	1	Sandy clay loam	0.00	0.00	0.28	0.15	4.92E-02
	2	Sandy clay loam	0.00	0.00	2.78	0.66	4.38E-02
	5	Sandy clay loam	0.00	0.00	2.58	0.15	4.06E-02
151	1	Sandy clay loam	0.00	0.19	4.41	0.15	4.01E-02
	2	Sandy clay loam	0.00	NA[f]	2.15	1.53	5.23E-02
	3	Sandy clay loam	0.00	NA[f]	2.64	0.15	4.05E-02
	4	Sandy clay loam	1.52	-	2.59	0.15	4.05E-02
	6	Sandy clay loam	2.44	-	2.59	0.15	4.05E-02
	8	Sandy clay loam	2.90	-	9.55	1.91	4.31E-02
	18	Sandy clay loam	2.90	-	9.55	1.91	4.31E-02
156	6	Silty clay loam	0.00	1.49	2.29	0.15	4.07E-02
	7	Silty clay loam	0.00	1.37	1.84	0.15	4.10E-02
	8	Silty clay loam	0.00	1.68	2.29	0.15	4.07E-02
	9	Silty clay loam	0.00	1.66	4.88	1.22	4.41E-02
159	1	Silty clay loam	0.30	-	0.76	0.46	5.04E-02
	2	Silty clay loam	0.00	0.914	0.51	0.26	4.88E-02
	3	Silty clay loam	0.00	0.914	6.33	0.40	4.06E-02
	4	Silty clay loam	2.65	-	0.74	0.09	4.17E-02
	5	Silty clay loam[g]	0.31	-	0.16	0.15	5.63E-02

(continued)

Table C-4-8. (continued)

Facility	Impoundment ID	Predominant Soil Type	Unsaturated Zone Thickness[a] (m)	Water Table Elevation[b] (m)	Ponding Depth of Surface Impoundment (m)	Effective Thickness of Liner (m)	Effective Hydraulic Conductivity of Liner (m/yr)
173	4	Silty clay loam	3.66	-	4.53	0.45	3.39E-02
	5	Silty clay loam	3.66	-	3.41	0.45	3.40E-02
	6	Silty clay loam	3.66	-	2.14	0.45	3.41E-02
	7	Silty clay loam	7.65	-	0.60	0.45	3.48E-02
	8	Silty clay loam	5.97	-	0.93	0.76	3.32E-02
182	1	Sandy clay loam	6.10	-	1.14	0.15	4.19E-02
	2	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	3	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	4	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	5	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	6	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	7	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	8	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	9	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
	10	Sandy clay loam	6.10	-	0.76	0.15	4.31E-02
184	2	Sandy clay loam	0.00	0.00	4.57	4.57	5.74E-02

a Value used in EPACMTP to calculate infiltration rate when bottom of impoundment is above the water table.
b Used to calculate the infiltration rate when the bottom of impoundment is at or below the water table; measured from bottom of impoundment.
c Data not available, used data from impoundment 1.
d Data not available, used the average of impoundments 2 and 3.
e Subsurface data not available; rate assumed to be average the rate of impoundments 1-5.
f Elevation of wastewater in the surface impoundment is below the water table.
g Data not available, assumed same soil type as impoundments 1-4.

The next step was to calculate a river dilution factor (RD) to account for the mixing of the seepage volume with the river water. RD is defined as

$$RD = \frac{Q_{River}}{Q_i} \qquad \text{(C.4-2)}$$

where

Q_{river} = river flow rate (m^3/yr).

The river flow rate, Q_{river}, was represented by the lowest 7-day average flow in a 10-year period (7Q10) when available. If the 7Q10 was not available, the mean flow rate was used.

The leachate migrating through the subsurface was assumed to be diluted by a factor equal to the groundwater DAF defined in the IWEM Tier 1 Tables (see Table C.3-1) corresponding to the constituent and liner scenario. Therefore, the concentration in the groundwater is given as:

$$C_{gw} = \frac{C_{leachate}}{DAF} \qquad \text{(C.4-3)}$$

where

C_{gw} = concentration in groundwater (mg/L),
$C_{leachate}$ = leachate concentration (mg/L), and
DAF = dilution attenuation factor.

The chemical concentration in groundwater reaches the river and is assumed to be instantaneously and fully mixed with clean river water. The resulting final river concentration is related to the appropriate analytical concentration in the leachate through the following equation:

$$C_{river} = \frac{C_{gw}}{RD} \qquad \text{(C.4-4)}$$

where

C_{river} = final river concentration (mg/L).

The final river concentration was then compared with the HH-AWQC concentration for the human usage. Specifically, if C_{river} was less than the appropriate HH-AWQC for a given constituent, then that constituent passed the surface water screening; however, if C_{river} equaled or exceeded the benchmark, then that constituent failed the screening. The modeling inputs for the surface water screening analysis are presented in Table C.4-9. Table C.4-10 identifies the exceedances at each of the nine facilities.

Table C.4-9 Input Parameters for Screening Calculations by Facility and Impoundment

Facility ID	Impound-ment ID	Surface Impoundment Area (m^2)	Liner Scenario	Distance to Surface Water Body (m)	Infiltration Rate[c] (m/yr)	Leachate Flux from Surface Impoundment (m^3/s)	River Flow Rate (m^3/s)	River Flow Rate Type	River Dilution Factor
22	1	7689	NA[a]	65	1.140	2.780E-04	2.251e-01	7Q10	8.099e+02
	3	148924	NA[a]	65	1.220	5.761E-03	2.266E-01	7Q10	3.933E+01
38	1	174015	No liner	200	0.219[d]	9.667E-04	2.286E+02	7Q10	1.892E+05
	2	129500	NA[a]	50	0.137	5.626E-04	2.286E+02	7Q10	4.063E+05
45	1	1012	No liner	270	0.486[d]	1.428E-05	3.115E-01	7Q10	1.997E+04
	2	169968	No liner	500	0.639[d]	3.228E-03	4.248E-01	Mean	1.233E+02
	3	6475	No liner	360	0.133[d]	1.916E-05	3.115E-01	7Q10	1.141E+04
	4	202343	NA[a]	140	0.299[d]	1.655E-03	4.248E-01	Mean	2.214E+02
	5	202343	NA[a]	25	0.192[d]	9.759E-04	3.115E-01	7Q10	2.529E+02
	6	24281	No liner	820	1.740	1.340E-03	4.248E-01	Mean	3.171E+02
	7	23067	No liner	845	1.410	1.031E-03	4.248E-01	Mean	4.119E+02
	8	48562	No liner	910	0.676[d]	9.781E-04	4.248E-01	Mean	4.081E+02
	9	8094	No liner	895	0.917[d]	2.250E-04	4.248E-01	Mean	1.805E+03
	10	8094	No liner	975	0.591[d]	1.413E-04	4.248E-01	Mean	2.801E+03
	11	8094	No liner	950	0.511[d]	1.207E-04	4.248E-01	Mean	3.239E+03
50	1	129904	No liner	280	0.632	2.603E-03	NA[B]	NA[b]	1.000E+00
68	3	708201	NA[a]	35	1.000	2.246E-02	1.558E+00	Mean	6.938E+01
	4	283280	NA[a]	35	1.220	1.096E-02	1.558E+00	7Q10	1.422E+02
	5	424920	NA[a]	35	0.744	1.002E-02	1.558E+00	7Q10	1.554E+02
	6	36422	NA[a]	20	0.141[d]	1.104E-04	1.558E+00	7Q10	9.567E+03
	7	26305	Single liner	215	0.005	4.146E-06	1.558E+00	7Q10	3.736E+05
78	1	26709	No liner	315	0.015[d]	2.685E-05	4.248e-01	Mean	3.344e+04
	2	30351	No liner	330	0.057[d]	1.424E-04	4.248E-01	Mean	7.744E+03
	3	62726	NA[a]	150	0.004[f]	7.340E-06	4.248E-01	Mean	5.339E+04
84	4	2023	NA[a]	65	0.327[d]	5.518E-06	5.914E+00	7Q10	2.819E+05
	5	469436	NA[a]	115	0.339[d]	5.051E-03	5.183E-02	7Q10	1.027E+01
103	1	6611	No liner	720	1.590	3.333E-04	4.248E-01	Mean	1.274E+03
	2	79318	No liner	565	0.948	2.384E-03	7.607E+00	7Q10	3.190E+03
	3	481576	No liner	670	0.488	7.452E-03	7.607E+00	7Q10	1.021E+03
	4	19223	NA[a]	40	0.956	5.827E-04	4.248E-01	Mean	7.290E+02
	5	19223	NA[a]	40	0.956	5.827E-04	4.248E-01	Mean	7.290E+02
	6	180490	NA[a]	95	0.988[g]	5.652E-03	1.487E+02	Mean	2.630E+04
105	1	109265	No liner	710	0.580	2.010E-03	9.884E+00	7Q10	4.918E+03
127	1	279233	No liner	905	0.141[d]	8.136E-04	6.587E+01	Mean	5.276E+04
	2	12141	No liner	950	0.229[d]	7.109E-05	2.719E+00	Mean	3.084E+04
	5	4856232	NA[a]	125	0.738[d]	1.074E-01	6.587E+01	Mean	5.796E+02
151	1	7469	No liner	395	1.169[d]	2.673E-04	6.522E+01	7Q10	2.356E+05
	2	20234	No liner	255	NA[e]	NA[e]	6.522E+01	7Q10	NA[E]
	3	214484	NA[a]	40	NA[e]	NA[e]	6.522E+01	7Q10	NA[E]
	4	348030	NA[a]	115	0.827	9.127E-03	6.522E+01	7Q10	7.146E+03

(continued)

Table C.4-9 (Continued)

Facility ID	Impound-ment ID	Surface Impoundment Area (m^2)	Liner Scenario	Distance to Surface Water Body (m)	Infiltration Rate[c] (m/yr)	Leachate Flux from Surface Impoundment (m^3/s)	River Flow Rate (m^3/s)	River Flow Rate Type	River Dilution Factor
151 (cont.)	6	24281	No liner	495	0.829	6.383E-04	6.522e+01	7Q10	1.022e+05
	8	48562	No liner	985	0.269	4.142E-04	6.522E+01	7Q10	1.574E+05
	18	48562	No liner	970	0.269	4.142E-04	6.522E+01	7Q10	1.574E+05
156	6	76890	NA[a]	20	0.257[d]	5.265E-04	2.832E+01	Mean	4.520E+04
	7	157828	No liner	215	0.169[d]	6.399E-04	2.832E+01	Mean	3.348E+04
	8	971	NA[a]	120	0.207[d]	5.122E-06	2.832E+01	Mean	4.443E+06
	9	267093	No liner	245	0.160[d]	9.850E-04	2.832E+01	Mean	2.090E+04
159	1	7525	No liner	460	0.150	3.579E-05	9.048E-01	Mean	2.528E+04
	2	52583	No liner	460	0.012[d]	3.652E-05	9.048E-01	Mean	4.522E+04
	3	18395	No liner	370	0.006[d]	3.476E-06	9.048E-01	Mean	2.585E+05
	4	436923	NA[a]	60	0.407	5.639E-03	9.048E-01	Mean	1.605E+02
	5	295421	NA[a]	30	0.167	1.564E-03	9.629E+00	Mean	6.155E+03
173	4	101172	No liner	795	0.376	1.206E-03	2.048E+02	7Q10	1.698E+05
	5	230671	No liner	270	0.295	2.158E-03	2.048E+02	7Q10	9.491E+04
	6	465389	NA[a]	105	0.206	3.040E-03	2.048E+02	7Q10	6.737E+04
	7	669	No liner	810	0.107	2.270E-06	2.048E+02	7Q10	9.023E+07
	8	3855	No liner	575	0.092	1.119E-05	2.048E+02	7Q10	1.821E+07
182	1	101172	No liner	700	0.469	1.505E-03	0.000E+00	NA[b]	1.000E+00
	2	215698	No liner	200	0.380	2.599E-03	0.000E+00	NA[b]	1.000E+00
	3	61917	NA[a]	20	0.380	7.461E-04	0.000E+00	NA[b]	1.000E+00
	4	531757	NA[a]	20	0.380	6.408E-03	0.000E+00	NA[b]	1.000E+00
	5	57061	NA[a]	40	0.380	6.876E-04	0.000E+00	NA[b]	1.000E+00
	6	135165	NA[a]	0	0.380	1.629E-03	0.000E+00	NA[b]	1.000E+00
	7	236337	No liner	300	0.380	2.848E-03	0.000E+00	NA[b]	1.000E+00
	8	28779	NA[a]	0	0.380	3.468E-04	0.000E+00	NA[b]	1.000E+00
	9	81034	NA[a]	0	0.380	9.764E-04	0.000E+00	NA[b]	1.000E+00
	10	7701	No liner	700	0.380	9.279E-05	0.000E+00	NA[b]	1.000E+00
184	2	230671	NA[a]	65	0.115[d]	1.612E-03	0.000E+00	7Q10	0.000E+00

[a] Liner scenario is not required since the impoundment is less than or equal to 150 meters; DAF assumed to be 1.0.
[b] The waterbody is a pond, therefore the River Flow Rate is essentially zero and the River Dilution Factor is assumed to be 1.
[c] Infiltration rates for this analysis were calculated using the semi-analytical solution in EPACMTP and impoundment-specific data unless otherwise noted.
[d] The base of the impoundment is at or below the water table, so the infiltration rate was calculated using the method described in Bear (1979).
[e] Infiltration rate, Leachate flux, and River Dilution Factor are not applicable because the elevation of the wastewater in the surface impoundment is at or below the water table.
[f] The infiltration rate was generated using the formula for composite liner leakage rate of Bonaparte et al. (1989).
[g] The infiltration rate was generated by averaging the infiltration from impoundments 1,2,3,4 and 5 because of the lack of subsurface data.

Table C.4-10. Summary of Water Quality Exceedances for Groundwater to Surface Water Pathway

Facility	SI	Constituent of Concern	C_{leach} [a] (mg/L)	C_{GW} [b] (mg/L)	C_{river} [c] (mg/L)	HH-AWQC [d] (mg/L)	C_{river}/HH-AWQC [e]
Risk Exceedances Based on Reported Chemical Concentrations							
50	1	Thallium	2.40e+00	3.29E-03	3.29E-03	1.70E-03	1.93E+00
68	3	Arsenic	1.20E-02	1.20E-02	1.73E-04	1.80E-05	9.61E+00
182	1	Arsenic	2.67E-01	8.09E-03	8.09E-03	1.80E-05	4.49E+02
182	2	Arsenic	2.53E-01	7.68E-03	7.68E-03	1.80E-05	4.26E+02
182	3	Arsenic	4.94E-02	4.94E-02	4.94E-02	1.80E-05	2.74E+03
182	4	Arsenic	1.55E-01	1.55E-01	1.55E-01	1.80E-05	8.63E+03
182	5	Arsenic	1.95E-01	1.95E-01	1.95E-01	1.80E-05	1.08E+04
182	8	Arsenic	3.70E-03	3.70E-03	3.70E-03	1.80E-05	2.06E+02
182	6	Arsenic	1.72E-02	1.72E-02	1.72E-02	1.80E-05	9.56E+02
Risk Exceedances Based on Surrogate/DL Chemical Concentrations							
22	1	Benzidine	3.50e+00	3.50E-02	4.32E-05	1.20E-07	3.60E+02
22	1	Benzo(a)anthracene	1.00E-02	1.00E-02	1.23E-05	4.40E-06	2.81E+00
22	1	Benzo(a)pyrene	1.00E-02	1.00E-02	1.23E-05	4.40E-06	2.81E+00
22	1	Benzo(b)fluoranthene	1.00E-02	1.00E-02	1.23E-05	4.40E-06	2.81E+00
22	1	Chrysene	5.00E-03	5.00E-03	6.17E-06	4.40E-06	1.40E+00
22	1	Dibenzo(a,h)anthracene	1.00E-02	1.00E-02	1.23E-05	4.40E-06	2.81E+00
22	1	Hexachlorobenzene	1.00E-02	1.00E-02	1.23E-05	7.50E-07	1.65E+01
22	1	Ideno 1,2,3-cd Pyrene	1.00E-02	1.00E-02	1.23E-05	4.40E-06	2.81E+00
22	1	N-Nitrosodimethylamine	5.00E-03	5.00E-03	6.17E-06	6.90E-07	8.95E+00
22	1	N-Nitrosodi-n-propylamine	1.00E-02	1.00E-02	1.23E-05	5.00E-06	2.47E+00
22	1	PCBs	1.75E-03	1.75E-03	2.16E-06	1.70E-07	1.27E+01
22	1	Toxaphene	1.00E-03	1.00E-03	1.23E-06	7.30E-07	1.69E+00
45	2	1,2-Diphenylhydrazine	1.00E-02	5.56E-03	4.50E-05	4.00E-05	1.13E+00
45	2	3,3'Dichlorobenzidine	2.00E-02	9.52E-03	7.72E-05	4.00E-05	1.93E+00
45	2	Acrylonitrile	4.33E-02	2.41E-02	1.95E-04	5.90E-05	3.31E+00
45	2	Benzidine	5.00E-02	2.78E-02	2.25E-04	1.20E-07	1.88E+03
45	2	Bis2-chloroethyl ether	1.00E-02	4.35E-03	3.53E-05	3.10E-05	1.14E+00
45	2	Hexachlorobenzene	1.00e+00	1.69E-04	1.37E-06	7.50E-07	1.83E+00

(continued)

Table C.4-10. (continued)

Facility	SI	Constituent of Concern	C_{leach} [a] (mg/L)	C_{GW} [b] (mg/L)	C_{river} [c] (mg/L)	HH-AWQC [d] (mg/L)	C_{river}/HH-AWQC [e]
45	2	n-Nitrosodimethylamine	1.00E-02	5.56E-03	4.50E-05	6.90E-07	6.53E+01
45	2	n-Nitrosodi-n-propylamine	1.00E-02	5.56E-03	4.50E-05	5.00E-06	9.01E+00
45	2	PCBs	1.65E-02	4.46E-05	3.62E-07	1.70E-07	2.13E+00
45	2	Toxaphene	8.80E-03	7.33E-04	5.95E-06	7.30E-07	8.15E+00
45	3	Benzidine	5.00E-02	2.78E-02	2.44E-06	1.20E-07	2.03E+01
45	4	1,2-Diphenylhydrazine	1.00E-02	1.00E-02	4.51E-05	4.00E-05	1.13E+00
45	4	3,3'Dichlorobenzidine	2.00E-02	2.00E-02	9.02E-05	4.00E-05	2.26E+00
45	4	4,4-DDD	3.67E-04	3.67E-04	1.65E-06	8.30E-07	1.99E+00
45	4	4,4-DDE	3.67E-04	3.67E-04	1.65E-06	5.90E-07	2.80E+00
45	4	4,4-DDT	3.67E-04	3.67E-04	1.65E-06	5.90E-07	2.80E+00
45	4	Acrylonitrile	4.33E-02	4.33E-02	1.96E-04	5.90E-05	3.31E+00
45	4	Aldrin	1.83E-04	1.83E-04	8.27E-07	1.30E-07	6.36E+00
45	4	Arsenic	1.00E-02	1.00E-02	4.51E-05	1.80E-05	2.51E+00
45	4	Benzidine	5.00E-02	5.00E-02	2.26E-04	1.20E-07	1.88E+03
45	4	Benzo(a)anthracene	1.00E-02	1.00E-02	4.51E-05	4.40E-06	1.03E+01
45	4	Benzo(a)pyrene	1.00E-02	1.00E-02	4.51E-05	4.40E-06	1.03E+01
45	4	Benzo(b)fluoranthene	1.00E-02	1.00E-02	4.51E-05	4.40E-06	1.03E+01
45	4	Bis2-chloroethyl ether	1.00E-02	1.00E-02	4.51E-05	3.10E-05	1.46E+00
45	4	Chlordane	7.33E-04	7.33E-04	3.31E-06	2.10E-06	1.58E+00
45	4	Chrysene	1.00E-02	1.00E-02	4.51E-05	4.40E-06	1.03E+01
45	4	Dibenzo(a,h)anthracene	1.00E-02	1.00E-02	4.51E-05	4.40E-06	1.03E+01
45	4	Dieldrin	7.33E-05	7.33E-05	3.31E-07	1.40E-07	2.36E+00
45	4	Heptachlor	1.83E-04	1.83E-04	8.27E-07	2.10E-07	3.94E+00
45	4	Heptachlor Epoxide	2.93E-03	2.93E-03	1.32E-05	1.00E-07	1.32E+02
45	4	Hexachlorobenzene	1.00E-02	1.00E-02	4.51E-05	7.50E-07	6.02E+01
45	4	Ideno 1,2,3-cd Pyrene	1.00E-02	1.00E-02	4.51E-05	4.40E-06	1.03E+01
45	4	n-Nitrosodimethylamine	1.00E-02	1.00E-02	4.51E-05	6.90E-07	6.54E+01
45	4	n-Nitrosodi-n-propylamine	1.00E-02	1.00E-02	4.51E-05	5.00E-06	9.02E+00
45	4	PCBs	1.65E-02	1.65E-02	7.45E-05	1.70E-07	4.38E+02
45	4	Toxaphene	8.80E-03	8.80E-03	3.97E-05	7.30E-07	5.44E+01

(continued)

Table C.4-10. (continued)

Facility	SI	Constituent of Concern	C_{leach} [a] (mg/L)	C_{GW} [b] (mg/L)	C_{river} [c] (mg/L)	HH-AWQC [d] (mg/L)	C_{river}/HH-AWQC [e]
45	5	3,3'Dichlorobenzidine	2.00e+00	2.00E-02	7.92E-05	4.00E-05	1.98E+00
45	5	4,4-DDD	3.67E-04	3.67E-04	1.45E-06	8.30E-07	1.75E+00
45	5	4,4-DDE	3.67E-04	3.67E-04	1.45E-06	5.90E-07	2.46E+00
45	5	4,4-DDT	3.67E-04	3.67E-04	1.45E-06	5.90E-07	2.46E+00
45	5	Acrylonitrile	4.33E-02	4.33E-02	1.72E-04	5.90E-05	2.91E+00
45	5	Aldrin	1.83E-04	1.83E-04	7.26E-07	1.30E-07	5.58E+00
45	5	Arsenic	1.00E-02	1.00E-02	3.96E-05	1.80E-05	2.20E+00
45	5	Benzidine	5.00E-02	5.00E-02	1.98E-04	1.20E-07	1.65E+03
45	5	Benzo(a)anthracene	1.00E-02	1.00E-02	3.96E-05	4.40E-06	9.00E+00
45	5	Benzo(a)pyrene	1.00E-02	1.00E-02	3.96E-05	4.40E-06	9.00E+00
45	5	Benzo(b)fluoranthene	1.00E-02	1.00E-02	3.96E-05	4.40E-06	9.00E+00
45	5	Bis2-chloroethyl ether	1.00E-02	1.00E-02	3.96E-05	3.10E-05	1.28E+00
45	5	Chlordane	7.33E-04	7.33E-04	2.90E-06	2.10E-06	1.38E+00
45	5	Chrysene	1.00E-02	1.00E-02	3.96E-05	4.40E-06	9.00E+00
45	5	Dibenzo(a,h)anthracene	1.00E-02	1.00E-02	3.96E-05	4.40E-06	9.00E+00
45	5	Dieldrin	7.33E-05	7.33E-05	2.90E-07	1.40E-07	2.07E+00
45	5	Heptachlor	1.83E-04	1.83E-04	7.26E-07	2.10E-07	3.46E+00
45	5	Heptachlor Epoxide	2.93E-03	2.93E-03	1.16E-05	1.00E-07	1.16E+02
45	5	Hexachlorobenzene	1.00E-02	1.00E-02	3.96E-05	7.50E-07	5.28E+01
45	5	Ideno 1,2,3-cd Pyrene	1.00E-02	1.00E-02	3.96E-05	4.40E-06	9.00E+00
45	5	n-Nitrosodimethylamine	1.00E-02	1.00E-02	3.96E-05	6.90E-07	5.74E+01
45	5	n-Nitrosodi-n-propylamine	1.00E-02	1.00E-02	3.96E-05	5.00E-06	7.92E+00
45	5	PCBs	1.65E-02	1.65E-02	6.53E-05	1.70E-07	3.84E+02
45	5	Toxaphene	8.80E-03	8.80E-03	3.48E-05	7.30E-07	4.77E+01
45	6	Acrylonitrile	4.33E-02	2.41E-02	7.59E-05	5.90E-05	1.29E+00
45	6	Benzidine	5.00E-02	2.78E-02	8.76E-05	1.20E-07	7.30E+02
45	6	n-Nitrosodimethylamine	1.00E-02	5.56E-03	1.75E-05	6.90E-07	2.54E+01
45	6	n-Nitrosodi-n-propylamine	1.00E-02	5.56E-03	1.75E-05	5.00E-06	3.50E+00
45	6	Toxaphene	8.80E-03	7.33E-04	2.31E-06	7.30E-07	3.17E+00
45	7	Benzidine	5.00E-02	2.78E-02	6.74E-05	1.20E-07	5.62E+02

(continued)

Table C.4-10. (continued)

Facility	SI	Constituent of Concern	C_{leach} [a] (mg/L)	C_{GW} [b] (mg/L)	C_{river} [c] (mg/L)	HH-AWQC [d] (mg/L)	C_{river}/HH-AWQC [e]
45	7	n-Nitrosodimethylamine	1.00E-02	5.56E-03	1.35E-05	6.90E-07	1.96E+01
45	7	n-Nitrosodi-n-propylamine	1.00e+00	5.56E-03	1.35E-05	5.00E-06	2.70E+00
45	7	Toxaphene	8.80E-03	7.33E-04	1.78E-06	7.30E-07	2.44E+00
45	8	Benzidine	5.00E-02	2.78E-02	6.81E-05	1.20E-07	5.67E+02
45	8	n-Nitrosodimethylamine	1.00E-02	5.56E-03	1.36E-05	6.90E-07	1.97E+01
45	8	n-Nitrosodi-n-propylamine	1.00E-02	5.56E-03	1.36E-05	5.00E-06	2.72E+00
45	8	Toxaphene	8.80E-03	7.33E-04	1.80E-06	7.30E-07	2.46E+00
45	9	Benzidine	5.00E-02	2.78E-02	1.54E-05	1.20E-07	1.28E+02
45	9	n-Nitrosodimethylamine	1.00E-02	5.56E-03	3.08E-06	6.90E-07	4.46E+00
45	10	Benzidine	5.00E-02	2.78E-02	9.91E-06	1.20E-07	8.26E+01
45	10	n-Nitrosodimethylamine	1.00E-02	5.56E-03	1.98E-06	6.90E-07	2.87E+00
45	11	Benzidine	5.00E-02	2.78E-02	8.57E-06	1.20E-07	7.14E+01
45	11	n-Nitrosodimethylamine	1.00E-02	5.56E-03	1.71E-06	6.90E-07	2.48E+00
50	1	Arsenic	5.00E-01	1.52E-02	1.52E-02	1.80E-05	8.42E+02
68	3	Benzo(a)anthracene	1.00E-02	1.00E-02	1.44E-04	4.40E-06	3.28E+01
68	3	Benzo(a)pyrene	1.00E-02	1.00E-02	1.44E-04	4.40E-06	3.28E+01
68	3	Benzo(b)fluoranthene	1.00E-02	1.00E-02	1.44E-04	4.40E-06	3.28E+01
68	3	Chrysene	1.00E-02	1.00E-02	1.44E-04	4.40E-06	3.28E+01
68	3	Dibenzo(a,h)anthracene	1.00E-02	1.00E-02	1.44E-04	4.40E-06	3.28E+01
68	3	Ideno 1,2,3-cd Pyrene	1.00E-02	1.00E-02	1.44E-04	4.40E-06	3.28E+01
78	2	Arsenic	1.00E+01	3.03E-01	3.93E-05	1.80E-05	2.18E+00
84	5	1,1,2,2-Tetrachloroethane	5.00E-03	5.00E-03	4.87E-04	1.70E-04	2.86E+00
84	5	1,1-Dichloroethylene	5.00E-03	5.00E-03	4.87E-04	5.70E-05	8.54E+00
84	5	1,2-Dichloroethane	5.00E-03	5.00E-03	4.87E-04	3.80E-04	1.28E+00
84	5	1,2-Diphenylhydrazine	1.00E-02	1.00E-02	9.73E-04	4.00E-05	2.43E+01
84	5	2,4-Dinitrotoluene	1.00E-02	1.00E-02	9.73E-04	1.10E-04	8.85E+00
84	5	3,3'-Dichlorobenzidine	1.00E-02	1.00E-02	9.73E-04	4.00E-05	2.43E+01
84	5	4,4-DDD	1.00E-05	1.00E-05	9.73E-07	8.30E-07	1.17E+00
84	5	4,4-DDE	1.00E-05	1.00E-05	9.73E-07	5.90E-07	1.65E+00
84	5	4,4-DDT	1.00E-05	1.00E-05	9.73E-07	5.90E-07	1.65E+00

(continued)

Table C.4-10. (continued)

Facility	SI	Constituent of Concern	C_{leach} [a] (mg/L)	C_{GW} [b] (mg/L)	C_{river} [c] (mg/L)	HH-AWQC [d] (mg/L)	C_{river}/HH-AWQC [e]
84	5	Acrylonitrile	1.00E-02	1.00E-02	9.73E-04	5.90E-05	1.65E+01
84	5	Aldrin	5.00E-05	5.00E-05	4.87E-06	1.30E-07	3.74E+01
84	5	Arsenic	3.00e+00	3.00E-03	2.92E-04	1.80E-05	1.62E+01
84	5	Benzidine	1.00E-02	1.00E-02	9.73E-04	1.20E-07	8.11E+03
84	5	Benzo(a)anthracene	5.00E-05	5.00E-05	4.87E-06	4.40E-06	1.11E+00
84	5	Benzo(a)pyrene	5.00E-05	5.00E-05	4.87E-06	4.40E-06	1.11E+00
84	5	Benzo(b)fluoranthene	5.00E-05	5.00E-05	4.87E-06	4.40E-06	1.11E+00
84	5	Bis(2-chloroethyl) ether	1.00E-02	1.00E-02	9.73E-04	3.10E-05	3.14E+01
84	5	Carbon Tetrachloride	5.00E-03	5.00E-03	4.87E-04	2.50E-04	1.95E+00
84	5	Chlordane	5.00E-05	5.00E-05	4.87E-06	2.10E-06	2.32E+00
84	5	Chlorodibromomethane	5.00E-03	5.00E-03	4.87E-04	4.10E-04	1.19E+00
84	5	Chrysene	5.00E-05	5.00E-05	4.87E-06	4.40E-06	1.11E+00
84	5	Dibenzo(a,h)anthracene	5.00E-05	5.00E-05	4.87E-06	4.40E-06	1.11E+00
84	5	Dieldrin	2.00E-04	2.00E-04	1.95E-05	1.40E-07	1.39E+02
84	5	Heptachlor	5.00E-05	5.00E-05	4.87E-06	2.10E-07	2.32E+01
84	5	Heptachlor Epoxide	5.00E-05	5.00E-05	4.87E-06	1.00E-07	4.87E+01
84	5	Hexachlorobenzene	5.00E-05	5.00E-05	4.87E-06	7.50E-07	6.49E+00
84	5	Hexachlorobutadiene	1.00E-02	1.00E-02	9.73E-04	4.40E-04	2.21E+00
84	5	Ideno 1,2,3-cd Pyrene	5.00E-05	5.00E-05	4.87E-06	4.40E-06	1.11E+00
84	5	N-Nitrosodimethylamine	1.00E-02	1.00E-02	9.73E-04	6.90E-07	1.41E+03
84	5	N-Nitrosodi-n-propylamine	1.00E-02	1.00E-02	9.73E-04	5.00E-06	1.95E+02
84	5	Pentachlorophenol	1.00E-02	1.00E-02	9.73E-04	2.80E-04	3.48E+00
84	5	Toxaphene	5.00E-03	5.00E-03	4.87E-04	7.30E-07	6.67E+02
159	4	Antimony	6.00E-02	6.00E-02	3.74E-04	1.40E-04	2.67E+00
159	4	Arsenic	3.00E-01	3.00E-01	1.87E-03	1.40E-04 [F]	1.34E+01
159	4	Thallium	2.00E+00	2.00E+00	1.25E-02	6.30E-03 [F]	1.98E+00
182	7	Arsenic	2.67E-01	8.09E-03	8.09E-03	1.80E-05	4.49E+02
182	9	Arsenic	2.53E-01	2.53E-01	2.53E-01	1.80E-05	1.41E+04
182	10	Arsenic	2.67E-01	8.09E-03	8.09E-03	1.80E-05	4.49E+02
184	2	Benzidine	5.00E-02	5.00E-02	3.82E-05	1.20E-07	3.19E+02

(continued)

Table C.4-10. (continued)

Facility	SI	Constituent of Concern	C_{leach} [a] (mg/L)	C_{GW} [b] (mg/L)	C_{river} [c] (mg/L)	HH-AWQC [d] (mg/L)	C_{river}/HH-AWQC [e]
184	2	Benzo(a)anthracene	1.00E-02	1.00E-02	7.65E-06	4.40E-06	1.74E+00
184	2	Benzo(a)pyrene	1.00E-02	1.00E-02	7.65E-06	4.40E-06	1.74E+00
184	2	Benzo(b)fluoranthene	1.00e+00	1.00E-02	7.65E-06	4.40E-06	1.74E+00
184	2	Chrysene	1.00E-02	1.00E-02	7.65E-06	4.40E-06	1.74E+00
184	2	Dibenzo(a,h)anthracene	1.00E-02	1.00E-02	7.65E-06	4.40E-06	1.74E+00
184	2	Hexachlorobenzene	1.00E-02	1.00E-02	7.65E-06	7.50E-07	1.02E+01
184	2	Ideno 1,2,3-cd Pyrene	1.00E-02	1.00E-02	7.65E-06	4.40E-06	1.74E+00
184	2	n-Nitrosodimethylamine	1.00E-02	1.00E-02	7.65E-06	6.90E-07	1.11E+01
184	2	n-Nitrosodi-n-propylamine	1.00E-02	1.00E-02	7.65E-06	5.00E-06	1.53E+00
184	2	PCBs	3.50E-02	3.50E-02	2.68E-05	1.70E-07	1.57E+02
184	2	Toxaphene	2.00E-03	2.00E-03	1.53E-06	7.30E-07	2.10E+00

[a] C_{leach} The estimated concentration in the leachate as it leaves the unit boundary.

[b] C_{GW} The estimated concentration in the groundwater as it enters the surface water; if this value exceeds a HH-AWQC then the facility is considered to have the potential for an environmental release.

[c] C_{river} The estimated concentration in the surface water after complete mixing.

[d] HH-AWQC Ambient Water Quality Criteria for human health.

[e] C_{river}/HH-AWQC The ratio of the surface water concentration to the ambient water quality criteria for human health; if this ratio exceeds one then the facility is considered to have a potential risk exceedance.

[f] The HH-AWQC selected is based on aquatic organism ingestion only because the impoundment is located next to an estuarine waterbody.

C.5 Indirect Exposure Pathway Analysis: Methodology and Results

C.5.1 Overview

The indirect exposure pathway (IEP) screening analysis was designed to evaluate the potential for indirect exposure pathway risk as a result of potential chemical release from surface impoundments. Only those facilities with impoundments that currently handle bioaccumulative constituents (i.e., SVOCs, dioxin-like compounds, mercury, and several additional metals), were included in this analysis.

Key Attributes of Indirect Exposure Pathway Screening Analysis

- Evaluated potential for indirect exposure pathway risk to offsite populations including residents, farmers, and fishers.
- Assigned facilities to one of three categories regarding potential for indirect exposure pathway risk: *potential concern, lower concern,* or *least concern*.
- Used numerical ranking algorithms combined with facility-specific and environmental setting criteria to assign rankings.
- Considered both current status and future closure scenarios. Future status scenario results were used only to qualify overall rankings, which were based on current status scenario results.

The IEP screening analysis used a combination of facility-specific and environmental setting criteria to assign each facility to one of three categories regarding the potential for indirect exposure pathway risk:

- **Potential concern:** The potential exists for indirect exposure pathway risk.
- **Lower concern**: There is a lower potential for indirect exposure pathway risk.
- Least concern: The analysis suggests that these facilities have the least potential for indirect exposure pathway risk.

In order for a facility to be placed in the category with the highest level of concern (i.e., the potential concern category), the IEP screening analysis had to suggest that the potential exists for indirect exposure pathway risk under current site conditions. Consequently, overall rankings for the facilities were assigned based on a current status scenario, which was designed to represent current conditions at the facilities. A future closure scenario was also included in the analysis to provide perspective on the number of facilities that could pose an indirect exposure pathway risk after impoundment closure. This future closure scenario analysis was based on precautionary assumptions regarding postclosure actions; consequently, the results of the analysis were used only to qualify the results of the current status scenario (i.e., future closure results were not used in assigning overall rankings to the facilities).

Although a number of the facility-specific and environmental setting criteria used in the numerical ranking of facilities were assessed at the impoundment level, the IEP screening analysis was implemented primarily at the facility level with overall rankings regarding indirect exposure pathway risk being assigned to facilities and not impoundments. In addition, although the types of chemical classes handled at facilities were considered part of the analysis (e.g., in determining which release scenarios were applicable), the analysis was not conducted at the level of individual chemicals and did not use chemical-specific concentration data. This level of analytical resolution was considered appropriate for the IEP screening analysis, which was

intended as a first-pass assessment of the potential for indirect exposure pathway risk at these facilities and not as a site-specific quantitative assessment of risk.

The IEP analysis considered a set of exposure pathways, each linked to a specific release scenario and receptor population. For example, the analysis considered volatilization of chemicals from impoundments with subsequent transport to offsite residential home gardens (this represented a specific exposure pathway that was evaluated for the resident receptor population). Each of these exposure pathways was evaluated using a specific set of facility-specific and environmental setting criteria, which in turn were used in a ranking algorithm to generate the overall ranking for that exposure pathway regarding the potential for indirect exposure pathway risk. Once all exposure pathways were evaluated for a given facility, those rankings were reviewed and an **overall ranking** was given to that facility for the IEP screening analysis. As noted above, these overall rankings were based only on the current status scenario.

The procedure used to complete the IEP screening analysis is presented below and illustrated in Figure C.5-1 (more detailed discussion of individual elements of the analytical framework is presented in the next section):

- *Step 1: Obtained facility-specific and environmental setting information used to establish criteria for the IEP screening analysis*. Reviewed SI survey data to obtain key facility-specific performance information (e.g., current impoundment status, postclosure actions taken for closed impoundments, impoundment size). Used U.S. Census data, aerial photos, topographic maps and other resources to characterize key environmental setting attributes (e.g., distance to receptor, potential for erosion/runoff, potential level of dilution for downgradient waterbodies)

- *Step 2: Converted information obtained in Step 1 into individual criteria scores used in the ranking algorithms for different exposure pathways*: Converted facility-specific and environmental setting information into specific criteria scores ranging from 1 to 3 (with 1 having a lower impact on potential exposure and risk, 2 having a moderate impact, and 3 having a higher impact). The parameter ranges that were used in defining the three categories for each criterion reflected the underlying characteristics of that parameter.

- *Step 3: Used exposure-pathway-specific ranking algorithms together with criteria from Step 2 to generate numerical rankings for each exposure pathway*: Separate ranking algorithms were developed for each exposure pathway reflecting the specific mix of criteria that should be considered in evaluating the potential for indirect exposure pathway risk for that pathway. These ranking algorithms were combined with applicable criteria to generate numerical rankings for each exposure pathway. Note that the numerical rankings were generated for both the current status scenario exposure pathways and the future closure scenario exposure pathways. This produced two sets of overall pathway-specific rankings for a given facility–one set for the current status scenario and

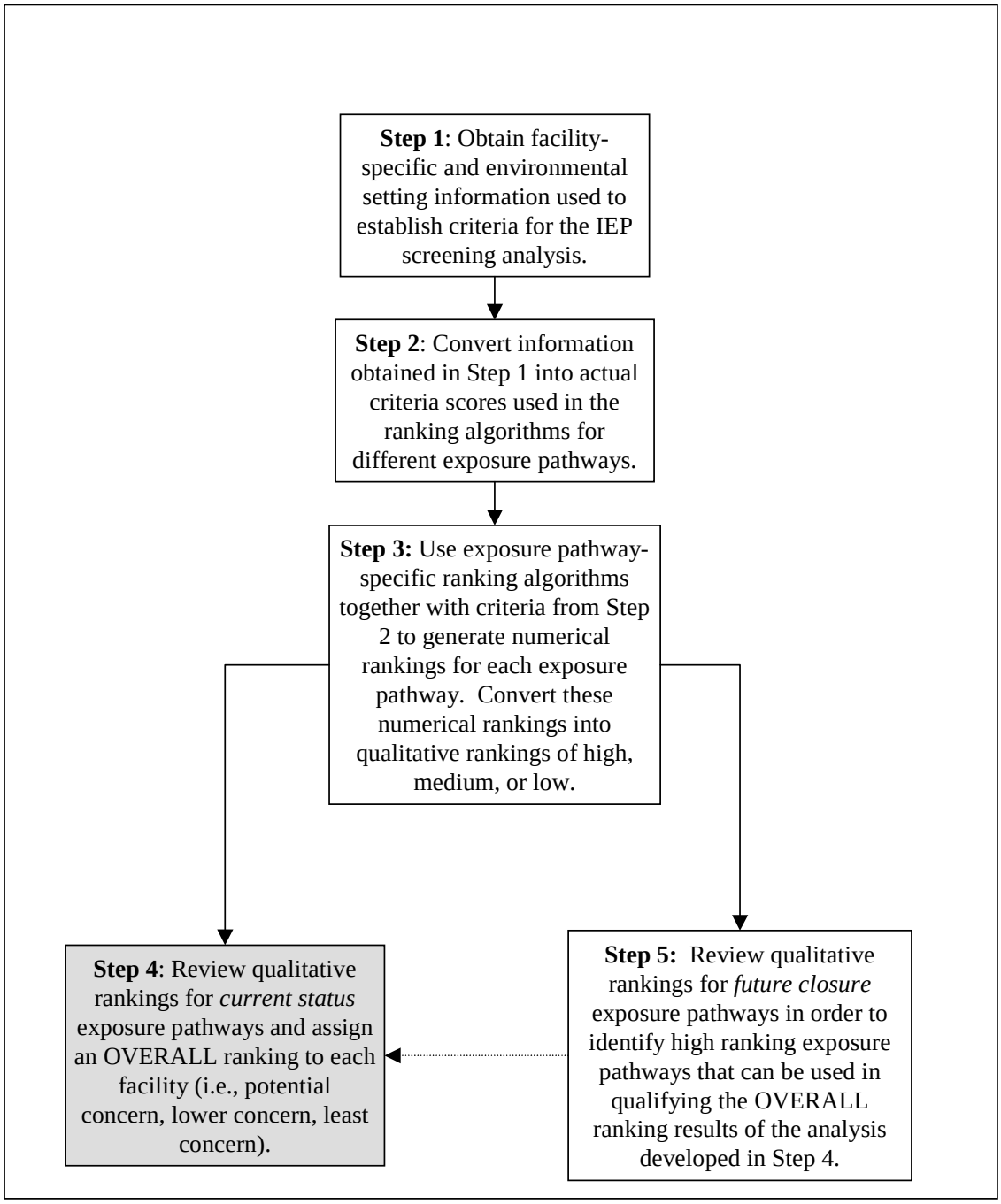


Figure C.5-1. Procedure used to assign overall rankings to facilities in indirect exposure pathway screening analysis.

one set for the future closure scenario. Ultimately, these exposure pathway-specific numerical rankings were converted into qualitative rankings of high, medium, or low for each exposure pathway, which were then used in assigning overall rankings to facilities.

- *Step 4: Reviewed qualitative rankings for current status exposure pathways and assigned an **overall** ranking to each facility*: Overall rankings for this analysis were assigned based on a review of the individual rankings assigned to each current status scenario exposure pathway. Specifically, to add confidence to conclusions that a facility has the potential for indirect exposure pathway risk (i.e., that that facility should be assigned a potential concern ranking), it was decided that a facility had to meet one of two criteria: (1) have at least two current scenario exposure pathways with a "high" ranking, or (2) have one current scenario pathway with a "high" rank and failure of the direct exposure pathway screen for air for at least one bioaccumulative constituent.

- *Step 5: Reviewed qualitative rankings for future closure exposure pathways in order to identify high-ranking exposure pathways that could be used in qualifying the **overall** ranking results of the analysis*: The results of pathway-specific rankings for the future closure scenario were reviewed for each facility to determine if any pathways have high rankings. This information was then used to qualify or augment overall rankings for those sites.

C.5.2 Technical Approach

This section provides an expanded discussion of the technical approach used in the IEP screening analysis, including a detailed explanation of how the semiquantitative ranking procedure was applied to each of the exposure pathways that were considered in the analysis.

C.5.2.1. Release Scenarios. To evaluate both the current status scenario and the future closure scenario, several different release scenarios were considered, including volatilization, particulate entrainment, erosion/runoff, and leaching to groundwater (with subsequent transport and release to surface water). Each of the release scenarios is associated with a specific set of indirect exposure pathways that can result when constituents are transported from the impoundments to different offsite receptor locations (i.e., residential areas with home gardens, farming areas with crop or grazing fields, or fishable waterbodies). Each of the release scenarios considered in the screening analysis is summarized below.

- **Volatilization:** Addressed release of volatile or semivolatile constituents from surface impoundments and subsequent transport to offsite receptors. This release scenario was considered only for constituents that have the potential to volatilize (i.e., SVOCs, dioxin-like compounds, and mercury–bioaccumulative metals other than mercury are not considered). Because the future closure scenario assumed that there was no residual wastewater in the impoundments after closure, volatilization was evaluated only for the current status scenario and was not considered for the future closure scenario.

- **Particulate entrainment.** Addressed the wind erosion and entrainment of particulates with subsequent dispersion and transport to offsite receptors. This release scenario was considered for all classes of constituents considered in the IEP screening analysis, since all have the potential to either exist in particulate form or be adsorbed to sludge particles. Particulate entrainment was considered only for those impoundments that are closed with the potential for exposed sludge which includes (1) facilities with currently closed impoundments that have been drained without being dredged or capped (this is a relatively small number) and (2) all facilities under the future closure scenario that assumed impoundments close without action being taken to reduce constituent mobility.

- **Erosion/runoff:** Addressed the potential for rainfall to create erosion and/or runoff from impoundments that impacts downgradient receptors including residential areas, farms, and waterbodies. This release scenario was considered for all classes of constituents, since it includes constituents that are either dissolved in rainwater (and carried offsite as runoff) or adsorbed to sludge particulates (and carried offsite as eroded material). The erosion/runoff release scenario was restricted to those facilities with impoundments that have closed without dredging or capping. These conditions would have to exist if rainfall in the vicinity of an impoundment results in either channel flow or sheet flow across the impoundment with subsequent runoff/erosion of sludge-bound constituents. Consequently, erosion/runoff was considered only for the current status scenario for those facilities with closed impoundments that have not been dredged or capped. The erosion/runoff scenario was considered for all facilities under the future closure scenario, since that scenario assumed that all impoundments close at grade without dredging or capping.

- **Groundwater to surface water recharge (gw-sw):** Addressed the potential for constituents in impoundments to leach into groundwater, move (with groundwater flow) offsite, and impact surfacewater through recharge. Once constituents have entered a surface waterbody through recharge, they then have the potential to bioaccumulate in fish, thereby presenting an indirect exposure pathway risk through fish ingestion. The gw-sw release scenario was evaluated for all bioaccumulative constituent groups. Because the future closure scenario assumes that all impoundments close without residual wastewater (i.e., only exposed sludge remains), this release scenario was considered only for the current status scenario.

Each of these four release scenarios was associated with specific indirect exposure pathways (e.g., volatilization of constituents can result in dispersion and transport of those constituents to adjacent farm fields where they can bioconcentrate in crops that are subsequently consumed by the farmer or the public). Table C.5-1 presents a matrix that shows which exposure pathways are associated with each release scenario and identifies whether each release scenario was considered for the current status scenario, the future closure scenario, or both.

Table C.5-1. Matrix Identifying which Facility Status Scenarios and Exposure Pathways are Considered for Each Release Scenario

Release Scenario	Facility Status Scenario		Exposure Pathway		
	Considered for Current Status Scenario	Considered for Future Closure Scenario	Home Garden Crop Consumption—Resident	Farm Commodity Consumption (Crops, Livestock, Dairy)—Commercial Farmer	Self-Caught Fish Consumption—Recreational/ Subsistence Fisher
Volatilization	Yes - considered for all volatile and semivolatile bioaccumulative chemicals at currently operational impoundments	No - only considered for currently operational impoundments	Yes - Constituents volatilize and travel to adjacent residential areas where they impact home gardens	Yes - Constituents volatilize and travel to adjacent farming areas where they impact farms (crops and grazing areas)	Yes - Constituents volatilize and travel to adjacent fishable waterbodies where they deposit directly (or from watersheds) and bioconcentrate in fish
Particulate entrainment	Yes - only for those impoundments that are currently closed without dredging or capping (relatively small number)	Yes - considered for all impoundments, since future closure scenario assumes SI closure with exposed sludge.	Yes - Constituents are entrained and carried to adjacent residential areas where they impact home gardens	Yes - Constituents are entrained and carried to adjacent farming areas where they impact farms (crops and grazing areas)	Yes - Constituents are entrained and carried to adjacent fishable waterbodies where they deposit directly (or from watersheds) and bioconcentrate in fish
Erosion/ runoff	Yes - only for those impoundments that are currently closed without dredging or capping (relatively small number)	Yes - considered for all impoundments, since future closure scenario assumes SI closure with exposed sludge.	Yes - Constituents are carried to downgradient residential areas as eroded material or in runoff where they impact home gardens	Yes - Constituents are carried to downgradient farm areas as eroded material or in runoff where they impact farms (crops and grazing areas)	Yes - Constituents are carried to downgradient waterbodies/ watersheds as eroded material or in runoff where they impact waterbodies and bioconcentrate in fish.

(continued)

Table C.5-1. (continued)

Release Scenario	Current Versus Future Scenarios		Exposure Pathway (Receptor Population)		
	Considered for Current Status Scenario	Considered for Future Closure Scenario	Home Garden Crop Consumption—Resident	Farm Commodity Consumption (Crops, Livestock, Dairy)—Commercial Farmer	Self-Caught Fish Consumption—Recreational/ Subsistence Fisher
Groundwater to surface water recharge	Yes - considered for all currently operating impoundments	No - considered only for currently operational SIS since release scenario requires presence of wastewater for leaching constituents to groundwater	No - only surface water recharge with possible fish bioconcentration considered[a]	No - only surface water recharge with possible fish bioconcentration considered	Yes - Constituents leach into groundwater and are discharged into surface water where they bioconcentrate in fish.

[a] Leaching of constituents into groundwater with subsequent transport to residential locations and possible health impacts through drinking water well usage is evaluated as part of the groundwater analysis (see Section C.3).

C.5.2.2 Criteria and Ranking Algorithms Used in Generating Rankings for Individual Exposure Pathways. Each exposure pathway was ranked for indirect exposure pathway risk using a specific mix of criteria and an additive unweighted ranking algorithm that allowed those criteria to be combined to generate an overall score for indirect exposure pathway risk. This score was then converted into a qualitative rank of high, medium, or low for each exposure pathway. The criteria were used as surrogates for key elements in the risk equation in order to support ranking of the facilities for indirect exposure pathway risk. For example, the following criteria were considered in evaluating the potential for indirect exposure pathway risk for the volatilization/home garden crop consumption exposure pathway: (1) aggregated surface area for all currently operating impoundments at the site under evaluation (represents a surrogate for source emissions strength for constituents from that site), and (2) distance between the facility and the nearest residential location (represents a surrogate for fate/transport and the resulting level of exposure for the receptor).

The criteria for a given exposure pathway were selected based on two factors: (1) what elements in the risk equation were most critical for assessing relative significance for a given exposure pathway, and (2) which elements could be characterized quantitatively or semiquantitatively given the combination of facility-specific and environmental setting data available for this screening analysis.

All of the criteria have assigned integer values ranging from 1 to 3, with 1 representing lower-risk facility-specific or environmental setting conditions, 2 representing intermediate conditions, and 3 representing higher risk conditions. One of two approaches was used in establishing the cutoff points for the criteria considered in the screening analyses:

- **Simple ranking of facility-specific and environmental values and separation into three equal-sized bins:** For those criteria where it was not possible to define the scores based on performance data (see next bullet), the raw criteria values across all facilities were simply ordered from lowest to highest and the 33rd percentile and 66th percentile values were identified as the cutoff points defining the boundary between the first, second, and third bins, respectively. This approach produced three equal-sized bins of values.

- **Performance-based cutoff points:** For several of the criteria, it was possible to use the results from previous regional- or national-scale risk assessments as a guide for defining cutoff points between the three scores (i.e., to support a performance-based approach). Specifically, for distance-to-receptor following volatilization and particulate entrainment, it was possible to review past modeling results for volatile air concentrations and dry deposition, respectively, to establish reasonable cutoff points for the distance to receptor criterion. In both cases, graphs of modeling results were reviewed to identify distances at which significant changes in vapor air concentration or particulate deposition occurred. These distance values were then used to establish the distance measures at which a receptor received a 1, 2, or 3. Ideally, the performance-based approach would have been used for more of the criteria; however, the complexity of the other

factors prohibits them from being evaluated using this approach without conducting sophisticated sensitivity analyses.

After the criteria for a specific exposure pathway were scored for a given facility (i.e., given values of 1 to 3 for each criterion), they were summed, without weighting, to generate an overall numerical score for that specific exposure pathway–the higher the aggregate score, the greater the level of concern for indirect exposure pathway impacts. The option of using weights to adjust the criteria to reflect differing degrees of significance in predicting indirect exposure pathway risk was considered as was the use of a different algorithm with a multiplicative or non-linear structure. However, for the IEP pathway screening analysis, it was decided that an unweighted summation approach would be used to derive the aggregated scores, since it would be difficult to develop defensible weights for individual criteria without further quantitative analysis or to develop a more complex algorithm.[1]

Table C.5-2 presents the specific criteria and the additive unweighted ranking algorithm used to generate numerical rankings for each exposure pathway. Table C.5-2 also presents the ranges for the numerical rankings that can be generated for each combination, as well as the ranges used in determining whether a given exposure pathway receives a high, medium, or low ranking for the potential for indirect exposure pathway risk. The specific approach and rationale used to establish cutoff points for assigning numerical scores of 1 to 3 for each of the criteria is presented in Table C.5-3. Figure C.5-2 presents a case study example for one of the facilities considered in the analysis that details the procedure followed in conducting the IEP screening analysis for a representative facility.

C.5.2.3 Use of Demographic Data to Augment Rankings. To provide additional information for assessing the potential for facilities to impact public health, the number of residents and farmers located within 1 km of the facility boundaries was estimated using 1990 U.S. Census block group-level data. Specifically, area-weighted apportionment was used to estimate the number of farmers and residents within the fraction of each block group that intersected the 1-km ring extending out from the facility boundaries. These demographic data were not included as a criterion in the ranking of individual facilities. Instead, they were used to augment the overall rankings assigned to each facility by flagging those facilities falling in each ranking category that also had a high ranking for either farmer or residential population totals. Cutoff points for a high ranking for both the residents and farmers were established by (1) ranking all of the facility population totals from lowest to highest, (2) identifying the 66th percentile facility within that ranking, and (3) using the population total for that facility as the cutoff point for a high ranking for population density (this analysis was completed separately for the residents and farmers, thereby generating two distinct cutoff points for population density).

[1] Because it can be argued that the criterion "distance to receptor" has greater predictive power in assessing indirect exposure pathway risk, the final aggregated rankings for the 107 facilities handling bioaccumulative constituents includes a category of results that flags those facilities with a high ranking for the potential for indirect exposure pathway risk and a 3 for "distance to receptor" for at least one exposure pathway (see Attachment C-17, Table C-17-2).

Table C.5-2. Criteria and Additive Unweighted Ranking Algorithms Used in Generating Aggregated Scores for Individual Release Scenario/Exposure Pathway Combinations

Exposure Pathway	Description of Exposure Pathway	Criteria[a]				Derivation of Aggregated Score for Exposure Pathways		
		SSI	DR	DF	PER	Additive Unweighted Ranking Algorithm	Range of Aggregated Score	Scores for Specific Qualitative Rankings
Volatilization/ home garden crop consumption	Constituents volatilize from impoundment and are transported to adjacent residential home gardens where they bioconcentrate in home garden crops	Yes	Yes	No	No	SSI + DR	36927	2-3: LOW 4: MED 5-6: HIGH
Volatilization/farm commodity consumption	Constituents volatilize from impoundment and are transported to adjacent farms where they bioconcentrate in crops and livestock	Yes	Yes	No	No	SSI + DR	36927	2-3: LOW 4: MED 5-6: HIGH
Volatilization/fish consumption	Constituents volatilize from impoundment and are transported to adjacent fishable waterbodies where they bioconcentrate in fish	Yes	Yes (receptor is waterbody)	Yes	No	SSI + DR + DF	36958	3-4: LOW 5-7: MED 8-9: HIGH
Particulate entrainment/home garden crop consumption	Constituents are entrained by wind erosion and transported to adjacent residential home gardens where they bioconcentrate in home garden crops	Yes	Yes	No	No	SSI + DR	36927	2-3: LOW 4: MED 5-6: HIGH
Particulate entrainment/farm commodity consumption	Constituents are entrained by wind erosion and transported to adjacent farms where they bioconcentrate in crops, and livestock	Yes	Yes	No	No	SSI + DR	36927	2-3: LOW 4: MED 5-6: HIGH
Particulate entrainment/fish consumption	Constituents are entrained by wind and transported to adjacent fishable waterbodies where they bioconcentrate in fish	Yes	Yes (receptor is waterbody)	Yes	No	SSI + DR + DF	36958	3-4: LOW 5-7: MED 8-9: HIGH

(continued)

Table C.5-2. (continued)

Release Scenario/ Exposure Pathway Combination	Description of Release Scenario/ Exposure Pathway Combination	Criteria[a]				Derivation of Aggregated Score for the RS/EP Combination		
		SSI	DR	DF	PER	Additive Unweighted Ranking Algorithm	Range of Aggregated Score	Scores for Specific Qualitative Rankings
Erosion-runoff/ home garden crop consumption	Erosion/runoff carries Constituents to downgradient offsite residential areas where they bioconcentrate in home garden crops	No - considered in establishing PER	Yes	No	Yes	DR + PER	36927	2-3: LOW 4: MED 5-6: HIGH
Erosion-runoff/ farm commodity consumption	Erosion/runoff carries Constituents to downgradient offsite farms where they bioconcentrate in crops and livestock	No - considered in establishing PER	Yes	No	Yes	DR + PER	36927	2-3: LOW 4: MED 5-6: HIGH
Erosion-runoff/ fish consumption	Erosion/runoff carries Constituents to downgradient offsite fishable waterbodies where they bioconcentrate in fish	No - considered in establishing PER	Yes (receptor is waterbody)	Yes	Yes	DR + DF + PER	36958	3-4: LOW 5-7: MED 8-9: HIGH
Groundwater to surface water recharge/fish consumption	Constituents leach from the impoundment to groundwater and are carried to adjacent waterbodies where they recharge into those waterbodies and bioconcentrate in fish	This release scenario/exposure pathway combination completed for bioaccumulative chemicals is a subset of the groundwater-surface water screening analysis completed for the full suite of SI chemicals. The methodology used in the screening analysis to rank BC sites for this combination is described in Section C.4						

DF = Dilution factor (for waterbodies).
DR = Distance to receptor.
PER = Potential for erosion/runoff.
SSI = Size of surface impoundment.

[a] All criteria have scores ranging from 1 to 3.

Table C.5-3. Overview of Methods Used to Establish Cutoff Points for Criteria Used in Generating Aggregated Scores for Individual Exposure Pathways

Criterion	Description	Approach Used to Establish Cutoff Points	Cutoff Points Established for Criterion
Surface area of impoundment	Surface area for impoundments aggregated across a facility represents a surrogate for the magnitude of potential source emissions of constituents from that facility.	*Ranking with three equal-sized bins:* Because of the range of factors that can influence the degree of source emissions (including impoundment surface area), a performance-based approach was not used. Instead, the aggregated surface area for all impoundments at each facility was calculated and these aggregated values were ranked from min to max and then the 33rd and 66th percentile surface area values were identified and used, respectively, as boundaries between the 1st and 2nd and 2nd and 3rd bins.[a]	1 = 0-4,214 m^2 2 = 4,214-59,937 m^2 3 = >59,937 m^2
Distance to receptor	The distance between the impoundment and nearest receptor (residential area, farm, or fishable waterbody) is a surrogate for the degree of exposure that an offsite receptor is likely to experience - as the distance between the receptor and the impoundment increases, the degree of exposure is likely to decrease (other things equal).	*Performance-based*: Although the relationship between receptor distance from the source and magnitude of indirect exposure pathway exposure is complex and is dependent on a wide range of factors in addition to receptor distance, past project work involving modeling of particulate and vapor dispersion that provide insights into how the degree of exposure may decrease as a receptor is located progressively farther from the source. Consequently, a performance-based approach was used to establish cutoff points for the distance to receptor criterion. Specifically, particulate deposition modeling results and vapor air concentration modeling results generated as part of evaluating risk for the application of sludge to agricultural fields were reviewed to identify reasonable distances from the sources where there were significant decreases in particulate deposition and vapor concentration, respectively.	Volatilization: 1 = >500 m 2 = 250-500 m 3 = <250 m Particulate entrainment: 1 = >300 m 2 = 150-300 m 3 = <150 m
Waterbody flow rate (flowing waterbodies) or surface area (stationary waterbodies)	Waterbody surface area (for stationary waterbodies) or flow rate (for flowing waterbodies) serves as a surrogate for the degree of dilution that is expected to occur once constituents are transported (by any of the 4 release scenarios considered in the IEP sensitivity analysis) to fishable waterbodies.	Because of the complexities associated with attempting to predict the degree of dilution (which depends on a range of waterbody characteristics), it was decided not to use a performance-based approach in establishing cutoff points for this criterion. Instead, waterbody surface areas (for stationary waterbodies) or flow rates (for flowing waterbodies) were ranked from lowest to highest and the 33rd and 66th percentile values were used to establish boundaries between the 1st and 2nd and 2nd and 3rd bins for this criterion (separate assessments were completed for the stationary and flowing waterbodies).	Stationary waterbodies 1 = >15,000 m^2 2 = 10,000-150,000 m^2 3 = < 10,000 m^2 Flowing waterbodies 1 = >5,000 ft^3/s 2 = 1,250-5,000 ft^3/s 3 = <5,000 ft^3/s

(continued)

Table C.5-3. (continued)

Criterion	Description	Approach Used to Establish Cutoff Points	Cutoff Points Established for Factor
Erosion/runoff potential	The potential for erosion/runoff was evaluated by reviewing USGS topographical maps and aerial photos; this criterion was not evaluated using a single surrogate factor as with other criteria in the IEP screening analysis	The potential for erosion/runoff was evaluated explicitly using a semiquantitative multi-factor approach that ranked each facility for the potential for significant erosion/runoff based on an analysis of USGS topographical maps and aerial photos. The following factors were considered in assessing erosion/runoff potential: ■ Slope: evaluated using criteria from EPA's Drastic model (1985) for evaluating potential for seepage to groundwater.[b] ■ Distance to downgradient receptors: evaluated using aerial photos. ■ Surface impoundment size: for impoundment selected for use in assessing erosion/runoff potential at a given facility (see below) The erosion/runoff score assigned to a given facility was based on the specific impoundment at each facility that (a) had a high potential for erosion/runoff, and (b) had the largest surface area. Once that impoundment was selected, it was assessed for the above factors and a numerical ranking of the potential for erosion/runoff was assigned (see categories in cell to right). Despite the use of quantitative site-specific data in conducting the erosion/runoff analysis for each facility, there was a certain amount of professional judgment associated with assigning the final erosion/runoff score to each facility. A number of judgment calls had to be made in assessing each facility for erosion/runoff potential, such as which impoundment had the greatest potential for erosion/runoff and therefore would be the focus of the analysis, how likely is it that erosion/runoff will reach a given downgradient receptor given the overall slope and specific topographical characteristics of the downslope area such as presence of gullies and physical barriers to flow.	None = slopes 0-2%; receptor >1 km or no receptors.[c] 1 = slopes 2%-6%; receptors 0.7-1 km; small SI. 2 = slopes 6%-12%; receptors 0.3-0.7 km; medium to small SI. 3 = close receptor <0.3 km; moderate to high slopes (>12%); size was given less importance for this category.

(continued)

Table C.5-3. (continued)

[a] The aggregated impoundment surface area values used in characterizing facilities for the "impoundment surface area" criterion were actually further differentiated based on several criteria. If a facility had a combination of currently operating and closed impoundments, then the aggregated impoundment surface area value for the current volatilization assessment would be based only on the aggregated value for currently operating impoundments (currently closed impoundments would be excluded). Similarly, only the aggregated closed impoundment surface areas would be considered in modeling the current particulate entrainment and current erosion/runoff scenarios (assuming those impoundments had not been dredged or capped). All impoundments were considered in generating the aggregated surface area estimate for use in the future particulate entrainment and future erosion/runoff scenarios.

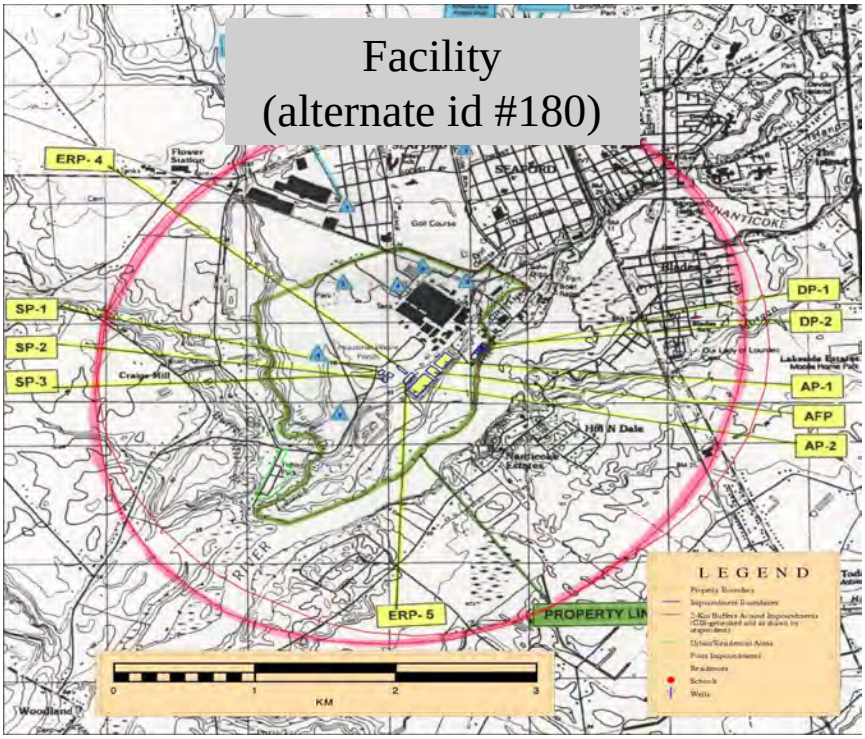
[b] Based on EPA's Drastic model, 0 to 2% slopes (i.e., 2 rise per 100 run is 2%) were identified as areas with minimal runoff, 2% to 6% slopes were assigned low runoff potential, 6% to 12% slopes were assigned medium runoff potential and anything greater was considered high. The slopes were measured from the topographical maps. Estimates of the slope were made using a general average of the topography both behind the SI and in the downgradient direction.

[c] Because the potential for erosion/runoff was evaluated explicitly, the assessment included a "none" category for those facilities for which erosion/runoff was judged to be highly unlikely or infeasible. Because other criteria considered in this screening analysis are based on surrogate factors that arguably have greater uncertainty than the erosion/runoff potential criterion, they do not include the "none" category. It is not possible to make a clear statement that the other surrogate factors have values sufficiently small (or large) to exclude consideration of a specific release scenario (e.g., the SI surface area cannot be so small as to completely rule out volatilization without considering other factors, while the presence of a railway embankment between an impoundment and a farm field could reduce the potential for erosion/runoff impacts to that farm to near zero).

USGS topographic map showing site boundary, impoundments and 2km site radius (red border).

• Used to assess runoff/erosion potential (e.g., slope of areas downgradient from impoundment, potential for sheet versus channel flow).

• Used along with aerial photograph to support identification of nearest fishable waterbody and downgradient waterbody.



Aerial photographs.

• Used to identify nearest receptors (farmers and residents) for volatilization and particulate entrainment and nearest downgradient receptors (farmers and residents) for erosion/runoff.

Figure C.5-2.Case study example of the IEP screening analysis procedure.

STEP 1 - Characterize Site: Review USGS topographic maps, aerial photos, and site-specific information reported in the SI Survey to characterize key facility-specific and environmental setting factors. This resulted in the following attributes being identified for Site #180:

- Site #180 handles bioaccumulative metals including mercury.
- Impoundments that manage bioaccumulative chemicals at the facility are all currently active and have an aggregate surface area of 40,745 m2.
- The nearest residential area is approximately 475m from the closest impoundment, while the nearest farming area is 1100m. The nearest fishable waterbody is Nanticoke River which is approximately 30m away from the closet impoundment. This river has a flowrate of 92.26 ft3/sec.
- The nearest downgradient fishable waterbody is the Nanticoke river as described above – there are no downgradient farms or residential areas identified.
- The potential for erosion/runoff is assessed as HIGH (the terrain is fairly flat, but the impoundment is moderately sized and the down-gradient waterbody is very close). The erosion/runoff predictive factor score of HIGH for Site #180 translates into a 3 for purposes of generating numerical rankings (see below).
- 293 residents and 1-2 farmers are estimated to reside within a 1km radius of the site (this translates into a medium residential population density and a high farmer population density for this site).
- Site #180 had no failure of the direct exposure pathway screen for air for any bioaccumulative constituents.

STEP 2 - Develop criteria scores based on facility and environmental setting characterization: The above characteristics translate into the following criteria scores (Note, values for all criteria range from 1 to 3 with a criteria score of 1 tending to decrease the overall potential for risk, while a 3 increases it):

The identified impoundment surface area is of average size for the sample of 107 facilities handling bioaccumulative chemicals (2). The nearest residential areas are located an average distance for volatilization (2) but fairly far away for particulate entrainment (1). The nearest farming areas are located relatively far for both volatilization and particulate entrainment (1 each). As mentioned in Step 1 above, this site has a HIGH potential for erosion/runoff which translates into a 3.

STEP 3: Assess *current status* exposure pathways (this scenario is evaluated based on current site conditions as reported in the SI survey)

- *volatilization/homegarden crop consumption*: intermediate sized aggregated impoundment (2) with intermediate distance residential area (2) produces a score of 4, which is ranked MEDIUM.
- *volatilization/farm commodity consumption*: intermediate sized aggregated impoundment (2) with a fairly distant farming area (1) produces a score of 3, which is ranked LOW.
- *volatilization/fish ingestion:* intermediate sized aggregated impoundment (2), with a close fishable waterbody (3) that has low dilution (3) produces a score of 8, which is ranked HIGH.
- *particulate entrainment (all pathways):* no currently closed impoundments with exposed sludge – no significant particulate entrainment for the current status scenario.
- *runoff/erosion (all pathways):* no currently closed impoundments with exposed sludge – no significant erosion/runoff for the current status scenario.

STEP 4: Assess *future closure* exposure pathways (assumption with this scenario is that all impoundments close at grade without measures to reduce chemical mobility)

- *particulate entrainment/homegarden crop consumption*: intermediate sized aggregated impoundment (2) with intermediate distance residential area (2) produces a score of 4, which is ranked MEDIUM.
- *particulate entrainment/farm consumption:* intermediate sized aggregated impoundment (2) with a fairly distant farming area (1) produces a score of 3, which is ranked LOW.
- *particulate entrainment/fish consumption:* intermediate sized aggregated impoundment (2), with a close fishable waterbody (3) that has low dilution (3) produces a score of 8, which is ranked HIGH.
- *runoff/erosion/homegarden crop consumption and farm commodity consumption:* No downgradient residential area or farm identified.
- *runoff/erosion/fish consumption:* intermediate sized aggregated impoundment (2), with a close fishable waterbody (3) that has low dilution (3) and a HIGH potential for erosion/runoff (3) produces a score of 11, which is ranked HIGH.

STEP 5: Assign overall rankings - review results from the current status scenario assessment and assign an overall ranking to the site (i.e., potential concern, lower concern, least concern). Then, review the future closure scenario and augment overall ranking as appropriate:

- **Overall Ranking**: Site #180 has one current scenario exposure pathway with a HIGH ranking and no bioaccumulative chemicals that failed the direct pathway screen for air. Therefore, it is assigned an **overall ranking** of **lower concern** for the potential to pose an indirect exposure pathway risk.

- **Augmenting the overall ranking:** (a) Facility #180 had two future closure exposure pathways with a HIGH rankings and consequently, the facility would be designated as " Lower concern + high future closure risk potential", and (b) the site has a high farm population density relative to other facilities that handle bioaccumulative chemicals and consequently would be designated as "Lower concern - with high farmer pop", in terms of population density-augmented results.

Figure C.5-2. (continued)

C.5.2.4 Results. This section presents the results of the indirect exposure pathway screening analysis completed for the SI study. Of the SI facility sample, 107 facilities reported managing bioaccumulative chemicals; consequently, the IEP screening analysis generated numerical rankings for this subset of facilities (all other facilities in the SI sample were assigned a default overall ranking of lowest criteria). The results presented in this section have not been weighted to reflect the entire SI universe (see Section 3.4 for presentation of weighted results). This section includes a variety of different results categories designed to present different perspectives of the IEP screening analysis including (all of the results presented in this section are aggregated across the 107 bioaccumulative constituent handling facilities):

- **Overall results**, which summarize the overall facility rankings across the set of 107 facilities that handle bioaccumulative chemicals.
- **Receptor population/exposure pathway perspective**, which presents aggregated results according to receptor population/exposure pathway
- **Release scenario perspective**, which presents aggregated results according to release scenario
- **Bioaccumulative chemical category perspective**, which presents aggregated results according to the bioaccumulative chemical category groups (i.e., SVOCs, mercury, dioxin-like compounds, metals).

The intent in providing these different categories of aggregated results is to allow consideration of a range of risk management questions in reviewing the results of the IEP screening analysis (e.g., "which receptor population appears to contribute the largest number of high ranked exposure pathway results in the analysis," or "how many facilities with at least one high ranking for the resident receptor also have a high residential population density within 1 km of the facility boundary?").

The remainder of this section is organized according to the four groupings of aggregated results listed above. In presenting these results, the significance of the different ranking categories is discussed as well as the sources of uncertainty that can impact each category.

C.5.2.5 Overall Results. This section presents the overall results for the 107 facilities that report managing bioaccumulative chemicals and, as such, represent the primary findings of the analysis. The overall rankings presented in this section are based on the current status scenario. The future status results were not considered in assigning overall rankings, but were used to augment the results as explained below. The overall rankings for the facilities were based on a review of the current status results for individual exposure pathways and the results of the screening-level modeling for air for the bioaccumulative chemicals at a given facility.

A facility could receive an overall ranking of potential concern if one of two criteria were met: (1) the facility had two or more current status exposure pathways with a high rank, or (2) the facility had one exposure pathway with a high rank and at least one bioaccumulative chemical that exceeded the direct exposure pathway screening analysis for air. This two-criteria approach

for identifying potential concern-ranked facilities, reflects the goal of having the IEP analysis identify the subset of facilities that have a strong probability of posing an indirect exposure pathway risk to nearby populations. Both of these criteria increase the potential that a facility will have completed indirect exposure pathways. With this approach, a facility with a single high-ranked exposure pathway (that does not exceed risk criteria for screening-level modeling for air) was assigned an overall rank of lower concern regarding the potential for indirect exposure pathway risk. Table C.5-4 presents the overall ranking results for the IEP screening analysis, which include the following categories (note, several categories of augmented results are included here):

- **Potential concern:** Identifies facilities that have either (1) two high-ranking current scenario exposure pathways, or (2) one high-ranking exposure pathway and at least one exceedance of the direct exposure pathway screen for air for a bioaccumulative chemical.

Table C.5-4. Overall Results for Indirect Exposure Pathway Screening Analysis (107 Unweighted BC Sites)

Category	Number of Sites
Overall Rankings	
Potential concern	**29**
Potential concern (high 2X)	27
Potential concern (one exceedance in air screening modeling)	12
Potential concern with nearby receptor	29
Potential concern + high future	7
Lower concern	**63**
Lower concern + high future	23
Least concern	**15**
Least concern + low future	3
Population density-augmented results	
Potential concern + high resident pop	9
Potential concern + high farmer pop	7
Lower concern + high resident pop	11
Lower concern + high farmer pop	4

- **Potential concern (high 2X):** Identifies the number of facilities that received a potential concern overall ranking because of having two or more current scenario exposure pathways with a high ranking.

- **Potential (one exceedance in air screen modeling):** Identifies the number of facilities that received a potential concern overall ranking because of having one current scenario exposure pathway with a high ranking and at least one bioaccumulative chemical that exceeded risk criteria for the screening level modeling for air.

- **Potential concern (with nearby receptor):** Identifies those sites that have a potential concern overall ranking that also have a "distance to receptor" criterion score of "3" for one of its high-ranking exposure pathways. A "3" distance to receptor criterion score designates that facility as having receptors very close/adjacent to impoundments. For example, a facility would fall into this category if it had a potential concern overall ranking and a high ranking for a volatilization/home garden exposure pathway where the resident location was less than 250 m from the facility and therefore received a score of "3" for distance to receptor. Inclusion of this category of results reflects the possibility that, all other things being equal, distance to receptor could have somewhat greater predictive power than the other criteria in characterizing the potential for indirect exposure pathway risk.

- **Potential concern + high future:** Identifies facilities assigned an overall ranking of potential concern (based on the current status scenario as described above) that also have at least one future closure scenario with a high rank.

- **Lower concern:** Identifies facilities that have either a single high-ranking current scenario exposure pathway, or at least one medium ranking current scenario exposure pathway and no high-ranking exposure pathway.

- **Lower concern + high future:** Identifies facilities assigned an overall ranking of lower concern that also have at least one future closure scenario exposure pathway with a high rank.

- **Least concern:** Identifies sites that have all current scenario exposure pathways assigned a low ranking.

- **Least concern + high future:** Identifies sites assigned an overall ranking of least concern that also have at least one future closure scenario exposure pathway with a high rank.

- **Potential concern + high resident pop**: Identifies those facilities that have a high ranking for resident-related exposure pathways and that also have a high residential population density (for the 1-km ring surrounding the facility boundary). For example, a facility that has a high ranking for volatilization of

constituents and transport to an adjacent residential area that also has a high ranking for residential population within the 1-km ring would have membership in this group. This category is included to allow more focused consideration of potential population-level impacts.

- **Potential concern + high farmer pop**: Parallels the "potential concern + high resident pop," except this category focuses on the farmer (i.e., farmer-related exposure pathways and farmer population density).

- **Lower concern + high resident pop; Lower concern + high farmer pop:** Mirror the last two categories described, except that these categories identify those facilities with medium-ranked exposure pathways that also have high rankings for the matching receptor population.

A number of conclusions can be drawn from the results presented in Table C.5-4, including (1) slightly less than one-third of the modeled facilities have a potential concern overall ranking for indirect exposure pathway risk, (2) nearly all of the sites with an overall ranking of potential concern (which is based on current status scenario results) also have at least one future closure pathway ranked as high, (3) all of the potential concern sites have receptor populations located very close to the facilities, and (4) roughly one-third of the potential concern facilities also have high population densities for residents and farmers. This subset of facilities could be given greater weight when considering the potential for population risk.

Sources of Uncertainty. A number of sources of uncertainty impact the overall ranking results presented in this section. Each of these sources of uncertainty is related to the broader issue of using criteria as surrogates for key elements in the risk equation. While the overall rankings given to the 107 bioaccumulative constituent handling facilities are considered to have sufficient confidence to support ranking of these facilities, there is the possibility that, when a potential concern facility is subjected to site-specific risk assessment, the risk estimates resulting from that assessment could show the facility to have insignificant risk. However, the goal of the IEP screening analysis is not to estimate potential risk levels for individual sites, but rather to identify the subset of facilities that would most likely have significant indirect exposures. Specific sources of uncertainty that impact the overall ranking results include the following:

- **Assessment of potential for erosion/runoff:** Topographic maps used to assess slope and the potential for sheet versus channel flow may not be current, in which case significant changes in land use (which would not show up on older maps) could introduce error into the characterization of this criterion.

- **Distance to nearest receptor**: The distance between specific impoundments and the nearest receptor (i.e., residential areas, farms, or fishable waterbodies) was estimated using a combination of aerial photos and topographic maps. Although these measurements were made using the most up-to-date photos and maps available, some of the photos and maps were somewhat dated. This introduces uncertainty in the distance to nearest receptor measurements because land use change could result in a receptor either being added to or removed from a given

study area (note, this is less of an issue in identifying fishable waterbodies). In addition, the possibility of having agricultural activity within facility boundaries was not considered, even though the aerial photos did show evidence of such activity. This activity could have been associated with bioremediation or some other non-agricultural commodity-related activity. If there is agricultural activity within facility boundaries, then some of the distance to nearest receptor measurements could be misrepresented.

- **Residential exposure scenarios and home gardening:** A critical assumption in assessing exposure pathways for the resident was that home gardening occurs within the residential areas located closest to the facility. To the extent that home gardening does not occur in these areas, then the exposure pathway would not be complete and any rankings for this receptor would be incorrect.

Receptor Population (Exposure Pathway) Perspective. This section presents aggregated results of the IEP screening analysis differentiated by receptor population (and, by implication, indirect exposure pathway).[2] The intent in presenting these results is to allow the reader to determine which receptor populations drive the overall rankings for the current status scenario for the 107 facilities that report handling bioaccumulative chemicals. As discussed below, each of the receptor populations has a different level of uncertainty associated with its inclusion in this screening analysis, which could impact the way rankings are interpreted.

Table C.5-5 shows the number of facilities that had achieved a given ranking for each of the three receptor populations (e.g., the number of facilities that had a high ranking for one of the exposure pathways that involved the resident).

Results presented in Table C.5-5 suggest that the resident and fisher receptor populations contribute the largest number of high-ranking exposure pathways in the screening analysis, although the farmer receptor population also makes a significant contribution. The fisher receptor population contributes the majority of the medium-ranking exposure pathways.

Table C.5-5. Receptor Population Perspective: Number of Facilities with Specific Ranking Level for Exposure Pathways Associated with Each Receptor Population

Receptor Population	High	Medium	Low
Resident	23	34	27
Farmer	14	25	20
Fisher	28	61	18

[2] Each of the receptor populations considered in this analysis is associated with a single, or distinct, set of indirect exposure pathways. These include fisher (self-caught fish consumption), resident (consumption of home garden-produced crops), and farmer (consumption of home-produced agriculture commodities such as crops, livestock, and dairy).

Sources of Uncertainty. Sources of uncertainty associated with this category of results include many of the same sources described in the last section for the overall ranking results. For example, the residential ranking results are impacted by (1) uncertainty associated with identifying the nearest residential areas using aerial photos that may be dated in some cases (i.e., land use change could have involved changes in the location of houses), and (2) uncertainty associated with the presence of home gardens in specific residential areas. Farmer rankings are impacted by the exclusion of areas within facility boundaries that could potentially be agricultural land use. Fisher rankings are impacted by uncertainty associated with assessing the potential for erosion/runoff and, consequently, assessing the magnitude of chemical loading to either nearest or downgradient fishable waterbodies.

Release Scenario Perspective. This section presents aggregated results of the IEP screening analysis differentiated by release scenario (i.e., volatilization, particulate entrainment, erosion/runoff, leaching to groundwater with subsequent transport, and surface water impact). This set of aggregated results is intended to provide perspective on how the rankings of exposure pathways relate to the different release scenarios considered in the analysis and, as such, can be used to answer a range of questions related to release scenarios and exposure pathway rankings (e.g., which release scenario dominates high exposure pathway rankings under the current status scenario).

Table C.5-6 presents the aggregated results differentiated by release scenario. Note that Table C.5-6 includes only particulate entrainment and erosion/runoff release scenarios for the future closure scenario since it is assumed for the future closure scenario that volatilization and groundwater impacts are minimal given the absence of wastewater recharge to the impoundment following closure.

Table C.5-6. Release Scenario Perspective: Number of Facilities with Specific Exposure Pathway Rankings for Each Release Scenario

Release scenario	Exposure Pathway Rankings		
	High	**Med**	**Low**
Current status			
Volatilization	40	31	1
Particulate entrainment (current)	5	20	2
Erosion/runoff (current)	5	13	3
Groundwater to surface water	15	49	43
Future closure			
Particulate entrainment (future)	42	43	10
Erosion/runoff (future)	39	56	12

Results presented in Table C.5-6 suggest that, for the current status scenario, volatilization is the dominant release scenario producing high rankings for indirect exposure pathways. However, high rankings under the future closure scenario are nearly evenly distributed between the two release scenarios considered for the future closure scenario (i.e., erosion/runoff and particulate entrainment).

Sources of Uncertainty. There is considerable uncertainty associated with using a screening approach based on predictive (surrogate) factors to represent complex fate/transport processes such as volatilization, dispersion, and runoff/erosion. However, the overall level of confidence associated with the approach used to represent these fate/transport processes in screening the facilities for indirect exposure pathway risk is considered sufficient to support the ranking and descriptive goal of the IEP screening analysis.

Bioaccumulative Chemical Group Perspective. This section presents overall rankings for the 107 bioaccumulative constituent handling facilities differentiated by constituent class (i.e., metals (excluding Hg), Hg, SVOCs, and dioxin-like compounds). This set of aggregated results is intended to provide perspective on how the rankings of facilities relate to the different bioaccumulative chemical classes considered in the analysis. Consequently, these results can be used to answer a range of questions related to bioaccumulative chemical classes and ranking scores (e.g., which chemical class is associated with potential concern-ranked sites).

Table C.5-7 presents the number of facilities with a specific overall rank that are reported to handle a particular bioaccumulative chemical class. In interpreting these results, it is important to note that the different chemical classes are not necessarily mutually exclusive (i.e., the set of eight facilities identified as having a "potential" overall ranking under the metals category for the current status scenario do not necessarily handle bioaccumulative metals exclusively; facilities in that category could also handle other constituents). However, the table does allow the reader to assess which chemical classes are consistently associated with potential concern, lower concern, or least concern ranks across all 107 facilities.

Table C.5-7. Bioaccumulative Chemical Group Perspective: Number of Facilities with Specific Overall Ranking for Each Chemical Class

	Overall IEP Screening Analysis Ranking		
Chemical Class	**Potential concern**	**Lower concern**	**Least concern**
Metals (excluding Hg)	25	56	15
Mercury	22	42	0
SVOCs	12	22	0
Dioxin-like compounds	17	10	0

SVOCs = Semivolatile organic compounds.

Results presented in Table C.5-7 suggest that the potential concern category is dominated by facilities that handle metals including mercury, although a significant number of potential concern facilities also handle SVOCs and dioxin-like compounds.

The different chemical classes cannot be differentiated in any meaningful way with regard to uncertainty in the screening analysis; consequently, the issue of uncertainty is not addressed specifically from the chemical class perspective.

C.6 Ecological Screening Assessment

Industrial wastes managed in surface impoundments not only can impact the health of people living near them, they can also have adverse effects on nonhuman organisms and natural systems. For example, wildlife can come into contact with contaminants by swimming or living in contaminated waters or by drinking or catching prey, such as fish, from contaminated waters. Plants that grow in soils containing constituents of concern (CoCs) can take them into their leaves and stems through root uptake, which can have detrimental effects on the plants as well as on the animals that eat them. Microorganisms and small invertebrates that live in close contact with the soil (e.g., worms) can accumulate CoCs through contact with contaminated soil. Therefore, it is important to evaluate risks posed to ecological receptors as well as those posed to humans. Protection of human health does not necessarily protect ecological receptors. Some chemicals are more toxic to nonhumans; wildlife species generally have higher metabolic rates than humans and, therefore, eat, drink, and breathe proportionately more contaminants than humans; and nonhuman organisms live in closer association with their immediate environment and often cannot avoid contamination or replace destroyed food sources as humans can (Suter, 1993).

The ecological risk screening is somewhat different from the human health screening in that a single comparison of screening factors and constituent concentrations was conducted. The scope of this phase of the assessment includes a subset of 43 constituents for which toxicological and exposure factor data were readily available. The assessment addresses 57 vertebrate species as well as 5 community-level receptors. Depending on the ecological receptor of concern, the analysis estimates risks from either the ingestion of contaminated plants, prey, and media or from direct contact with a contaminated medium such as sediment or soil. The ecological risk estimates were compared to risk criteria to prioritize the list of constituents, impoundments, and facilities that warrant further evaluation of the likelihood of adverse ecological effects.

C.6.1 Overview and Goals

The primary goal of the ecological screening assessment was to establish a priority list of constituents, impoundments, and facilities based on the potential for adverse ecological effects. The screening approach considers the potential for adverse effects to a suite of ecological receptors, including mammals and birds and aquatic, benthic, and soil fauna that are found in terrestrial, freshwater, and wetland habitats. Facilities with impoundments that exceed the ecological risk criterion for one or more chemicals are carried forward for further analysis. The habitats and receptors considered in this study are consistent with the national assessment strategy developed to support the Hazardous Waste Identification Rule proposed in November 1999. Because the HWIR risk assessment framework was intended to support national studies of waste management practices, the SI Study has adopted this framework as the basis for selecting receptors and habitats.

C.6.2 Management Goals and Assessment Endpoints

Assessment endpoints, defined as "explicit expressions of the actual environmental value that is to be protected" (U.S. EPA, 1998a), serve as a critical link between the ecological risk assessment and the management goals. For the SI Study, the management goals may be summarized as follows: "prioritize impoundments and facilities based on the potential for adverse ecological effects and describe the national distribution of ecological risks associated with the management of wastes in surface impoundments." Two key elements are required to define an assessment endpoint: (1) a valued ecological entity (e.g., a species, a community) and (2) an attribute of that entity that is important to protect (e.g., reproductive fitness).

For the SI Study, ecological exposures are assumed to occur at facilities that may be located anywhere within the contiguous United States. Consequently, a suite of assessment endpoints was chosen based on

- Significance for ecosystem functions
- Ability to represent a variety of habitat types
- Position along a continuum of trophic levels
- Susceptibility to chemical stressors managed in surface impoundments.

In Table C.6-1, the assessment endpoints (i.e., values to be protected) selected for the SI Study analysis are defined in terms of (1) the significance of an ecological entity, (2) the ecological receptor representing that entity, (3) the characteristic about the entity that is important to protect, and (4) the measures of effect used to predict risk. The intent of including multiple receptors is that, by protecting producers (i.e., plants) and consumers (i.e., predators) at different trophic levels, as well as certain structural components (e.g., benthic community), a degree of protection from chemical stressors may be inferred to the ecosystem as a whole. Consequently, the selection of the assessment endpoints for each receptor taxon is critical to the development of ecological screening factors.

Risk for sensitive receptors such as threatened and endangered species or managed lands (e.g., national wildlife refuges, state and national parks, and national forests) were not estimated for a screening level assessment. However, the SI Study included a qualitative assessment of the presence of sensitive ecosystems in proximity to SI facilities. Facilities with managed lands within 3 kilometers or with wetlands within 1 kilometer were identified, and this information was used in identifying facilities of potential concern.

C.6.3 Summary of Approach

As with the screening approach for human health, the ecological screening analysis calculates risks to individual ecological receptors (e.g., red fox, aquatic biota) based on the ratio between ecological risk screening factors and the concentrations of constituents in surface

Table C.6-1. Assessment Endpoints and Measures of Effects

Examples of Ecological Significance	Assessment Endpoint	Representative Receptors	Characteristic(s)	Measure of Effect
■ Multiple trophic levels represented ■ Represent species with large foraging ranges ■ Represent species with longer life spans ■ Variety of dietary exposures represented	Viable mammalian wildlife populations	Deer mouse, meadow vole, red fox, e.g.	Reproductive and developmental success	Chronic or subchronic NOAEL(s) for developmental and reproductive effects
	Viable avian wildlife populations	Red-tailed hawk, northern bobwhite, e.g.	Reproductive and developmental success	Chronic or subchronic NOAEL(s) for developmental and reproductive effects
■ Species represent unique habitat niches ■ Many species are particularly sensitive to exposure	Protection of amphibian and reptile populations ("herps") against acute effects	Frog, newt, snake, turtle, e.g.	Lethality and percent deformity	Acute LC_{50}s for developmental effects resulting from early life stage exposures
■ Represents base food web in terrestrial systems ■ Habitat vital to decomposers and soil aerators ■ Crucial to nutrient cycling	Sustainable soil community structure and function	Nematodes, soils mites, springtails, annelids, arthropods, e.g.	Growth, survival, and reproductive success	95% of species below no effects concentration at 50th percentile confidence interval
■ Primary producers ■ Act as food base for herbivores ■ Constitute essential habitat for virtually all receptor groups (e.g., nests)	Maintain terrestrial primary producers (plant community)	Soy beans, alfalfa, rye grass, e.g.	Growth, yield, germination	10th percentile from LOEC data distribution
■ Important food source for animals that live in waterbody margins ■ Diverse aquatic life important to maintain biotic integrity	Sustainable aquatic community structure and function	Fish (salmonids), aquatic invertebrates (daphnids), e.g.	Growth, survival, reproductive success	National Ambient Water Quality Criteria for aquatic life (95% species protection)
■ Provide habitat for reproductive lifestages (e.g., eggs, larval forms) ■ Act to process nutrients and decompose organic matter	Sustainable benthic community structure and function	Protozoa, flat worms, ostracods, e.g.	Growth, survival, reproductive success	10th percentile from LOEC data distribution
■ Primary producers ■ Base food source in the aquatic system	Maintain primary aquatic producers (algal and plant community)	Algae and vascular aquatic plants, e.g.	Growth, mortality, biomass, root length	EC_{20} for algae; lowest LOEC for aquatic plants

impoundments reported in the survey questionnaire. Consequently, ecological risk screening factors are given in units of concentration (e.g., mg/kg or mg/L). The use of screening factors is considered to be protective because the factors are

- Derived using established EPA protocols for use in evaluating ecological risk (e.g., sediment quality criteria)
- Based on highly protective assumptions regarding the toxicological potency of a constituent (e.g., no adverse effects levels and low adverse effects levels)
- Calculated assuming that all media and food items originate from a contaminated source.

In addition, the application of the screening factors assumes that ecological receptors are exposed directly to chemical concentrations in the sludge and wastewater found in the surface impoundment. For mammals, birds, and selected herpetofauna, these screening factors reflect ingestion of contaminated media, plants, and prey. For other receptor groups, such as soil fauna, these screening factors reflect both the direct contact and ingestion routes of exposure.

C.6.3.1 Selection of Representative Species/Receptor Groups. The 62 ecological receptors used for the HWIR assessment were selected for use in the screening analysis. The HWIR receptors were developed to support the assessment of ecological risks in 14 different terrestrial, waterbody margin, and wetland habitats. They are representative of the entire continental United States, and they reflect potential exposure for a variety of trophic levels, feeding strategies, and taxa (see Attachment C-19 to this appendix). Furthermore, the HWIR databases for these receptors contain complete exposure factor data as well as a compilation of selected ecotoxicological data that are relevant to the surface impoundment study endpoints. Thus, this group of receptors constitutes a readily available data set that is appropriate for use in the assessment.

In the screening analysis for the SI Study, it was assumed that each facility site supports terrestrial receptors. Receptors found in waterbody margin habitats (i.e., stream corridor and lake or pond margin) were assumed to occur at sites where there are fishable waterbodies. Fishable waterbodies were defined as lakes and ponds designated in Reach File Version 3.0 Alpha Release (RF3-Alpha) (U.S. EPA, 1994c) and streams of order 3 or higher. Receptors found in wetlands were assumed to occur at sites where wetlands are designated by the National Wetland Inventory (NWI) data (U.S. FWS, 1998), where available, or by EPA's Geographic Information Retrieval and Analysis System (GIRAS) (U.S. EPA, 1994d) where NWI coverage was not available. The HWIR ecological receptor databases include information on the geographic distribution of each receptor species. These data were used to match species distribution with facility location so that risk for each receptor species was estimated only at those facilities located within its geographic range.

C.6.3.2 Identification of Relevant Exposure Pathways. Ecological exposure pathways for the screening analysis were identified based on (1) both active and postclosure scenarios for surface impoundments, and (2) likely routes of exposure for receptors assigned to simple food

webs. Chemical constituents may volatilize from active surface impoundments and deposit onto adjacent soils, plants, or surface waters. In addition, constituents may leach into groundwater and contaminate nearby surface waters and sediments. Following closure, a surface impoundment may be integrated with local habitats (assuming the contaminant concentration does not prevent vegetative growth) and serve as a long-term source of exposure to certain types of constituents (e.g., metals). As shown in Figures C.6-1 and C.6-2, receptors may be exposed to contaminated media and/or prey and plants in both terrestrial and aquatic systems. Consequently, the exposure pathways that were assessed are

- Direct contact with contaminated sludge/soil (e.g., plants, soil fauna)
- Ingestion of contaminated sludge/soil (e.g., mammals, birds)
- Ingestion of plants/prey from contaminated sludge/soil (e.g., mammals, birds)
- Direct contact with contaminated surface water (e.g., fish, amphibians)
- Direct contact with contaminated sludge (e.g., benthos)
- Ingestion of aquatic plants/prey from contaminated surface water (e.g., birds)
- Ingestion of contaminated surface water (e.g., mammals).

Exposure routes that were not addressed in the ecological screening assessment include

- Dermal absorption from contaminated surface water or sludge (e.g., mammals)
- Inhalation of volatile constituents in air.

Dermal absorption of constituents is considered to be an insignificant exposure pathway for potentially exposed wildlife receptors and was not assessed for two reasons:

- Dense undercoat or down effectively prevents chemicals from reaching the skin of wildlife species and significantly reduces the total surface area of exposed skin (Peterle, 1991; U.S. ACE, 1996).

- Results of exposure studies indicate that exposures due to dermal absorption are insignificant compared to ingestion for terrestrial receptors (Peterle, 1991).

Inhalation of volatile compounds was not assessed for wildlife receptors for two reasons:

- Concentrations of volatile chemicals released from soil to aboveground air are drastically reduced, even near the soil surface (U.S. ACE, 1996).

- Significant concentrations of VOCs would be required to induce noncarcinogenic effects in wildlife based on inhalation toxicity data for laboratory rats and mice (U.S. ACE, 1996).

C.6.4 Development of Ecological Screening Factors

The screening analysis addresses constituents that were identified as occurring in surveyed surface impoundments and that were included in the HWIR analysis. Constituents included in the HWIR analysis are supported by available ecotoxicological data and by exposure

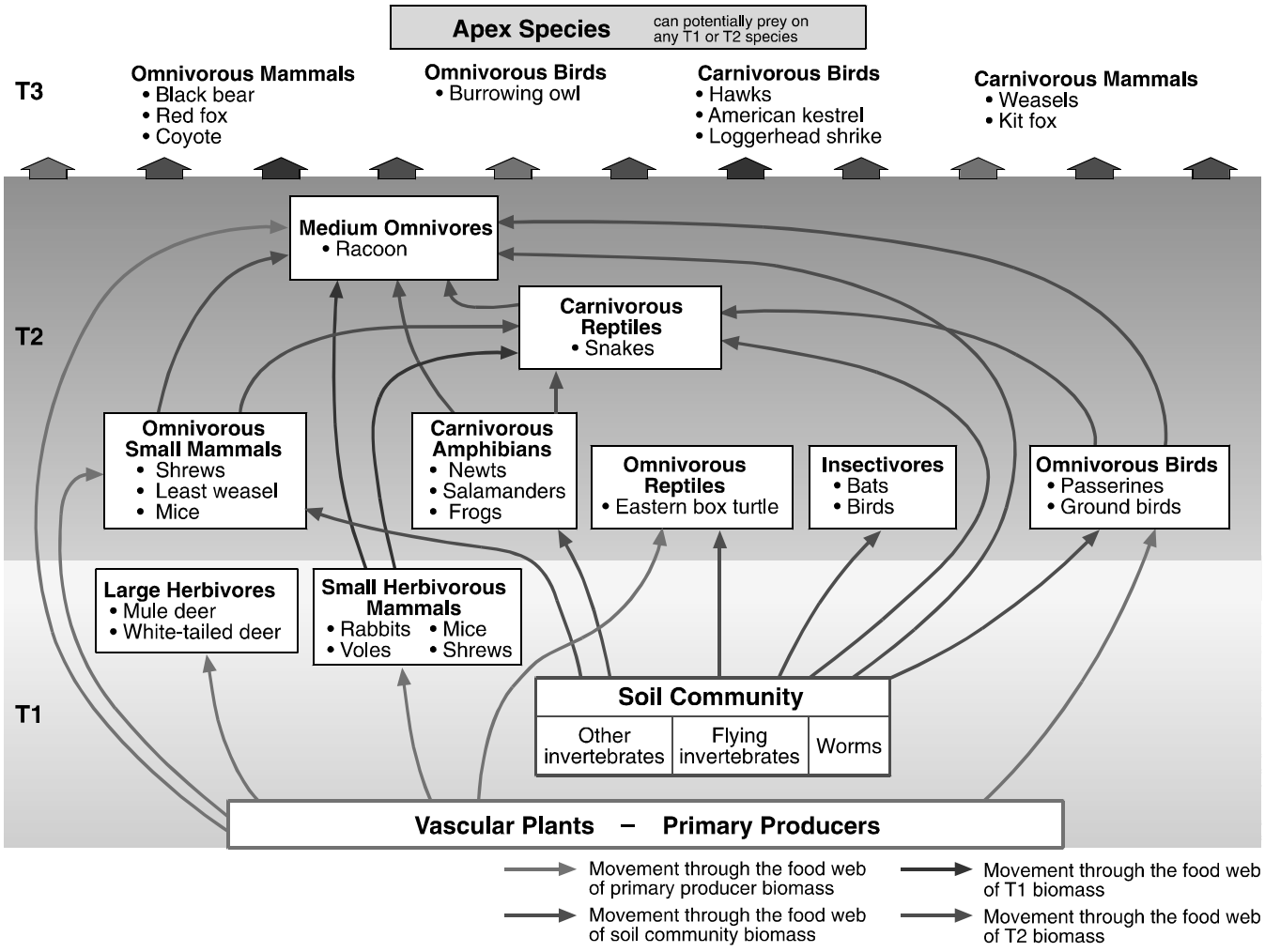


Figure C.6-1. Terrestrial web, including example receptors.

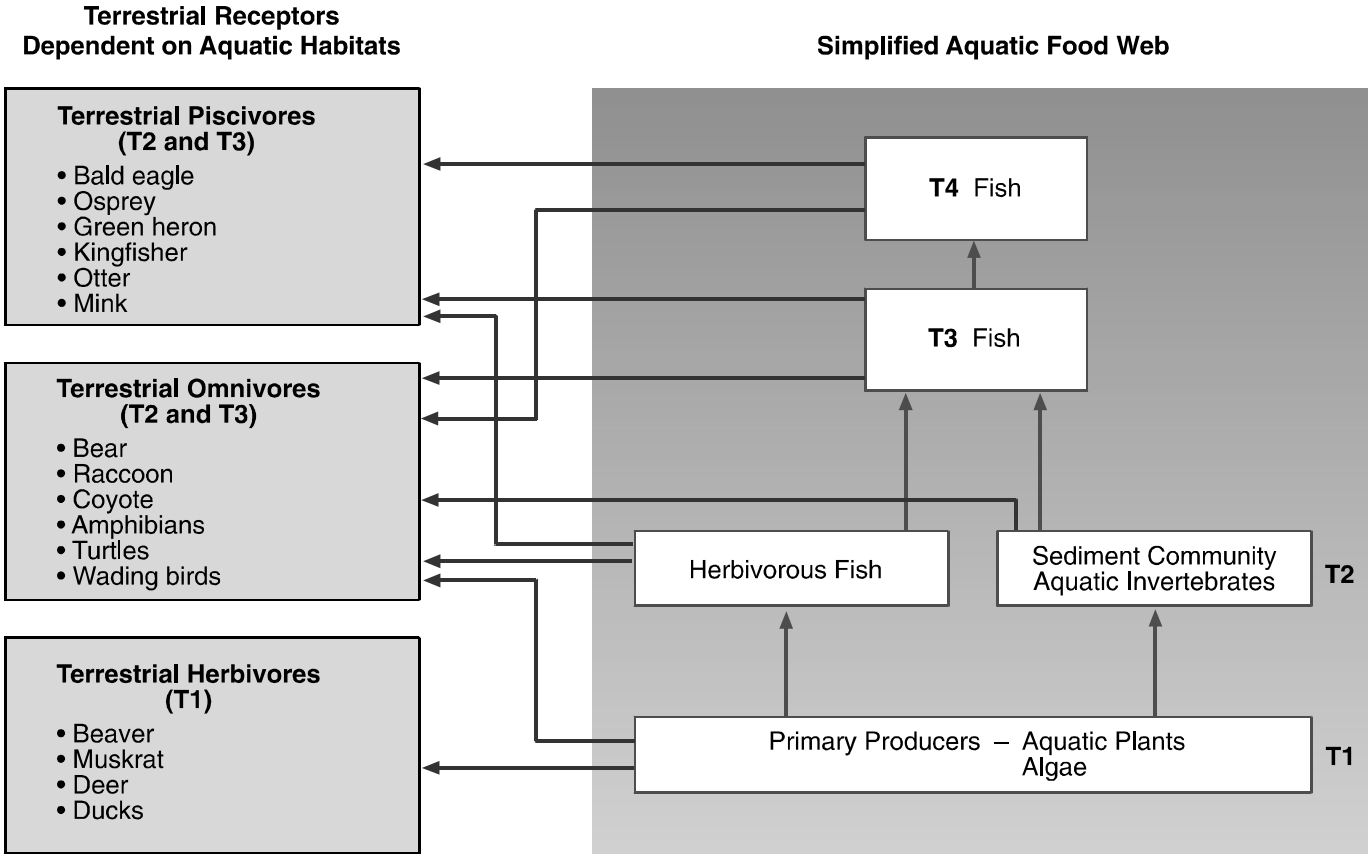


Figure C.6-2 Interface between terrestrial and aquatic food webs, including example receptors.

factor data for the relevant receptors and, therefore, could be assessed without further literature review or extensive data collection and processing. The screening factors for these constituents were taken directly from the HWIR analysis, where appropriate, and calculated using the HWIR ecological databases in other cases. The following discussion describes the methods and data sources used in the development of screening factors, which are presented in Attachment C-23 to this appendix.

C.6.4.1 Selection of Appropriate Ecotoxicological Studies—Population Inference. As suggested in Table C.6-1, risks to three groups of receptors (mammals, birds, and amphibians) were estimated based on endpoints relevant to population sustainability. It is important to note that screening factors were not developed based on population-level studies. Rather, ecotoxicological data on selected physiological endpoints (e.g., developmental effects) were used to infer risks to wildlife populations.

Table C.6-2 presents some examples of key data sources used analysis to identify suitable ecotoxicological studies.

Table C.6-2. Selected Sources of Toxicity Data

Databases

- Hazardous Substances Data Bank (HSDB). National Library of Medicine, National Toxicology Information Program. Bethesda, MD.
- PHYTOTOX. Chemical Information System (CIS) Database.
- Registry of Toxic Effects of Chemical Substances (RTECS). National Institute for Occupational Safety and Health (NIOSH), Washington, DC.

Compilations

- Agency for Toxic Substances and Disease Registry (ATSDR). 1997. *Toxicological Profiles*. On CD-ROM. CRC press. U.S. Public Health Service. Atlanta, GA.
- Devillers, J. and J.M. Exbrayat. 1992. *Ecotoxicity of Chemicals to Amphibians*. Grodon and Breach Science Publishers. Philadelphia, PA.
- Eisler, R. 1985-1993. *Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*. U.S. Fish and Wildlife Service Biological Reports.
- Hudson, R.H., R.K. Tucker, and M.A. Haegele. 1984. *Handbook of Toxicity of Pesticides to Wildlife*. U.S. Fish and Wildlife Service. Resour. Publ. 153. 90 pp.
- Sample, B.E., D.M. Opresko, and G.W. Suter II. 1996. *Toxicological Benchmarks for Wildlife: 1996 Revision*. Prepared for the U.S. Department of Energy.

For amphibians, the development of screening factors is severely limited by data availability. Several compendia presenting amphibian ecotoxicity data (e.g., U.S. EPA, 1996a; Power et al., 1989) as well as primary literature sources were reviewed, and it was determined that there was a general lack of chronic or subchronic ecotoxicological studies. Consequently, studies on acute exposures during sensitive amphibian life stages were selected for developing

screening factors. The potential sensitivity of this receptor group warrants their inclusion even though chronic study data are not yet available. All studies used to develop amphibian screening factors included the following information:

- Test organism
- Toxicological endpoint
- Exposure duration
- Life stage at which exposure occurred (e.g., embryo, tadpole).

Appropriate toxicity data for amphibians included reproductive effects, developmental effects, or lethality from studies conducted for an exposure duration of less than 8 days. Limiting the study duration to short exposures allowed use of a larger data set in deriving the screening factors.

For mammals and birds, only toxicity studies relevant to ingestion were reviewed (e.g., gavage); studies where the chemical was administered via injection or implantation were not reviewed. At a minimum, studies reported the following data elements to be considered for use in developing the ecological screening factors:

- Test organism
- Toxicological endpoint
- Dose-response information
- Exposure duration
- Exposure route
- Sample size.

Preferred Studies—Toxicity studies that reported reproductive impairment, developmental abnormalities, and mortality were preferred to studies on other physiological endpoints because these endpoints are highly relevant to the assessment endpoints selected for the SI Study (e.g., population sustainability). In addition, the use of reproductive and developmental toxicity data has been recommended in guidance across several federal agencies (U.S. EPA, 1998b; Department of the Air Force, 1997; U.S. ACE, 1996). Studies that report NOAELs as well as LOAELs were preferred. Several other important aspects of study selection are summarized below.

Duration of Exposure. Duration is critical in assessing the potential for adverse effects to wildlife. However, since definitive guidance is not available on subchronic versus chronic exposures, chronic exposures are defined as greater than 50 percent of the life span of mammalian wildlife representative species. Little information exists concerning the life span of birds used in toxicity studies, and a standard study duration has not been established for avian toxicity tests. Therefore, exposures greater than 10 weeks were considered chronic for birds; exposures less than 10 weeks were considered subchronic (Sample et al., 1996).

Timing of Exposure. The timing of exposure is critical in assessing the potential for adverse effects to wildlife. For example, early development is a particularly sensitive life stage due to the rapid growth and differentiation occurring within the embryo and juvenile. For many species, exposures of a few hours to a few days during gestation and early fetal development may

produce severe adverse effects (Sample et al., 1996). Therefore, in the absence of chronic studies on developmental or reproductive effects (e.g., multigenerational studies), studies that report exposures during reproductive and/or developmental stages were in some cases selected for use in developing ecological screening factors.

Endpoint of Interest. A review of toxicity data indicated that reproductive or developmental effects were frequently observed at lower doses than those causing mortality . Therefore, chronic mortality studies were used only when reproductive or developmental data were not available. Physiological (e.g., enzyme activity), systemic, and behavioral responses were less preferred because it is often difficult to relate these responses to quantifiable decreases in reproductive fitness or the persistence of wildlife populations. Tumorigenic and carcinogenic toxicity studies are not considered ecologically relevant and were not used to develop toxicity benchmarks because debilitating cancers in wildlife are exceedingly rare under field conditions.

C.6.4.2 Selection of Appropriate Ecotoxicological Studies—Community Inference. The community-based screening factors generally reflect direct exposures to a contaminated medium, which, in the screening analysis, is represented by actual impoundment concentrations in water and sludge. Risks were estimated for five community-level receptors: soil fauna, terrestrial plants, aquatic biota, algae and aquatic plants, and benthos. Risk was estimated based on endpoints relevant to sustainability of community structure and function. The screening factors for communities generally are not based on community-level studies in the sense that they do not reflect endpoints relevant to community dynamics (e.g., predator-prey interactions). Rather, they are based on the theory that protection of 95 percent of the species in the community will provide a sufficient level of protection for the community (see, for example, Stephan et al., 1985, for additional detail). As with the wildlife populations, ecotoxicological data on individual species were used to infer risks to the community.

Appropriate ecotoxicological studies to derive screening factors for these receptor groups were identified in a number of compendia; as a result, it was not necessary to conduct primary literature reviews to identify suitable studies. These compendia generally present threshold concentrations that may be used directly as screening factors with little or no modification. Table C.6-3 presents the primary data sources used to support the derivation of screening factors for the community receptors. The selection process for screening factors and the screening factor calculations are discussed in the following section.

C.6.4.3 Calculation of Ecological Screening Factors—Receptor Populations. Screening factors for receptor populations consist of media concentrations that are assumed to be protective. Each screening factor is species- and medium-specific. Calculation of the screening factors was based on the ecotoxicological data identified as described above in Section C.6.4 and on species-specific exposure factors from the HWIR analysis. These exposure factors include body weight, ingeston rates, and dietary composition; Attachment 21 presents the exposure factor values used in the assessment.

Table C.6-3. Examples of Primary Data Sources for Derivation of Screening Factors for Community Receptors

Source	Contents
Plant Community	
Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten. 1997a. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision*.	This document provides effects data for terrestrial plants exposed in soil and solution mediums. Approximately 45 constituents have proposed soil criteria.
PHYTOTOX Database. Office of Research and Development, U.S. Environmental Protection Agency.	This database contains over 49,000 toxicity tests on terrestrial plants for more the 1,600 organic and inorganic chemicals and 900 species.
Freshwater Community / Algae and Aquatic Plants	
AQUIRE (AQUatic toxicity Information REtrieval) Database. 1997. Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Duluth, MN	This database contains over 145,000 toxicity tests for more than 5,900 organic and inorganic chemicals and 2,900 aquatic species.
U.S. EPA. 1989a. *Ambient Water Quality Criteria.* Washington, DC.	These chemical-specific documents provide the ecotoxicity data and derivation methodologies used to develop the National Ambient Water Quality Criteria (NAWQC).
U.S. EPA. 1995. *Great Lakes Water Quality Initiative Criteria Documents for the Protection of Aquatic Life in Ambient Water. Office of Water*. (U.S. EPA, 1996a Update)	For a limited number of constituents, the GLWQI has proposed surface water criteria for aquatic biota using analogous methods as implemented in the derivation of the NAWQC.
Suter II, G.W., and C. Tsao. 1996. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Aquatic Biota: 1996 Revision.*	This compendia reference provides acute and chronic water quality criteria for freshwater species including algae.
Soil Community	
Efroymson, R.A., M.E. Will, and G.W. Suter II. 1997b. *Toxicological Benchmarks for Contaminants of Potential Concern for Effects on Soil and Litter Invertebrates and Heterotrophic Process: 1997 Revision*. Oak Ridge National Laboratory.	This document provides effects data for soil biota (i.e., microbial processes and earthworms). Approximately 35 constituents have proposed soil criteria, and some field studies are included.
CCME (Canadian Council of Ministers of the Environment), 1997. *Recommended Canadian Soil Quality Guidelines*.	The criteria developed by the CCME are concentrations above which effects are likely to be observed.
Sediment Community	
U.S. EPA. 1993a. *Technical Basis for Deriving Sediment Quality Criteria for Nonionic Organic Contaminants for the Protection of Benthic Organisms by Using Equilibrium Partitioning*.	This document supplies toxicological criteria for nonionic hydrophobic organic chemicals using FCVs (final chronic values) and SCVs (secondary chronic values) developed for surface water (Sediment Quality Criteria, SQC).

(continued)

Table C.6-3. (continued)

Source	Contents
Plant Community (continued)	
Long and Morgan. 1991. *The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program*. National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum. Update: (Long et al., 1995)	Field-measured sediment concentrations are correlated with impacts to sediment biota in estuarine environments. Measures of abundance, mortality, and species composition are the primary toxicity endpoints.
Jones, D.S., G.W. Sutter III, and R.N. Hall. 1997. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment-Associated Biota: 1997 Revision.* Oak Ridge National Laboratory.	This document proposes sediment criteria for both organic and inorganic constituents using both field and estimation methodologies.
MacDonald, D.D. 1994. *Approach to the Assessment of Sediment Quality in Florida Coastal Waters*. Florida Department of Environmental Protection (FDEP), Tallahassee.	This approach applies statistical derivation methods to determine sediment criteria using NOAA data. The resulting criteria are more conservative than NOAA values.

The calculation of ecological screening factors for receptor populations is based on the implicit assumption that each receptor species forages only within the contaminated area, regardless of the size of its home range. For smaller animals, this assumption has little impact on the estimates of exposure. However, for larger animals with more extensive foraging areas, this assumption may overestimate exposure if the animal's foraging patterns tend to be evenly spread over the home range. Thus, it is important to recognize both the explicit **and** implicit sources of protection in this methodology.

For amphibian populations, a screening factor for water (SF_{water})was derived as the geometric mean of acute studies meeting the data requirements discussed above (i.e., relevant endpoint, acute exposure, high effect level). However, it is important to point out that this screening factor should be construed as only "protective" of gross effects to amphibian populations (e.g., lethality to 50 percent of the population), and careful consideration should be given in interpreting the screening results for amphibians. The remainder of this section outlines the basic technical approach used to convert avian or mammalian benchmarks (in daily doses) to soil and water screening factors (in units of concentration).

Once the appropriate ecotoxicological study was identified for mammals and/or birds,[1] the screening factors were calculated for each medium of interest using a three-step process:

1. Scale benchmark from test species to receptor species.
2. Identify uptake/accumulation factors.
3. Calculate protective concentration (i.e., screening factor).

[1] Reptiles are not discussed in this section because of the data deficiencies for this receptor group.

Step 1. Scale Benchmark from Study Species to Receptor Species

The benchmarks for the mammalian and avian receptors were extrapolated from the study species to the receptor species within the same taxa using a cross-species scaling equation (Sample et al., 1996). Benchmarks were based on the geometric mean of NOAEL and LOAEL values. For population-inference benchmarks for mammals, the extrapolation is performed using Equation C.6-1.

$$GEOMN_{RS} = GEOMN_{SS} \cdot \left(\frac{bw_{SS}}{bw_{RS}} \right)^{1/4} \quad \text{(C.6-1)}$$

where

$GEOMN_{SS}$	=	GEOMN for the study species
bw_{RS}	=	body weight of the receptor species
bw_{SS}	=	body weight of the study species.

This is the default methodology EPA proposed for carcinogenicity assessments and reportable quantity documents for adjusting animal data to an equivalent human dose.

For avian species, research suggests that the cross-species scaling equation used for mammals is not appropriate (Mineau et al., 1996). Mineau et al. (1996) used a database that characterized acute toxicity of pesticides to avian receptors of various body weights. The results of the regression analysis revealed that applying mammalian scaling equations may not predict sufficiently protective doses for avian species. Mineau et al. (1996) suggested that a scaling factor of 1 provides a better dose estimate for birds, as shown in Equation C.6-2. This recommendation was adopted for developing screening factors for avian receptors.

$$GEOMN_{RS} = GEOMN_{SS} \cdot \left(\frac{bw_{SS}}{bw_{RS}} \right)^{1} \quad \text{(C.6-2)}$$

Attachment 20 to this appendix presents the scaled benchmarks for mammals and birds.

Step 2. Identify Uptake/Accumulation Factors

Movement of contaminants through the food web is an important exposure vector for mammals and birds. Consequently, estimates of chemical accumulation in the tissues of plants and prey items are required. For receptors likely to rely on aquatic systems for food (e.g., kingfisher), bioaccumulation factors and/or bioconcentration factors are required for aquatic biota such as fish, benthos, and aquatic plants. These data were identified in the open literature or estimated for organic constituents using regression equations such as that shown in Equation C.6-3 (Lyman et al., 1990):

$$\log BCF = 0.76 \ [\log (K_{ow})] - 0.23 \quad \text{(C.6-3)}$$

where

BCF = estimated bioconcentration factor for fish
K_{ow} = constituent-specific octanol-water partition coefficient.

For receptors found primarily in terrestrial systems, bioconcentration factors (BCFs) were required for terrestrial plants, soil invertebrates (e.g., earthworms), and vertebrates. These BCFs report the relationship between tissue concentrations and soil concentrations. As with aquatic accumulation factors, these values were identified in the open literature and EPA references or calculated based on the relationship between log K_{ow} and accumulation in lipid tissue (Sample et al., 1998a, 1998b). To ensure that the ecological screening assessment is protective, a default value of 1 was assigned to each uptake/accumulation factor that could not be derived through estimation methods or identified in the literature. Attachment 22 presents the biouptake factors used in the screening factor calculations.

Step 3. Calculate Protective Concentration for Receptor

Based on the $GEOMN_{RS}$, the screening factor for a receptor that relies on aquatic biota as the primary food source was calculated as a function of the receptor's body weight, the receptor's ingestion rate for food and water, and the bioaccumulation potential of the constituent, as shown in Equation C.6-4:

$$SF_{water} = \frac{GEOMN_{RS} \times bw}{(I_{food} \sum BAF_j \times F_j \times AB_j) + (I_{water})} \quad \text{(C.6-4)}$$

where

bw = body weight (kg)
I_{food} = total daily intake of aquatic biota (kg WW/d)
BAF_j = bioaccumulation factor for food item j (L/kg WW))
F_j = fraction of diet consisting of food item j (unitless)
AB_j = absorption of chemical in the gut from food item j (assumed = 1)
I_{water} = total daily soil intake (kg/d).

Equation C.6-4 can also be used to derive an "impoundment use only" screening factor for sites that do not have any fishable waterbodies identified in the survey data. For these cases, only I_{water} would be included in the denominator to reflect use of the impoundment as a drinking water source.

For terrestrial systems, Equation C.6-5 is simply modified to account for soil or sludge intake:

$$SF_{soil/sludge} = \frac{GEOMN_{RS} \times bw}{(I_{food} \sum BCF_j \times F_j \times AB_j) + (I_{soil/sludge})} \quad \text{(C.6-5)}$$

where

bw	=	body weight (kg)
I_{food}	=	total daily food intake of terrestrial biota (kg/d)
BCF_j	=	bioconcentration factor for food item j (assumed unitless)
F_j	=	fraction of diet consisting of food item j (unitless)
AB_j	=	absorption of chemical in the gut from food item j (assumed = 1)
$I_{soil/sludge}$	=	total daily soil intake (kg/d).

Information sources to develop the input values for body weight (bw), ingestion rates (I_{xx}), and dietary fractions (F_j) were taken from the extensive HWIR databases. The HWIR databases were developed using EPA's *Wildlife Exposure Factors Handbook* (U.S. EPA, 1993b) and augmented by substantial literature review and synthesis of a variety of information sources.

The dietary fractions (F_j) were derived from the HWIR dietary preference database and reflect the variability in receptor species' dietary composition. The dietary preference database consists of the minimum and maximum proportion of a species'diet that different diet items can constitute. Diet items are categorized as one of 17 types, including different types of vegetation (e.g., fruits, forage, grain, roots) and several categories of prey (e.g., small birds, small mammals, invertebrates, fish). For example, the Eastern box turtle's dietary proportion ranges are:

Diet Item	Dietary Proportion Range
Soil invertebrates	8 to 93
Fruits	7 to 92
Worms	15 to 27
Forage	0 to 24

The development of the dietary preference database is fully described in the HWIR documentation (U.S. EPA 1999d). Each receptor's diet was constructed using the midpoint of dietary proportions for each diet item, beginning with the item with highest midpoint value and proceeding through the diet items until a full diet (100 percent) was accumulated. Thus, the turtle's diet would consist of 50.5 percent soil invertebrates and 49.5 percent fruits based on the following dietary proportion midpoints:

Diet Item	Dietary Proportion Midpoint
Soil invertebrates	50.5
Fruits	49.5
Worms	21
Forage	12

The dietary composition used for each receptor species is presented in Attachment 21.

C.6.4.4 Calculation of Ecological Screening Factors—Receptor Communities. The calculation of ecological screening factors for receptor communities relied heavily on existing

data sources, many of which have produced peer-reviewed concentrations for soils and surface water presumed to be protective of ecological receptors. Examples include:

- **Aquatic Biota:** U.S. EPA's National Ambient Water Quality Criteria
- **Sediment-Associated Biota:** National Oceanic and Atmospheric Administration's (NOAA) Effects Range-Low (ER-Ls)
- **Soil Invertebrates:** Dutch National Institute of Public Health and Environmental Protection's (RIVM) Ecotoxicological Intervention Values (EIVs).

The methods used to develop each of the receptor community screening factors are briefly described here.

***Aquatic Community*.** For aquatic biota in freshwater systems, the final chronic value (FCV) developed for the National Ambient Water Quality Criteria were chosen as the screening factor. If an AWQC was not available, the continuous chronic criterion (CCC) developed for the Great Lakes Water Quality Initiative (GLWQI) was used (U.S. EPA, 1995a, 1996f). If neither of these criteria were available, a secondary chronic value (SCV) was calculated using the Tier II methods developed through the Great Lakes Initiative (Stephan et al., 1985; Suter and Tsao, 1996).

The SCV is calculated using methods analogous to those applied in calculating the FCV. However, the Tier II methods (1) require chronic data on only one of the eight family requirements, (2) use a secondary acute value (SAV) in place of the FAV, and (3) are derived based on a statistical analysis of AWQC data conducted by Host et al. Host et al. (1991) developed adjustment factors (AFs) depending on the number of taxonomic families that are represented in the database. The Tier II methodology was designed to generate SCVs that are below FCVs (for a complete data set) with a 95 percent confidence limit.

***Algae and Aquatic Plants*.** For algae and aquatic plants, toxicological data were available in the open literature and in data compilations such as the *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision* (Suter and Tsao, 1996). Studies on freshwater vascular plants are seldom available; however, toxicity data are available from standard algal tests. In order of preference, the screening factors for algae and aquatic plants were based on either (1) a lowest observed effects concentration (LOEC) for vascular aquatic plants or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, generally a species of green algae.

***Benthic Community*.** Two methods were applied to develop screening factors for the sediment community. The first and preferred method uses measured sediment concentrations that resulted in de minimis effects to the composition and abundance of the sediment community. The second derivation method uses the equilibrium partitioning relationship between sediments and surface waters to predict a protective concentration for the benthic community using the chronic FCV. A brief discussion of each method is provided below.

- **Screening Factors from Measured Data:** The premier sources of measured sediment toxicity data are NOAA and the Florida Department of Environmental Protection (FDEP). These data are used by NOAA to estimate the 10th percentile effects concentration effects range-low (ER-L) and a median effects concentration effects range-median (ER-M) for adverse effects in the sediment community. The FDEP sediment criteria are developed from the ER-L and ER-M values to approximate a threshold effects level (TEL) (estimated from ER-L data). The TELs are preferable to the ER-L primarily because they have been shown to be analogous to TELs observed in freshwater organisms (Smith et al., 1996).

- **Predicted Sediment CSCLs.** If neither a TEL nor an ER-L is available for nonionic, organic constituents, the screening factor will be calculated using the sediment quality criteria (SQC) method (U.S. EPA, 1993b). This method assumes that equilibrium-partitioning between the sediment and water column is a function of the organic carbon fraction (f_{oc}) in sediment and the organic carbon partition coefficient of the constituent. The screening factor is calculated as shown in Equation C.6-6, assuming that the f_{oc} is equivalent to 1 percent total organic carbon (Jones et al., 1997).

$$SF_{sediment} = f_{oc} \times K_{oc} \times FCV \qquad \text{(C.6-6)}$$

Terrestrial Plant Community. For the terrestrial plant community, screening factors for soil were derived according to the methodology presented in the *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Terrestrial Plants: 1997 Revision* (Efroymson et al., 1997a). The authors derive ecologically relevant benchmarks by rank-ordering the phytotoxicity data according to the LOECs. This analysis adopted the same approach and selected screening factors for constituents with 10 or fewer values at the lowest LOEC. For constituents with more than 10 LOEC values, the 10th percentile LOEC was selected. Because the toxicity endpoints reflect endpoints such as plant growth and yield reduction, the screening factors are presumed to be relevant to sustaining "healthy" plant communities.

Soil Community. The screening factors for soil fauna were estimated to protect species found in a typical soil community, including earthworms, insects, and other soil fauna. Eight taxa of soil fauna are represented to reflect the key structural (e.g., trophic elements) and functional (e.g., decomposers) components of the soil community. The methodology presumes that protecting 95 percent of the soil species will ensure long-term sustainability of a functioning soil community. The toxicity data on soil fauna were gleaned from several major compendia and supplemented with additional studies identified in the open literature. The mathematical construct shown in Equation C.6-7 was developed by Dutch scientists (i.e., the RIVM methodology) and was used to calculate screening factors at a 50th percentile level of confidence (Sloof, 1992). For the screening factors for soil biota ($SF_{soil5\%}$), the 50th percentile level of confidence was selected because the 95th percentile has been shown to be overly conservative (e.g., well below background levels).

$$SF_{soil_5\%} = [x_m - k_l\ s_m] \quad \text{(C.6-7)}$$

where

x_m = sample mean of log LOEC data
k_l = extrapolation constant for calculating one-sided leftmost confidence limit
s_m = sample standard deviation of log LOEC data.

When data were insufficient to calculate screening factors using this methodology, two other sources of screening factors were used. First, the ecotoxicological data presented on indicator species such as earthworms were used to select a protective soil concentration (Efroymson et al., 1997b). Second, the criteria developed by the Canadian Council of Ministers of the Environment (CCME, 1997) for the protection of soil organisms were adopted as screening factors.

C.6.5 Screening Procedures

In most respects, the ecological risk screening procedure mirrors the methods for the risks from noncancer constituents to human health. The salient features of the ecological risk screening are summarized below.

C.6.5.1 Risk Calculation. Ecological risks were estimated by selecting appropriate screening factors and constituent concentrations for each facility and impoundment and calculating HQs. The screening factors for the assessment were developed from the HWIR ecological databases, as described in the previous sections. It was assumed that all sites supported terrestrial receptors (e.g., terrestrial plants, birds, and mammals). However, surface impoundments are not intended to support aquatic plants, aquatic invertebrates, fish, or sediment-associated receptors; therefore, aquatic and sediment-associated biota were assessed only if a potentially affected waterbody was identified within 2 kilometers of the surface impoundment. Although not intended to support amphibians, birds, and mammals, surface impoundments are likely to be attractive to these receptors (especially if impoundments support vegetation); therefore, amphibians, birds, and mammals were assessed for all surface impoundments.

Risk was defined as the ratio between the impoundment concentration and the screening factor, or hazard quotient. To evaluate the receptor risks from exposure to a chemical constituent at a particular surface impoundment, Equation C.6-8 was used:

$$HQ^{\,i}_{constituent} = \frac{C_{imp_{water}}}{SF_{water}} \quad or \quad \frac{C_{imp_{sludge}}}{SF_{sludge}} \quad or \quad \frac{C_{imp_{soil}(sludge)}}{SF_{soil}} \quad \text{(C.6-8)}$$

where

C_{imp_water}	=	impoundment water concentration
C_{imp_sludge} and C_{imp_soil}(sludge)	=	impoundment sludge concentration
SF_{water}, SF_{sludge}, and SF_{soil}	=	corresponding ecological screening factors for each medium.
$HQ^{i}_{constituent}$	=	risk to receptor i associated with that impoundment and facility.

The HQ values for each receptor i may be summed across the entire facility in generating facility risks because (1) the screening factors for each receptor are based on the same study data (and endpoints) and (2) receptors may be exposed through both terrestrial and aquatic systems. Attachment C-23 shows the results of the ecological screening assessment.

C.6.5.2 Risk Screening Methods. Risk estimates generated by the ecological screening assessment were reported for receptors, constituents, surface impoundments, and facilities by the following categories of interest.

Facility

- Regulatory status

Surface Impoundment

- Waste type
- Treatment type

Constituent

- Constituent type

Ecological Attributes

- Receptor group
- Habitat type.

The facility risk is defined as the maximum surface impoundment risk to receptor i for a particular facility. Facility risk estimates are used to develop regulatory-type risk distributions. The surface impoundment risk is defined as the cumulative risk to receptor i from exposure to all constituents at a particular surface impoundment.

For the ecological screening assessment, the constituent risk is defined as risk to the most sensitive receptor across all impoundments at a facility. Constituent risk estimates are used to develop constituent-specific risk distributions.

Construct Risk Distributions. Separate risk distributions were constructed from risk estimates to evaluate categories of interest. Risk distributions consist of the following five risk intervals (risk bin):

- <0.1
- ≥0.1 and <1
- ≥1 and <10
- ≥10 and <100
- ≥100.

A unitary value (1), representing the constituent, surface impoundment, or facility, was added to the appropriate risk bin. Since sample facilities represent a number of facilities nationwide, unitary values were weighted by the facility sample weight before being added to the bin.

The facility- and surface impoundment-related risk distributions were constructed from risk estimates for all receptors considered at a particular surface impoundment or facility. These risk distributions are used to screen facilities, surface impoundments, and constituents. Risk distributions constructed from maximum risk estimates (i.e., risk estimate for the most sensitive receptor) were compared to risk distributions for all receptors to determine if the number of receptors affects the facility- and impoundment-level risk distributions. In addition, risk distributions for each trophic level were developed to evaluate potential impacts on food webs. These risk distributions for receptor groups and trophic levels provide useful metrics for the risk characterization.

Establish Risk Criterion. A risk criterion of 1 was used to screen ecological risk estimates. Risk estimates less than 1 (e.g., $HQ^i < 1$) indicate a negligible potential for adverse ecological impacts. Alternatively, risk estimates of 1 or greater indicate a potential for adverse ecological effects. Surface impoundments and facilities with risk estimates of 1 or greater may be assigned for further evaluation, depending on the results of the human health screening.

Conduct Risk Screening. The ecological risk screening process is very similar to the health risk decision process. However, there are distinct differences in the ecological risk screening procedure. Whereas the human health risk screening is intended to protect individuals, the ecological risk screening is intended to protect species populations and communities from adverse effects. In addition, the ecological risk screening does not include cancer effects; only the endpoints described under Section C.6.1 were considered.

Based on the results of the surface impoundment pilot study, it was anticipated that, for each facility, at least one constituent would exceed the ecological risk criterion for the terrestrial plant receptor group. Because impoundment sludge/soils are not intended to support terrestrial habitats and because the screening factors for terrestrial plants are based on a data set that does not reflect adaptation by plant communities, EPA determined that a simple exceedance of the plant screening factor does not provide an adequate basis to determine the potential for adverse ecological effects. Thus, if plants are the only receptors with an HQ of 1 or higher, the

constituent, impoundment, or facility proceeds to further analysis only if the HQ for plants exceeds 10 (indicating a greater potential for adverse effects than a simple exceedance).

C.6.6 Screening Results

Ecological risk was calculated in a manner similar to that used to estimate noncancer risks for humans. Chemical concentrations that are assumed to be protective of wildlife and plants were established based on toxicological data. These protective concentrations are referred to as screening factors. Individual screening factors were developed for each of 62 receptors for 35 chemicals. The screening factors and the reported chemical concentrations in surface impoundments were used to calculate hazard quotients for each chemical and each receptor at each impoundment at each facility. HQs were calculated by dividing the chemical concentration in the impoundment by the receptor's screening factor.

Results by Facility. A total of 108 facilities out of 133 exceeded the ecological risk criterion for at least one receptor. Table C.6-4 shows a summary of the screening results by facility. Forty-six facilities had exceedances at three or more impoundments, 24 facilities had exceedances at two impoundments, and 38 facilities had exceedances at only one impoundment.

Results by Chemical. A total of 34 chemicals exceeded the risk criterion for at least one receptor at one impoundment. Table C.6-5 shows how frequently each chemical had the highest HQ for a particular impoundment. These chemicals are referred to as the "risk drivers" for that impoundment.

Results by Receptor. The screening ecological assessment addressed 62 receptors, including several species of mammals, birds, and amphibians as well as several ecological communities (e.g., the soil community and the sediment community). (See Attachment C-19 for a list of receptor species.) Based on the screening results, 54 receptors exceeded the risk criterion at at least 1 impoundment. One receptor, the Great Basin pocket mouse inhabits a relatively limited geographic area in the northwestern United States; no SI facilities fell within its geographic range, and, therefore, no exceedances occurred for this receptor. Table C.6-6 shows the receptors that exceeded the risk criterion.

The receptors that exceeded the risk criterion include all of the community receptors assessed as well as representative mammals and birds at all level of the food chain. Furthermore, receptors that depend on aquatic systems for food (e.g., mink, river otter, kingfisher, great blue heron) as well as those that depend on terrestrial systems (e.g., terrestrial plants, coyote, white tailed deer, and cerulean warbler) exceeded the risk criterion. HQs greater than 1 also occurred for receptors in all three habitat types—terrestrial, wetland, and aquatic, indicating that potential ecological risks are not restricted to any single type of habitat.

Sensitive Ecosystems. The presence of managed areas was assessed for 133 sites; 21 sites had managed areas within 3 km. Considering only the 108 sites that exceeded the risk criterion (i.e., had at least one HQ greater than 1), 18 facilities are within 3 km of a managed area. Twenty seven of the 108 facilities are within 1 km of wetlands. Three facilities are both

within 3 km of a managed area and within 1 km of a wetland. Table C.6-7 summarizes the proximity to sensitive habitats for facilities with exceedances.

Table C.6-4. Summary of Risk Criterion Exceedances by Facility

Facility	Number of Impoundments		Number of Constituents	
	Lower Concern	Potential Concern	Lower Concern	Potential Concern
1		1	5	2
4		1	6	2
5		1	8	1
7		1	6	2
11		1	1	2
12	1	3	19	6
14	1	1	10	1
18		2	10	1
19		3		3
22	2	2	20	4
28	1	1	3	3
29	6	1	11	1
32		4	14	3
33		1	4	
35	1	2	5	1
36	4	9	6	8
38	1	1	4	1
41	4	10	7	5
44		1	6	1
45		11	11	14
46	2	3	19	8
50		1	13	
57		2	1	1
64		1	1	1
68		7	13	11
71	6	1	3	2
78	1	2	2	1
80		5	7	11
82	1	1	3	1

(continued)

Table C.6-4 (Continued)

Facility	Number of Impoundments		Number of Constituents	
	Lower Concern	Potential Concern	Lower Concern	Potential Concern
84		5	15	11
86	1	3	7	5
96		1	1	2
98		2	14	3
103		6	8	8
104		2	15	2
115	1	2	14	3
116		1	2	1
120		1	2	1
126	1	2	12	4
127	4	6	4	6
133	3	1		2
135		5	3	9
140	1	1	8	
144		1	2	1
156	1	8	2	3
157	1	2	8	1
160		1	16	1
164		3	10	9
172		2	1	2
173	5	3	5	2
176	1	1	5	1
180	8	2	6	6
182	7	3	1	2
2	4		6	2
6	7		3	5
8	2		2	
13	2		2	
21	2		6	

(continued)

Table C.6-4 (Continued)

Facility	Number of Impoundments		Number of Constituents	
	Lower Concern	Potential Concern	Lower Concern	Potential Concern
23	4		7	6
31	2		17	4
40	1		9	
43	1		21	
47	6		12	
48	1		4	
49	1		3	
51	5		1	1
52	1		7	
54	4		1	
55	1		3	
58	3		10	1
63	1		1	
65	2		4	
67	2		6	
70	2		4	2
74	1		1	
81	10		4	
85	2		8	
89	5		3	1
90	1		5	
91	9		11	6
97	1		7	
105	2		5	
107	1		4	
111	2		1	
112	1		2	
118	9		6	11
122	1		2	

(continued)

Table C.6-4 (Continued)

Facility	Number of Impoundments		Number of Constituents	
	Lower Concern	Potential Concern	Lower Concern	Potential Concern
132	1		2	
134	1		1	
137	1		4	
141	1		2	
145	1		3	
148	1		1	
149	1		4	
151	23		7	2
153	1		1	
155	3		11	
159	6		11	5
167	1		1	
170	2		6	1
175	3		17	4
177	2		1	
181	2		5	
183	1		2	
185	9		2	2
186	1		5	
187	15		5	5
193	3		1	

Table C.6-5. Frequency That Constituent Has the Maximum HQ Value Exceeding a Risk Criterion at an Impoundment

Constituent of Concern	Number of Impoundments where Constituent Is Max HQ
Toluene	8
Phenol	20
Bis(2-ethylhexyl) phthalate [dioctyl phthalate]	6
2,3,7,8-TCDD [2,3,7,8-Tetrachlorodibenzo-p-dioxin]	18
Chromium VI [hexavalent chromium]	1
Benzo(a)pyrene	9
Dibenz[a,h]anthracene	27
Chloroform [trichloromethane]	6
Benzene	3
Methoxychlor	1
Lead	107
Mercury	10
Nickel	18
Silver	3
Thallium	3
Arsenic	49
Barium	37
Beryllium	6
Cadmium	2
Vanadium	4
Zinc	35
Carbon disulfide	8
Selenium	5
Pentachlorophenol [PCP]	1

Table C.6-6. Receptors with HQ >1

Trophic Level	Species Common Name	Number of Exceedances
Communities	Aquatic Community	1306
Communities	Sediment Community	1481
Communities	Soil Community	732
Producers	Aquatic Plants	565
Producers	Terrestrial Plants	299
T1	Beaver	799
T1	Black-Tailed Jackrabbit	97
T1	Canada Goose	614
T1	Eastern Cottontail	489
T1	Meadow Vole	280
T1	Mule Deer	49
T1	Muskrat	694
T1	Pine Vole	340
T1	Prairie Vole	142
T1	White-tailed Deer	605
T2	American Kestrel	779
T2	American Robin	797
T2	American Woodcock	788
T2	Belted Kingfisher	869
T2	Bullfrog	366
T2	Burrowing Owl	229
T2	Cerulean Warbler	354
T2	Deer Mouse	280
T2	Eastern Newt	519
T2	Flatwoods Salamander	197
T2	Gopher Frog	192
T2	Great Blue Heron	791
T2	Green Frog	445
T2	Green Heron	872
T2	Herring Gull	934
T2	Least Weasel	71
T2	Lesser Scaup	742
T2	Little Brown Bat	554
T2	Loggerhead Shrike	721
T2	Long-Tailed Weasel	554

(continued)

Table C.6-1. (Continued)

Trophic Level	Species Common Name	Number of Exceedances
T2	Mallard Duck	975
T2	Marsh Wren	602
T2	Mink	992
T2	Northern Bobwhite	616
T2	Raccoon	1057
T2	River Otter	847
T2	Short-Tailed Shrew	399
T2	Short-Tailed Weasel	69
T2	Spotted Sandpiper	1104
T2	Tree Swallow	944
T2	Western Meadowlark	245
T3	Bald Eagle	896
T3	Black Bear	616
T3	Cooper's Hawk	578
T3	Coyote	717
T3	Kit Fox	51
T3	Osprey	536
T3	Red Fox	635
T3	Red-Tailed Hawk	614

Table C.6-7. Facilities That Have Exceedances and Are Near Sensitive Habitats

Facility	Wetlands Within 1 km	Managed Area Within 3 km	Wetland Within 1 km and Managed Area Within 3 km
1	No	No	No
2	No	No	No
4	Yes	No	No
5	No	Yes	No
6	No	No	No
7	No	No	No
8	Yes	No	No
11	No	No	No
12	No	No	No
13	No	No	No
14	No	No	No
18	No	No	No
19	No	No	No
21	Yes	No	No
22	No	No	No
23	No	No	No
28	No	No	No
29	No	No	No
31	Yes	No	No
32	No	No	No
33	No	No	No
35	No	No	No
36	No	Yes	No
38	Yes	No	No
40	No	Yes	No
41	No	No	No
43	No	No	No
44	Yes	No	No
45	Yes	No	No
46	Yes	No	No

(continued)

Table C.6-7. (Continued)

Facility	Wetlands Within 1 km	Managed Area Within 3 km	Wetland Within 1 km and Managed Area Within 3 km
47	No	Yes	No
48	No	Yes	No
49	Yes	No	No
50	No	No	No
51	Yes	Yes	Yes
52	No	No	No
54	No	No	No
55	No	No	No
57	No	No	No
58	No	No	No
63	No	No	No
64	No	No	No
65	No	Yes	No
67	No	No	No
68	No	No	No
70	No	No	No
71	No	No	No
74	No	Yes	No
78	No	No	No
80	No	No	No
81	Yes	No	No
82	No	No	No
84	Yes	No	No
85	No	Yes	No
86	No	No	No
89	No	No	No
90	No	No	No
91	No	No	No
96	No	No	No

(continued)

Table C.6-7. (Continued)

Facility	Wetlands Within 1 km	Managed Area Within 3 km	Wetland Within 1 km and Managed Area Within 3 km
97	No	Yes	No
98	No	Yes	No
103	Yes	No	No
104	Yes	No	No
105	Yes	No	No
107	Yes	No	No
111	No	No	No
112	No	No	No
115	No	No	No
116	No	No	No
118	Yes	No	No
120	No	No	No
122	No	No	No
126	Yes	Yes	Yes
127	No	No	No
132	No	No	No
133	No	No	No
134	Yes	No	No
135	No	Yes	No
137	No	Yes	No
140	No	No	No
141	No	Yes	No
144	No	No	No
145	No	No	No
148	No	No	No
149	Yes	No	No
151	Yes	No	No
153	No	No	No
155	Yes	No	No

(continued)

Table C.6-7. (Continued)

Facility	Wetlands Within 1 km	Managed Area Within 3 km	Wetland Within 1 km and Managed Area Within 3 km
156	Yes	No	No
157	No	No	No
159	No	Yes	No
160	Yes	No	No
164	No	No	No
167	No	No	No
170	No	No	No
172	No	No	No
173	No	No	No
175	No	No	No
176	Yes	Yes	Yes
177	No	No	No
180	No	No	No
181	No	No	No
182	Yes	No	No
183	No	Yes	No
185	No	No	No
186	No	No	No
187	No	No	No
193	Yes	No	no

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