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Re-evaluation of the Final Remediation Goals for Mercury at the CFA-04 (CFA-674 Pond)

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ABSTRACT

This study presents the re-evaluation of the remedial action goal for the Central Facility Area (CFA)-04 cleanup of mercury-contaminated soils. It was determined that a re-evaluation of the final remediation goal (FRG) for mercury was appropriate for both human and ecological receptors based on new toxicity and fate and transport information availability from the Environmental Protection Agency (EPA). Based on EPA information, more realistic modeling for ecological receptors was also available. Since the possibility of methylation of Hg is of concern, due to its much greater toxicity and mobility in the environment, a percentage of Hg in the CFA-674 pond was considered to be meHg. Lacking analytical data for meHg at CFA-04, the Bailey and Gray's paper on the *Mercury in the Terrestrial Environment, Kuskokwin Mountains Region, Southwestern Alaska* was used as the basis to assume a percentage of meHg to total Hg which is used to calculate an acceptable remediation goal for cleanup of the CFA-674 pond.

Based on this re-evaluation of both the human health risk and ecological risk assessments, a new FRG for Hg of 8.4 mg/kg is being proposed. Using the updated approach and values, the re-evaluation indicates that the amount of contamination requiring cleanup can be reduced while maintaining the same level of risk reduction to both human and ecological receptors.

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ACRONYMS

ABS	absorbed through skin
ANL-W	Argonne National Laboratory – West
AUF	area use factor
Ba	biotransfer factor
BAAP	Badger Army Ammunition Plant
CEL	Chemical Engineering Laboratory
CFA	Central Facilities Area
COPC	contaminants of potential concern
DD	daily dose
DOE	Department of Energy
DOE-ID	Department of Energy, Idaho Operations Office
EPA	Environmental Protection Agency
ERA	ecological risk assessment
F	Fahrenheit
FRG	final remediation goal
GI	gastrointestinal absorption efficiency factor
Hg	mercury
HI	hazard index
HQ	hazard quotient
INEEL	Idaho National Engineering and Environmental Laboratory
meHg	methyl mercury
NOEC	no observed effects concentration
OM	organic matter
OU	operable unit
PRG	preliminary remediation goal

RfD	reference dose
RI/FS	remedial investigation/feasibility study
ROD	record of decision
UCL	upper confidence limit
UTL	upper tolerance limit

Re-evaluation of the Final Remediation Goals for Mercury at the CFA-04 (CFA-674 pond)

1. INTRODUCTION

This study presents the re-evaluation of the remedial action goal for the Central Facility Area (CFA)-04 cleanup of mercury-contaminated soils. After new information recently became available from Environmental Protection Agency (EPA) sources, it was determined that a re-evaluation of the final remediation goal (FRG) for mercury (Hg) was appropriate for both human and ecological receptors. For human health, new toxicity and fate and transport information recently became available (EPA 2001, 1997a). For ecological receptors, more accurate modeling as well as additional toxicity, fate, and transport information has become available (EPA 1997b, 1999). Based on the new information available for both human and ecological receptors, a more consistent and less conservative approach to developing a FRG for Hg (assuming a percentage of the total Hg detected has been methylated to methyl mercury [meHg]) could be implemented. The rationale for the assumed percentage of methyl mercury to mercury in the soil for the re-evaluation is discussed in Section 2.

From the re-evaluation of both the human health risk and ecological risk assessments, a new FRG for Hg of 8.4 mg/kg is being proposed. Based on this new FRG, the amount of contamination requiring cleanup can be reduced while obtaining the same risk targets for both human and ecological receptors. The results of the ecological preliminary remediation goal development are presented in Section 3. The results of the human health evaluation are presented in Section 4.

2. DETERMINATION OF INORGANIC TO ORGANIC MERCURY

Limited information is available on the methylation of inorganic Hg to meHg in the terrestrial soil environment (see discussion in Appendix A). Bailey and Gray's paper on the Mercury in the Terrestrial Environment, Kuskokwin Mountains Region, Southwestern Alaska is one of the few published studies. Although the data is limited, the results can be used to calculate a percentage of methylation in soil. Table 1 presents the results of this calculation and indicates that in the Kuskokwin Mountain Region, the percentage of methylation can range from 0.0003% to 0.56%. Information found in Appendix A indicates the methylation in soil is highly complex and dependent on soil conditions such as pH and organic matter (OM) concentration. The soil characteristics for pH and OM at the INEEL (Table 2) superficially appear within the range of those collected in the Kuskokwin Mountains (Table 1). Lacking analytical data for meHg at CFA-04, the Baily and Gray study was used as the basis to assume a percentage of meHg to total Hg which is used to calculate an acceptable remediation goal for cleanup of the CFA-674 pond. Based upon this re-evaluation for ecological risk, the new FRG at the CFA-674 pond is 8.4 mg/kg. Sampling is planned during the summer of 2002 to verify the appropriate percentage of methylation to use in the analysis. The CFA 04 remediation goal will be re-calculated based upon the sample analysis results and presented to the agencies for approval.

Table 1. Analysis of methyl mercury to total mercury from Bailey and Gray (1997).

Sample Number	meHg (ppm)	Total (ppm)	% of meHg to Total Hg	Disturbance	pH	OM (pct)
1	0.00273	300	0.0009%	Mined	6.4	0.98
2	0.00419	1200	0.0003%	Mined	6.8	1.59
33	0.00821	5.3	0.1549%	Unmined	4.4	6.4
53	0.133	1,500	0.0089%	Mined	6.4	0.61

Table 1. (Continued).

Sample Number	meHg (ppm)	Total (ppm)	% of meHg to Total Hg	Disturbance	pH	OM (pct)
42	0.00503	108	0.0047%	Unmined	7.6	0.68
39	0.000884	0.39	0.2267%	Background	4.3	6.98
60	0.000902	0.16	0.5638%	Background	5	1.1
Total	0.154946	3113.85	0.0050%	Average		

Table 2. Soil characteristics ranges from CFA alluvial soils (Martin et. al. 1992).

pH	OM (%)
7.22 to 8.33	0.13 to 1.87

3. ECOLOGICAL RISK ASSESSMENT

Since an established ecological remediation goal is not available, one approach to developing a remediation goal is to back calculate the number assuming an acceptable hazard quotient (HQ) or hazard index (HI) using calculations presented in Appendix B. Appendix B presents the revised modeling based on new information obtained from EPA (1999) which was used for these calculations. Based on the waste stream at the CFA-674 pond (see discussion in Appendix A), it was decided that mercuric chloride could be used to develop an ecological remediation goal for Hg at the pond. However, the possibility of methylation of Hg is of concern due to its much greater toxicity and mobility in the environment. Therefore, to ensure protectiveness, a percentage of the Hg in the CFA-674 pond was considered to be meHg.

3.1 Analysis of Remediation Goals for Ecological Receptors

Table 3 presents the sets of HIs based upon the concentration of Hg as mercuric chloride ($HgCl_2$) and a percentage of the Hg as meHg, using more realistic modeling developed after EPA (1993, 1999). The Hg remediation goal for ecological receptors of 8.4 mg/kg was obtained by back calculating risk iteratively until the HIs were less than 10.0. Receptors were solely terrestrial and represented different trophic levels (Table 3). First, the HQs and HIs based on the 95% UCL for mercury concentration at the site were assessed. Two sets of HIs were calculated using a concentration of 74 mg/kg Hg and assuming a concentration of 0.5% and 0.005% mgHg. Using the new modeling and toxicity data, the HIs range from less than 1 to 2.0 for plants. Two sets of HIs were calculated using a concentration of 8.4 mg/kg Hg with 0.5% and 0.005% meHg.

As is shown in Table 3, when using a Hg concentration of 8.4 mg/kg the HQs are all under 10, with the exception of plants (24). When the more conservative 0.5% meHg (concentration of 0.042 mg/kg meHg) of 8.4 mg/kg is calculated, the HQs range from 0.076 for the Bald Eagle to 9.7 for the deer mouse. When the HQs for Hg and meHg are summed, the meHg at 0.042 mg/kg contributes significantly to the total HIs. However, even assuming this conservative percentage of meHg, all HIs, except for plants and one deer mouse scenario, are below 10. When the less conservative, average 0.005% meHg (0.00042 mg/kg meHg) is assumed, lower HQs are produced. The mercuric chloride risk to plants (HI=24) and soil fauna (HI=3.4) are the sole contributors to HIs over 1.0. The rest of the HQs and HIs are below the levels of concern.

Table 3. Maximum HIs and HQs for Terrestrial Receptors from Hg plus percentage of meHg.

		Hg at 74 mg/kg and meHg at 0.37 mg/kg (0.5%)			Hg at 74 mg/kg and meHg at 0.0037 mg/kg (0.005%)			Hg at 8.4 mg/kg and meHg at 0.042 mg/kg (0.5%)			Hg at 8.4 mg/kg and meHg at 0.00042 mg/kg (0.005%)		
		Total (HI)	Hg (HQ)	meHg (HQ)	Total (HI)	Hg (HQ)	meHg (HQ)	Total (HI)	Hg (HQ)	meHg (HQ)	Total (HI)	Hg (HQ)	meHg (HQ)
Terrestrial plant		**2.1E+02**	**2.1E+02**	**No TRV**	**2.1E+02**	**2.1E+02**	**No TRV**	**2.4E+01**	**2.4E+01**	**No TRV**	**2.4E+01**	**2.4E+01**	**No TRV**
Soil Fauna		**3.0E+01**	**3.0E+01**	1.5E-01	**3.0E+01**	**3.0E+01**	1.48E-03	**3.4E+00**	**3.4E+00**	1.7E-02	**3.4E+00**	**3.4E+00**	1.7E-04
Mule Deer	MD:TP	1.4E-01	9.6E-02	4.7E-02	9.6E-02	9.6E-02	4.66E-04	1.6E-02	1.1E-02	5.3E-03	1.1E-02	1.1E-02	5.3E-05
Mourning Dove	MDV:TP	**2.3E+00**	4.9E-01	**1.8E+00**	5.1E-01	4.9E-01	1.78E-02	2.6E-01	5.6E-02	2.0E-01	5.8E-02	5.6E-02	2.0E-03
Sage Grouse	SG:SI	**8.3E+01**	2.7E-01	**8.3E+01**	**1.1E+00**	2.7E-01	8.31E-01	**9.5E+00**	3.0E-02	**9.4E+00**	1.2E-01	3.0E-02	9.4E-02
Big Eared Bat	BEB:SI	**5.8E+01**	**1.8E+00**	**5.6E+01**	**2.4E+00**	**1.8E+00**	5.57E-01	**6.5E+00**	2.0E-01	**6.3E+00**	2.7E-01	2.0E-01	6.3E-02
Deer Mouse	DM:SI,Ctp	**4.5E+01**	**1.6E+00**	**4.3E+01**	**2.0E+00**	**1.6E+00**	4.29E-01	**5.1E+00**	1.8E-01	**4.9E+00**	2.3E-01	1.8E-01	4.9E-02
Deer Mouse	DM:SI	**8.8E+01**	**2.7E+00**	**8.6E+01**	**3.6E+00**	**2.7E+00**	8.57E-01	**1.0E+01**	3.1E-01	**9.7E+00**	4.0E-01	3.1E-01	9.7E-02
Deer Mouse	DM:TP	6.2E-01	4.3E-01	1.9E-01	4.3E-01	4.3E-01	1.88E-03	7.0E-02	4.9E-02	2.1E-02	4.9E-02	4.9E-02	2.1E-04
Bald Eagle	BE:MDV, DM, SG	**3.2E+01**	8.5E-02	**3.2E+01**	4.0E-01	8.5E-02	3.15E-01	**3.6E+00**	9.6E-03	**3.6E+00**	4.5E-02	9.6E-03	3.6E-02
Bald Eagle	BE:MDV	9.3E-02	2.6E-02	6.6E-02	2.7E-02	2.6E-02	6.65E-04	1.1E-02	3.0E-03	7.5E-03	3.1E-03	3.0E-03	7.5E-05
Bald Eagle	BE: DM	**3.2E+01**	8.4E-02	**3.2E+01**	4.0E-01	8.4E-02	3.15E-01	**3.6E+00**	9.6E-03	**3.6E+00**	4.5E-02	9.6E-03	3.6E-02
Bald Eagle	BE: SG	**6.3E+01**	1.4E-01	**6.3E+01**	7.7E-01	1.4E-01	6.30E-01	**7.2E+00**	1.6E-02	**7.2E+00**	8.8E-02	1.6E-02	7.2E-02
Red-tailed Hawk	RTH:MDV, DM, SG	**4.2E+01**	1.1E-01	**4.2E+01**	5.3E-01	1.1E-01	4.19E-01	**4.8E+00**	1.3E-02	**4.8E+00**	6.0E-02	1.3E-02	4.8E-02
Red-tailed Hawk	RTH:MDV	1.2E-01	3.5E-02	8.8E-02	3.6E-02	3.5E-02	8.83E-04	1.4E-02	4.0E-03	1.0E-02	4.1E-03	4.0E-03	1.0E-04
Red-tailed Hawk	RTH: DM	**4.2E+01**	1.1E-01	**4.2E+01**	5.3E-01	1.1E-01	4.19E-01	**4.8E+00**	1.3E-02	**4.8E+00**	6.0E-02	1.3E-02	4.8E-02
Red-tailed Hawk	RTH: SG	**8.4E+01**	1.9E-01	**8.4E+01**	**1.0E+00**	1.9E-01	8.38E-01	**9.5E+00**	2.2E-02	**9.5E+00**	1.2E-01	2.2E-02	9.5E-02
Coyote	COY:MD, DM	**6.7E+00**	3.6E-01	**6.4E+00**	4.3E-01	3.6E-01	6.37E-02	7.6E-01	4.1E-02	7.2E-01	4.8E-02	4.1E-02	7.2E-03
Coyote	COY:MD	2.1E-01	1.8E-01	2.7E-02	1.8E-01	1.8E-01	2.74E-04	2.3E-02	2.0E-02	3.1E-03	2.0E-02	2.0E-02	3.1E-05
Coyote	COY:DM	**1.3E+01**	5.5E-01	**1.3E+01**	6.8E-01	5.5E-01	1.27E-01	**1.5E+00**	6.2E-02	**1.4E+00**	7.7E-02	6.2E-02	1.4E-02

Although the HIs for toxicity to plants is over the target value of 10 this is considered acceptable at this site. First, there is uncertainty related to the toxicity value. The toxicity value for plants is developed from one study by Panda et al. (1992). Panda et al. (1992) evaluated the phytotoxicity of mercury from the solid waste deposits of a chloralkali plant. After exposure of barley to mercury waste for 7 days, seedling height was reduced by 19% at 64 ppm mercury in soil. Germination of barley was reduced by 20% at 103 ppm. The no observed effects concentration (NOEC) was 34.9 ppm. The NOEC was reduced to 0.349 mg/kg for evaluation of toxicity in the assessment process based on the uncertainty. Additionally, the site is less than 3 acres in size. With a site this size, it was considered appropriate to accept this limited risk to plants.

4. HUMAN HEALTH RISK ASSESSMENT

Based upon new toxicity and fate and transport data shown in Table 4, the human health remediation goal for Hg at the CFA-674 Pond (CFA-04) was re-evaluated. The re-evaluation updated meHg values for: toxicity (RfD), soil to water partitioning coefficient (Kd) and plant uptake factors; and for inorganic Hg: a new solubility limit, Kd, and plant uptake factor. Table 4 documents these changes and presents the source of this new information (primarily the *Mercury Study Report to Congress*, Volume III: Fate and Transport of Mercury in the Environment (EPA 1997a). Based upon this re-evaluation for human health risk the new remediation goal for human health is 9.5 mg/kg.

Table 4. Comparison of Hg values for modeling of human health risk.

	Previous Hg Values	Updated Hg Values	Updated meHg Values
Fate and Transport			
Soil-water partition coefficient Kd (mL/g)	1.00E+02 [a]	1.00E+03 [b,c]	7.00E+03 [b,c]
Solubility limit (mg/L)	1.00E+06 [a]	5.6E-02 [b,c]	1.00E+06 [a]
Plant uptake factors (PUFs)	9.0 E-01[d]	1.0E-01[b,c]	2.0E-01[b,c]
Toxicity (mg/kg-day)			
Oral RfD	3.00E-04[e]	3.00E-04[f]	1.00E-04[f]
Inhalation RfD	8.57E-05[e]	8.57E-05[f]	NA
Dermal RfD[a]	3.00E-04[e]	2.10E-05[f]	9.00E-05[f]

a. Conservative default values from the Track 2 Guidance (DOE-ID 1994).

b. Conservatively assumed the Kd for Hg was for Hg^0 (EPA 1997a).

c. EPA, 1998.

d. Burns, 1996.

e. DOE-ID, 2000.

f. EPA, 2001

4.1 Analysis of Remediation Goal for Human Health

The following approach was used for this re-assessment.

First, the assessment in the Operable Unit (OU) 4-13 Comprehensive Remedial Investigation/Feasibility Study (RI/FS) (DOE-ID 2000) was recreated. The input exposure point concentrations, masses, input parameters and assumptions from the OU 4-13 Comprehensive RI/FS (DOE-ID 2000) were compiled and are presented in Appendix A. The future resident scenario was then recalculated. The results of this assessment are presented in Table 5. Using the 95% upper confidence limit (UCL) value for Hg (74 mg/kg) a HQ of 43 is calculated. The primary risk path is through ingestion of homegrown produce. This result closely replicated the result of the assessment in the OU 4-13 Comprehensive RI/FS (DOE-ID 2000) where the HQ was 40 (also primarily through ingestion of homegrown produce). The previous FRG of 1.26 mg/kg for human health was also evaluated resulting in a HQ of 0.74 (Table 5).

Second, the new input data was used to recalculate the risk for inorganic Hg using the 95% UCL value for Hg (74 mg/kg). The re-assessment resulted in a reduction in the calculated risk from a HQ of 43 to a HQ of 7.56. As before, the primary contribution to the total HQ was from ingestion of homegrown produce.

Third, a new remediation goal for human receptors based on the future residential scenario was developed using the new input parameters. A percentage of the inorganic Hg at the CFA-04 pond was assumed to have been methylated to meHg, due to environmental processes. Similar to the approach used during the development of the ecological remediation goal (see Section 2), both a 0.5 % and a 0.005 % methylation of inorganic Hg were assumed. As discussed in Section 2, 0.5% is considered conservative and 0.005% more realistic. As shown in Table 5, two sets of hazard indices (HIs) were calculated using a concentration of 9.5 mg/kg Hg with 0.5% and 0.005% meHg respectively. The Hg remediation goal concentration of 9.5 mg/kg was obtained by back calculating risk iteratively until a HI of less than 1.0 was obtained. As shown in Table 5, the HIs for both assumed meHg concentrations are 1.0 or under. The driving risk is from the inorganic Hg to the homegrown produce pathway. The meHg does not contribute significantly to the total risk for the human receptor. Sampling is planned for the summer of 2002 to determine the appropriate site-specific percent methylation to use in these analyses.

4.2 Discussion

The new toxicity values for human health do not have a major effect on the assessment but do allow the more realistic assessment of both inorganic and organic Hg. In the OU 4-13 baseline risk assessment, inorganic Hg and meHg were not differentiated and generally the most conservative number available was used in the assessment. In this assessment a proportion of meHg to Hg is considered and assessed separately. This approach uses the higher solubility limit and Kd values for Hg (EPA 1997a) in the groundwater modeling. It also allows the calculation of a meHg concentration in the groundwater. Using the new higher solubility limit and Kd values noted above reduced the amount of Hg that was modeled as migrating to the groundwater, however, the increased solubility limit results in more Hg remaining in the soil and subsequently available through the homegrown produce pathway.

As shown in Table 4, the plant uptake factor taken from the EPA (1997a) is significantly less than the default value taken from Burns (1996). This new uptake value has a major effect on the homegrown produce pathway (the significant risk contributor) and allows for the development of a more realistic FRG. Based on this assessment, the FRG of 9.5 mg/kg would be protective of human receptors under the future residential scenario.

Table 5. Human health HQ assessment of CFA-04 remediation goals (shading indicated HQ or HI above acceptable levels)[a].

CoPC	Concentration (mg/kg)	Ingestion of Soil	Ingestion of Groundwater	Ingestion of Homegrown Produce	Inhalation of Fugitive Dust	Inhalation of Volatiles from Soil	Inhalation of Volatiles from Groundwater	Dermal Absorption of Soil	Dermal Absorption of Groundwater	HI
Reassessment of Original Input Parameters (just HG)										
Hg	74 (95% UCL from DOE-ID 2000)	9.3E-01	9.9E-01	4.1E+01	3.2E-03	0.0E+00	0.0E+00	2.0E-02	1.2E-04	4.3E+01
Hg	1.26 (FRG from DOE-ID 2000)	1.6E-02	1.3E-02	7.1E-01	5.4E-05	0.0E+00	0.0E+00	3.4E-04	1.6E-06	7.4E-01
Risk Assessment with Input Parameters (just Hg)										
Hg	74 (95% UCL from DOE-ID 2000)	9.4E-01	6.6E-02	6.5E+00	3.2E-03	0.0E+00	0.0E+00	2.0E-02	8.2E-06	7.6E+00
Assessment of Final Remediation Goal										
Assuming 0.5% meHg										
meHg	0.0475 (calculated %)	1.8E-03	2.1E-05	2.6E-02	NTD	0.0E+00	0.0E+00	7.7E-04	5.1E-08	
Hg	9.5 (remediation goal)	1.2E-01	9.6E-03	8.4E-01	4.1E-04	0.0E+00	0.0E+00	3.6E-03	1.7E-06	
Total		1.2E-01	9.61E-03	8.6E-01	4.1E-04	0.0E+00	0.0E+00	4.4E-03	1.8E-06	1.0E+00
Assuming 0.005% meHg										
meHg	0.000475 (calculated %)	1.8E-05	2.1E-07	2.6E-04	NTD	0.0E+00	0.0E+00	7.7E-06	5.1E-10	
Hg	9.5 (remediation goal)	1.2E-01	9.6E-03	8.4E-01	4.1E-04	0.0E+00	0.0E+00	3.6E-03	1.7E-06	
Total		1.2E-01	9.6E-03	8.4E-01	4.1E-04	0.0E+00	0.0E+00	3.6E-03	1.7E-06	9.7E-01

a. The GWSCREEN groundwater transport model was used in this assessment to determine the concentration of contamination in the groundwater. GW screen requires a mass of contamination for assessment. This calculation is based on an evaluation of the amount of contaminated soil (by volume) to the concentration in the soil. Masses for the groundwater calculations were back calculated from that value presented in the OU 4-13 Comprehensive RI/FS (DOE-ID 2000) as discussed in Appendix A.

5. COMPARISON TO OTHER REMEDIATION GOALS

In order to evaluate the types of remediation goals for mercury that have been used at other sites, the web was searched. The results of this investigation yielded the remediation goals presented in Appendix A and summarized in Table 6. Of particular interest was the work done by the Washington State Department of Ecology in developing cleanup levels for ecological receptors for both Hg and meHg.

From this evaluation it appears that remediation (and or screening goals) can differ greatly from site-to-site and it would be difficult to generalize based on this limited snapshot of remediation goals. However, it appears that those sites with higher rainfall and the potential of aquatic receptors have lower cleanup goals than sites in drier climates where it appears that primarily terrestrial receptors have been evaluated. The exception is the Argonne National Laboratory (ANL) where the cleanup included an evaluation of phytoremediation.

Table 6. Evaluation of remediation goals for inorganic Hg (based on ecological receptors) at other sites.

Location	Remediation Goal (mg/kg)	Site Information	Comments
ANL-W – ANL-01, ANL-01A and ANL-04 (1998)	0.74	INEEL, 8.5 inches of rainfall/year (no aquatic issues)	Developed from the ANL-W background. As per Agency agreement to use 10 times background for screening and cleanup.
SNL/NM Classified Waste Landfill (2000)	9.96	8 inches of rainfall/year (no aquatic issues)	This number was divided by the number of COCs (10) to determine the PRG level that was suggested.
Marine Corps Recruit Depot, Parris Island (2000)	0.11	47.9 inches of rainfall/year (aquatic issues are of concern)	The highest detection was 0.43 and this area is near a water source. Based on facility background. Causeway through a salt marsh and this area was capped and mercury left in place. Interim remedy only.
Former BP Casper Refinery, South Properties Area (2001)	41.64	12.1 inches of rainfall/year (no aquatic component)	For deer mouse. Other receptors had significantly higher screening levels.
Tourtelot Remediation (former Benicia Arsenal), Benicia, CA (2001)	0.77	19.6 inches of rainfall/year, area within 100 ft of a designated wetland	For demolition site # 3.
Remedial Goals for Badger Army Ammunition Plant (1998)	0.38	31.2 inches of rainfall/year. Although this is not an aquatic site, groundwater contamination is the major issue.	0.38 was not the final remediation goal. This goal is currently under evaluation. It was developed for surface soil media based on background concentration since the ecological risk concentration calculated was below background.
Washington State Department of Ecology Toxics Cleanup Program (2002)	9	Varies across state	Washington State Department of Ecology has proposed this cleanup level if a site qualifies for a simplified evaluation (http://www.ecy.wa.gov/programs/tcp/policies/terrestrial/TEEHome.htm#TEE%20Flow%20Diagram). The cleanup level for meHg is 0.7 mg/kg.

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Appendix A

Supporting Discussions

Appendix A

Supporting Discussions

A-1. MERCURY IN THE TERRESTRIAL ENVIRONMENT

Based on present evidence, mercury is not an essential element for living organisms and has no known nutritional function (NAS 1980). Ecological receptors can be exposed to soil either through direct ingestion of contaminated soil or through plant uptake. Plants take up mercury and translocate it throughout the plant. Kabata-Pendias (2001) discusses that the Hg affinity to the sulfhydryl groups is apparently the key reaction in disrupting metabolic processes of plants. It is known that metals such as Hg generally enter plants in ionic form, which could imply either a methylated or chelated state, and that uptake is influenced by soil factors such as pH and cation exchange capacity.

Wren, et al., (1995) discusses that the adsorption of mercury compounds to soils is probably the dominant process that determines its fate in the terrestrial environment. Mercury not adsorbed to soil will eventually be volatilized, precipitated, leached, or taken up by plants. It is commonly known that the adsorption of mercury is highly dependent on its form; the amount and chemical nature of inorganic and organic soil colloids, the soil pH, the soil type, and other soil parameters, and initial Hg concentration in the soil solution as well as the presence other ions (e.g. Cl). Figure A-1 presents a graphic representation of the ionic species and transformations of mercury compounds in soils (from Kabata-Pendias 2001). The presence of an excess of Cl- ions in soils appears to decrease the sorption of Hg+ onto both mineral particles and organic matter, because the highly stable Hg-Cl complexes are rather poorly sorbed.

The mechanism of the methylation of mercury (transformation of Hg^{+2} to CH_3Hg^+) in soils is still not well understood (Kabata-Pendias 2001). Methylation may occur abiotically, however, a large number of organisms carry out these reactions. It has also been shown that several types of bacteria and yeasts can reduce cationic Hg2+ to elemental Hg (Kabata-Pendias 2001). Therefore it is possible that the methyl Hg to Hg proportions could come to equilibrium in the environment. The literature does not discuss the methylation of mercury in the plant as a major source of methyl mercury and it is not considered a concern.

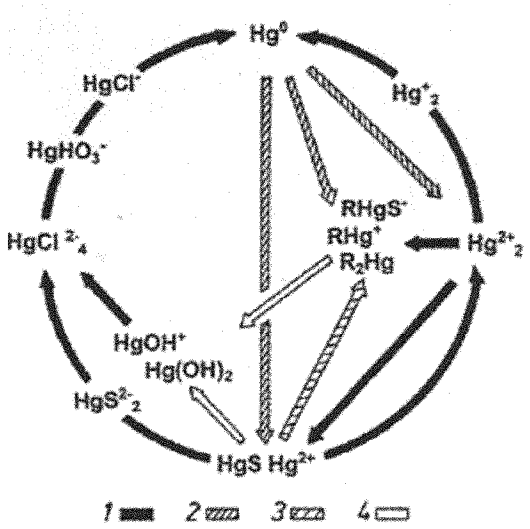

Figure A-1. Ionic species and transformations of mercury compounds in soils. (1) Reduction; (2) oxidation; (3) formation of organic compounds; (4) hydration; R: CH_3, CH_3CH_2, C_8H_5 (Kabata-Pendias 2001).

A-2. CFA-674 WASTE GENERATION PROCESSES

Three waste generation processes were identified as sources of contamination from CFA-674 to the pond. First from approximately 1953 to 1965 mercury-contaminated wastes from the calcine development work in CFA-674 were disposed in the pond. Second, from approximately 1953 to 1969 liquid laboratory effluents from the Chemical Engineering Laboratory (CEL) were disposed to the pond, and lastly bulky waste from construction projects was placed in the pond.

Liquid and solid waste from CEL operations may have included simulated calcine sodium nitrate, nitric acid, tributyl phosphate, uranyl nitrate, a high grade kerosene, aluminum nitrate as well as hydrochloric and chromic acid, di-chromate solutions, terpheyls, heating oil, zirconium, hydrofluoric acid, trichlorethylene and acetone.

The history of this site indicates that high concentrations of mercury were often present in the calcine because it was used as a catalyst in the dissolution of simulated aluminum nuclear fuel cladding. Effluent from scrubbers on the calciners would also have contained mercury, probably in the form of mercuric nitrate. There is limited toxicity information for mercuric nitrate, however, this compound is considered to be very reactive and is not anticipated to remain in this form in the soil at the CFA-674 pond.

A-3. REMEDIATION GOALS AT OTHER SITES

A-3.1 Sandia National Laboratory/New Mexico Landfill

This landfill is located within the boundaries of Kirtland Air Force Base, south of Albuquerque, New Mexico. The Albuquerque area has four distinct seasons, all characterized by sunny days. Humidity averages a comfortable 43%. Temperatures ordinarily average a high of 77 degrees Fahrenheit (F) and a low of 42 degrees F year-round. Annual rainfall averages about eight inches a year.

Limited information is available from the paper presented to the Waste Management Conference (Galloway and Slavin 2000) and very little on the web. The risk assessment for metals was based on an industrial land-use scenario. For ecological receptors there is an assumption of a final 1.5 m (5 ft) of material of clean backfill to ensure compliance with ecorisk (for burrowing animals, activity assumed to be negligible below a depth of 1.5 m [5 ft]). The remediation goal of 9.96 mg/kg was used when mercury was the only contaminant present and was based on burrowing owl exposure.

A-3.2 Former BP Casper Refinery South Properties Area

The 340-acre processing area (Former Refinery) is located west of central Casper just south of the North Platte River. While many people associate it with Casper, most of this property is actually outside the city limits. The city of Casper is located in central Wyoming in the North Platte River Valley. The climate in this area is semi-arid, with an average annual precipitation of 12.1 inches. The wettest months are April, May, and June. The greatest average daily temperature is 71 degrees F and occurs in July, while the lowest average daily temperature is 22 degrees F and occurs in January.

From evaluation of the information on the web, 41.64 mg/kg was used as a screening value at this facility for mercury in soil. This value was based on the deer mouse. Receptors assessed included, the mule deer, deer mouse, red fox, meadow lark and Canada goose. The site doesn't appear to have an aquatic component. Based on this screening criteria, no ecological risk was apparent from mercury contamination, and final remediation goals were not developed.

A-3.3 Benicia, California, Tourtelot Cleanup Project

The Tourtelot Property in Benicia, California, was used by the U.S. Army as the Benicia Arsenal for over 100 years. Benicia, CA, is located inland from San Francisco off the bay. Activities at the site included ordnance storage, issuance, transshipment, as well as artillery testing and the demolition (or demilitarization) of damaged and obsolete munitions. The average annual precipitation is 49.8 cm (19.6 in.).

Ecological risk was the driver. This assessment was based on criteria for terrestrial, aquatic, or sediment-dwelling organisms for screening. This area is within 30.5 m (100 ft) of a designated wetland. Calculated upper tolerance limit (UTL) of the ambient soil concentration was used as the remediation goal for metals.

A-3.4 Argonne National Laboratory

Argonne National Laboratory is located in the southeast section of the Idaho National Engineering and Environmental Laboratory (INEEL), Idaho. The average annual precipitation at the INEEL is 21.5 cm (8.5 in.). The months with the highest precipitation rates are May and June, and the month with the lowest is July. The average summer-daytime maximum temperature of 83 degrees F and an average winter-daytime maximum temperature of 31 degrees F.

A-3.5 Parris Island Marine Corps Recruit Depot

Parris Island is located along the coast in southeast South Carolina. Parris Island Marine Corps Recruit Depot serves as the training site for approximately 20,000 young men and women entering the United States Marine Corps each year. The climate is temperate to semi-tropical with moderate winters and hot summers. Snowfall is rare, but electrical storms are common, particularly in summer months. Average annual rainfall is 122 cm (47.9 in.). The average annual humidity is 75%. The annual average high temperature is 76.5 degrees F, and the annual average low temperature is 57.2 degrees F.

Contamination at two landfill sites was the primary cause for this action. Most of the sites are landfills or spill areas where groundwater and sediment are contaminated with solvents and petroleum/oil/lubricants. The installation has several past disposal sites that are adjacent to salt water marshes. Previous studies have documented contaminant releases from some of those sites. The potential exists for contaminants to affect fish, shrimp, crabs, and mollusks that inhabit the marshes and are harvested by commercial and recreational fishermen. The cleanup level was presented in the proposed plan (2000) and was based on ecological issues. The concentration used as the cleanup goal is representative of background since the calculated ecological remediation goal was lower than background. The ecological receptors evaluated included terrestrial plants, soil invertebrate, shrew, mouse, robin and hawk.

The site of concern is located on a causeway through a salt marsh. As an interim action this area was capped with the mercury left in place. However, this is an interim remedy and the Marine Corps is still working to come to a final remedy and mercury remains a contaminant of concern.

A-3.6 Badger Army Ammunition Plant

Badger Army Ammunition Plant (BAAP) is located in south central Wisconsin, approximately 14.5 km (9 miles) south of Baraboo, Wisconsin. The BAAP facility covers approximately 7,354 acres and

has been in use since the 1940's. This site has an annual precipitation of 79.2 cm (31.2 in.). The annual average high temperature is 55.8 degrees F, and the annual average low temperature is 32.7 degrees F.

The cleanup standard for mercury (0.38 mg/kg) was developed for the propellant burning ground. The contaminated waste area is approximately 3 acres in size and contains three former waste disposal pits and a large open area formerly used for burning propellant-contaminated materials and organic solvents. This site is believed to be the source of the groundwater contamination plume that has moved off the installation. Currently this site is planned for remediation including vapor extraction, soil excavation, wasting and composting. The surface soil media cleanup standards for mercury are based on the background concentration, which is greater than the concentration developed by the ecological risk assessment. There does not appear to be any aquatic site (such as a pond or stream) near the site.

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Appendix B

Human Health and Ecological Evaluation Calculations

Appendix B

Human Health and Ecological Evaluation Calculations

B-1 HUMAN HEALTH EVALUATION CALCULATIONS

B-1.1 Exposure Scenarios, Pathways, and Routes

The human health evaluation used the baseline risk assessment approach documented in the OU 4-13 Comprehensive RI/FS (DOE-ID 2000). This approach is based on the *EPA's Risk Assessment Guidance for Superfund (RAGS)* (EPA 1989), the *INEL Track 2 Guidance Document* (DOE-ID 1994), and the *Guidance Protocol for the Performance of Cumulative Risk Assessments at the INEL* (Burns 1995). The results of the OU 4-13 Comprehensive RI/FS indicated that no contaminants were detected that resulted in an estimated excess cancer risk greater than 1E-04 from any of the scenarios at CFA-04. At this site, the potential exposure route that produced estimated hazard quotients greater than EPA permissible levels was ingestion of mercury in homegrown produce and soil by future residents. Both the current and future worker scenarios had acceptable hazard quotients. Therefore, only mercury and a percentage of mercury that may become methylated were assessed for all pathways previously evaluated in the residential scenario. This included some pathways with limited contributions to risk (e.g., air pathway); however, they were included for completeness.

Additional EPA guidance and direction have been finalized since the development of this approach. This updated information was compared to the initial approach and incorporated as necessary into this new evaluation.

As discussed in Section 6 of the OU 4-13 Comprehensive RI/FS (DOE-ID 2000), once potentially exposed populations have been identified and characterized, exposure pathways can be traced from the site to the exposed populations. Each exposure pathway describes a mechanism by which a population or individual could be exposed to contaminants originating from the release site. In the OU 4-13 baseline risk assessment, the following exposure scenarios, exposure pathways, and exposure routes were all evaluated. In the development of the final remediation goal the residential intrusion scenario was used since the other scenarios did not pose a risk. The residential intrusion exposure scenario considers a future resident that moves to the site in 100 years and lives there for 30 years. As a conservative assumption, future residents are expected to construct 3-m (10 ft) basements beneath their homes. As a result, all contamination detected in the upper 3 m (10 ft) of each release site will be evaluated for surface pathway exposures. Contaminant related pathways and exposure routes were evaluated as indicated below in **bold**:

- Exposure scenarios
  - Current occupational
  - Future occupational
  - **Residential intrusion (used to develop final remediation goals)**
- Exposure pathways
  - **Groundwater**
  - **Air captured**

- Soil exposure routes
  - **Ingestion**
    - **Soil**
    - **Groundwater (residential intrusion scenario only)**
    - **Homegrown produce (residential intrusion scenario only)**
  - **Inhalation**
    - **Fugitive dust**
    - Volatiles from soil (not assessed)
    - Volatiles from indoor groundwater use (residential intrusion scenario only, however not assessed)
  - **Dermal absorption**
    - **Soil**
    - **Groundwater (residential intrusion scenario only).**

Generally, both risk and hazard quotients are calculated for each contaminant if the contaminant is cancer causing and produces other hazardous effects. Risk is determined using slope factors obtained from EPA. However, mercury and methyl mercury do not have slope factors (they are both non-carcinogenic); therefore, only the hazard quotient calculations are discussed in this section. For a more detailed discussion of the EPA standard risk methodology see Section 6 of the OU 4-13 Comprehensive RI/FS (DOE-ID 2000). Also, cumulative risk assessment strategies were not used for the CFA-04 pond.

B-1.2 Methodology

B-1.2.1 Soil Ingestion Methodology

In general, the residential exposure scenario evaluates only adult exposures. The reason for this limitation is that the risk results are calculated using very conservative exposure assumptions. These assumptions would most likely cause the risk calculations to overestimate the actual risks to sensitive subpopulations, such as children. The exception to this rule is associated with the soil ingestion exposure route. Under this exposure route, six years of childhood soil ingestion and 24 years of adult soil ingestion are included in the contamination intake calculation. Soil ingestion is the most critical exposure route for children because of the relatively large amount of soil that children can ingest.

The soil ingestion intake factor equations for the residential scenario is presented below in Equation B-1.

$$\text{Intake Rate residential, soil ingestion} = \frac{C_{soil} * FI * EF_a * CF}{AT} * \left(\frac{IRS_a * ED_{as}}{BW_a} + \frac{IRS_c * ED_{cs}}{BW_c} \right) \qquad \text{(B-1)}$$

where:

C_{soil} = contaminant concentration in soil, contaminant dependent, (mg/kg or pCi/g)

FI = fraction ingested from contaminated source, (assumed = 100 pecent)

EF_a = exposure frequency, adult, (350 days/year)

CF = conversion factor, nonradionuclide (1E-6 kg/mg)

AT = averaging time, noncarcinogenic (30 years * 350 days/year = 10,500 days [EPA 1991, DOE-ID 1994])

$IRS_{a/c}$ = soil ingestion rate, adult (100 mg/day), child (200 mg/day) (EPA 1991, DOE-ID 1994)

$ED_{as/cs}$ = exposure duration, adult soil (24 years), child soil (6 years) (DOE-ID 1994)

$BW_{a/c}$ = body weight, adult (75 kg), child (15 kg) (EPA 1991, DOE-ID 1994).

HQs for soil ingestion exposures are calculated using Equation B-2.

$$HQ = \frac{\text{Intake Rate}}{\text{RfD}} \tag{B-2}$$

where:

HQ = contaminant specific noncarcinogenic hazard quotient (unitless)

RfD = contaminant specific oral reference dose (mg/kg-d).

B-1.2.2 Homegrown Produce Ingestion Methodology

The homegrown produce ingestion exposure route includes an evaluation of contaminant concentrations in plants caused by both root uptake and irrigation with contaminated groundwater. This approach is documented in detail in the *White Paper on the Food Crop Ingestion Exposure Pathway* (Burns 1996) and has been used to evaluate this exposure at the INEEL. The homegrown produce ingestion pathway is evaluated on a site-by-site basis since residents are not likely to be growing produce at more than one site at a time. The total source concentration evaluated in the homegrown produce ingestion exposure route is calculated by combining exposure point concentration with the soil concentration that would result from equilibrium partitioning between soil and groundwater contaminated with the contaminant. To address radionuclides at the INEEL, the average soil concentration of radioactive COPCs in soil when irrigating with groundwater was determined using the integrated form of Equation 5.39 in Nuclear Regulatory Commission (NRC) Guidance Document (NRC 1983) as shown in Equation B-3.

$$C_s(t) = \frac{\frac{\acute{I}_v}{L_i + \lambda}\left(t_e + \frac{e^{-(L_i+\lambda)t_e}}{L_i + \lambda}\right) + \frac{C_{so}}{L_i + \lambda}\left(1 - e^{-(L_i+\lambda)t_e}\right) - \frac{\acute{I}_v}{(L_i + \lambda)^2}}{t_e} \tag{B-3}$$

where:

$C_s(t)$ = the average concentration of a COPC in soil for the exposure period, t_e (ρCi/g)

$\acute{I}_v$ = CPOC input rate from irrigation (ρCi-day/g)

L_i = leach rate constant (day)-1

λ = radioactive decay rate constant (day)-1

t_e = exposure period (10,950 day [30 years * 365 days/year])

C_{so} = average concentration of COPC in the top 3 m (10 ft) of soil at the start of the residential exposure period (pCi/g).

Equation B-4 is comprehensive and applicable to nonradioactive COPCs. For nonradioactive COPCs, the decay rate is set to zero and the equation reduces to the following:

$$C_s(t) = \frac{\frac{\acute{I}_v}{L_i}\left(t_e + \frac{e^{-(L_i t_e)}}{L_i}\right) + \frac{C_{so}}{L_i}\left(1 - e^{-(L_i t_e)}\right) - \frac{\acute{I}_v}{L_i^{\,2}}}{t_e} \qquad \text{(B-4)}$$

where

$C_s(t)$ = the average concentration of a COPC in soil for the exposure period, t_e (mg/kg)

$\acute{I}_v$ = COPC input rate (mg-day/g)

L_i = leach rate constant $(\text{day})^{-1}$

t_e = exposure period (10,950 days [30 years * 365 days/year] [EPA 1991, DOE-ID 1994])

C_{so} = average concentration of COPC in the top 3 m (10 ft) of soil at the start of the residential exposure period (mg/kg).

The COPC input rate from irrigation is given by following Equation B-5:

$$\acute{I}_V = C_W \times \frac{I_R}{\rho \times T} \qquad \text{(B-5)}$$

where:

$\acute{I}_v$ = COPC input rate from irrigation (mg-day/g)

C_w = concentration of a COPC in groundwater (calculated from GWSCREEN, Appendix D) for the exposure period (mg/L)

I_R = irrigation rate (8.47 L/m^2-yr × 90 days/365 yr) (Maheras et al. 1994)

ρ = soil density (1.5E+06 g/m^3 [DOE-ID 1994])

T = thickness of root zone (0.2 m [7 in.]) (International Atomic Energy Agency [IAEA] 1994).

The leach rate constant is given by following Equation B-6 (Baes and Sharp 1983):

$$L_i = \frac{P}{\theta_c\left(1 + \frac{K_d \times \rho}{\theta_c}\right) \times T} \times CF \qquad \text{(B-6)}$$

where:

P	=	net water percolation rate (0.86 m/1 year) (infiltration rate of 0.1 m/1 year, as presented in *INEL Track 2 Guidance* [DOE-ID 1994], plus the contribution from irrigation)
θ_c	=	volumetric water content in source volume (0.41 m^3/m^3) (Rood 1994)
K_d	=	COPC-specific soil-to-water partition coefficient (cm^3/g)
ρ	=	soil density (1.5 g/cm^3 [DOE-ID 1994])
T	=	thickness of root zone (0.2 m) (IAEA 1994)
CF	=	conversion factor (1 year/365 days).

Finally, concentrations of COPCs in affected homegrown produce are calculated using Equation B-7 (EPA 1996):

$$C_p(t) = C_s(t) \times B_v \tag{B-7}$$

where:

$C_p(t)$	=	average concentration of a COPC in homegrown produce from root uptake (mg/kg)
$C_s(t)$	=	average concentration of a COPC in soil for the exposure period (mg/kg)
B_v	=	COPC-specific soil-to-plant uptake coefficient (mass of COPC/dry mass of plant material per mass of COPC/dry mass of soil).

Intake rates from homegrown produce ingestion are calculated using Equation B-8.

$$\text{Intake Rate residential, HGP} = \frac{C_{produce} * IRP * EF_a * ED_a * CF}{AT} \tag{B-8}$$

where:

$C_{produce}$	=	concentration of COPC in homegrown produce
IRP	=	Intake rate produce (2.76E-1 g/kg-day [Burns 1996])
CF	=	conversion factor (nonradionuclides [1E-3 kg/g])

HQs for homegrown produce ingestion exposures are calculated using Equation B-9.

$$HQ = \frac{\text{Intake Rate}}{RfD} \tag{B-9}$$

where:

HQ	=	contaminant specific noncarcinogenic hazard quotient (unitless)
RfD	=	contaminant specific oral reference dose (mg/kg-d).

B-1.2.3 Dermal Exposure Methodology

The approach used to assess dermal exposure was initially taken from EPA's *Assessing Dermal Exposure from Soil* (EPA 1995) and is documented in the OU 4-13 Comprehensive RI/FS (DOE-ID 2000). Recent EPA guidance (Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual [Part E, Supplemental Guidance for Dermal Risk Assessment]), Interim, (September 2001) became available in September 2001. The approach presented in this guidance was

compared to the methodology and input parameters used in the OU 4-13 (DOE-ID 2000) and did not change the overall results. The major differences in the approach would occur primarily with contaminants other than mercury (i.e., organics and some metals). However, the adjustment for the toxicity values for both mercury and methyl mercury are available (Section 4 EPA 2001). These values were used in the assessment.

Risks from dermal absorption of soil are driven by a contaminant's potential for being absorbed through skin. This potential is quantified by a contaminant's dermal absorption factor (i.e., the fraction of a given contaminant that can be absorbed through skin [ABS]). ABS default values were used for both mercury and methyl mercury.

Equation B-10 below shows how dermal absorption intakes were calculated for the dermal absorption exposure route:

$$\text{Dermal absorption, residential} = \frac{C_{soil} \times SA_{as} \times AF_a \times EF \times ED \times ABS \times CF}{BW \times AT} \qquad \text{(B-10)}$$

where:

C_{soil} = average exposure point concentration of COPC in soil (mg/kg)

SA_{as} = skin surface area available for contact, adult (5700 cm^2/event [EPA 2001])

AF_a = soil to skin adherence factor, adult (0.2 mg/cm^2)

ABS = absorption factor (unitless and chemical specific [0.1 was used for both mercury and methyl mercury])

CF = conversion factor (1E–06 kg/mg).

Absorption factors (ABS) are not presented for either methyl mercury or mercury in the latest EPA dermal guidance (EPA 2001). Conservatively, the default ABS (0.1) for semi-volatiles suggested by this guidance was used.

Absorbed dose for the dermal absorption exposure route is similar to contaminant intakes for other exposure routes. However, oral toxicity numbers are more available than the dermal toxicity numbers. Therefore, the HQs are calculated using the reference doses and adjusted with a gastrointestinal absorption efficiency factor (GI). The new guidance (EPA 2001) provides a recommended GI absorption value for those compounds with chemical-specific dermal absorption factors from soil. For mercury salts it is recommended to use the RfD with a 7% adjustment. For methyl mercury it is recommended to use the RfD without adjustment. HQs for dermal absorption exposures are calculated using Equation B-11.

HQs for dermal absorption exposures are calculated using Equation B-11.

$$HQ = \frac{AD}{RfD} * GI \qquad \text{(B-11)}$$

where:

HQ = contaminant specific noncarcinogenic hazard quotient (unitless)

RfD = contaminant specific oral reference dose (mg/kg-d).

Dermal pathway assumptions are included in Section 6 of the OU 4-13 Comprehensive RI/FS (DOE-ID 2000). These were compared to the latest EPA dermal guidance (EPA 2001) and are still applicable.

B-1.2.4 Air Pathway Methodology

The air pathway methodology is presented in detail in DOE-ID (1994). This approach was used in the baseline risk assessment presented in the OU 4-12 RI/FS (DOE-ID 2000). The air pathway, although a minor pathway, is included for completeness. The inhalation of fugitive dust was the only exposure pathway evaluated.

Any site with contamination in the top 3 m (10 ft) of soil is assumed to have a contaminant source that can be released into the air pathway. The concentration of each retained contaminant in the respirable particulate matter above the site will be equal to each contaminant's site-wide average soil concentration. The air pathway receptor will be assumed to spend the entire exposure duration (30 years for future residents) living within the boundaries of the site, with the exception of a two week per year vacation for the residential scenario.

Averaging contaminant concentrations above the site, for the air pathway, produces one contaminant-specific risk estimate for each air pathway exposure route (i.e., for each time period, each air pathway exposure route has the same risk or hazard index (HI) at every retained site).

Equation B-12 shows how the fugitive dust concentration was calculated.

$$C_{air} = CF \times R \times C_{soil} \qquad \text{(B-12)}$$

where:

C_{air} = contaminant concentration in air as fugitive dust (mg/m^3)

CF = conversion from kg to mg

R = airborne respirable particulate matter concentration (0.013 mg/m^3). Value is given in Appendix B of the *INEL Site Environmental Monitoring Reports* (e.g., Hoff et al., 1993), and represents the grand mean from all the sites monitored at the INEEL.

These equations produce conservatively high estimates of airborne COPC concentrations because no credit is taken for dilution of airborne concentrations caused by dust blown from uncontaminated areas of the INEEL.

As with the soil pathway analysis, the air pathway receptor is a hypothetical future resident (who was assumed to be exposed for 30 years).

Intakes of fugitive dust are calculated using Equation B-13 below for residents.

$$\text{Intake residential, fugitive dust} = \frac{C_{air} * IRI * EF_a * ET_a * ED_a}{BW_a * AT} \qquad \text{(B-13)}$$

where:

C_{air} = concentration of contaminant in the air as fugitive dust (mg/m^3 or pCi/m^3)

IRI = inhalation intake rate, (0.83 m^3/hr [DOE-ID 1994]).

Air pathway HQs are calculated at 100 years in the future for the residential scenario. These HQs are calculated from the intakes above by adjusting the intakes with the inhalation RfDs. Air pathway assumptions are included in Section 6 of the OU 4-13 Comprehensive RI/FS (DOE-ID 2000).

HQs for inhalation exposures are calculated using Equation B-14.

$$HQ = \frac{\text{Intake Rate}}{\text{RfD}} \tag{B-14}$$

where:

HQ = contaminant specific noncarcinogenic hazard quotient (unitless)

RfD = contaminant specific inhalation reference dose (mg/kg-d).

B-1.2.5 Groundwater Pathway Methodology

To quantify the hazardous effects to the future residential receptor (there is no occupational receptor for this exposure pathway), modeling of contaminant concentrations in groundwater is required. For the groundwater pathway analysis, every contaminant that is not eliminated by the contaminant screening process is assumed to have the potential for migrating to groundwater, but only manmade sources of contamination are considered in the analysis. The following exposure routes are evaluated as part of the groundwater pathway analysis:

- Ingestion of groundwater
- Dermal absorption of groundwater
- Inhalation of volatiles produced by indoor use of groundwater (not assessed).

The inhalation exposure from showering was the only exposure discussed in the new EPA dermal guidance (EPA 2001) that was not evaluated in this assessment. Generally, the dermal exposure to water is considered negligible to the dermal exposure to the soil and inhalation exposure to showering with contaminated groundwater is considered to be an issue only with volatiles. It is assumed that the volatile forms of mercury, metallic, and Hg+2 do not remain in the soil to transfer to the groundwater and subsequently be available to volatilize for inhalation during showering.

Exposure through the groundwater pathway is calculated at 100 years in the future for use in the 100-year residential exposure scenario. Groundwater concentrations resulting from surface and near surface sources are estimated using the computer code GWSCREEN (Rood 1994). For each COPC, GWSCREEN produces groundwater concentrations versus time as the codes output. From the output, the maximum 30-year average groundwater concentration of each COPC and the 30-year average concentrations at 100 years in the future are calculated. The average concentrations at year 100 are used to calculate groundwater pathway intakes (or dose) for the residential exposure scenario, and the maximum average concentrations are used to calculate maximum expected groundwater intakes.

The total mass of each contaminant, considered in the GWSCREEN modeling, was calculated as discussed and presented in Section 3. Additional information about how GWSCREEN calculates groundwater concentrations is included in the Track 2 Guidance (DOE-ID 1994).

Three input parameters shown in Table B-1 (length of source parallel to flow, width of course perpendicular to flow, and thickness of source) are based on the site dimensions. The length and width values were taken from Track 1 (DOE-ID 1992) and Track 2 (DOE-ID 1994) documents and from previous sampling activities. The thickness of the contaminated area is the maximum depth at which sampling occurred.

Table B-1. Site dimensions of the CFA-04 Pond.

Site Dimensions	Input Parameter (m)
Length of source	150.7
Width of source	45.6
Thickness of source	5.5

Appendix D contains the results of the GWSCREEN runs. The GWSCREEN results are assumed to be conservative estimates of the maximum groundwater concentrations that might occur at any point beneath a retained site or group of sites if geographically in the same area of the INEEL during the residential exposure scenario.

The contaminant concentrations shown in Appendix D are expected to overestimate the true aquifer concentrations that would be produced by infiltration of contaminants. Because of the great complexity of the subsurface beneath the INEEL and limited information about factors that influence flow and transport of contaminants in groundwater, the uncertainty about potential contaminant concentrations, associated with the groundwater pathway exposure routes, is greater than the uncertainty associated with any other exposure pathway assessed. To compensate for this relatively large uncertainty, conservative assumptions are used throughout the groundwater pathway analysis. Some of the conservative assumptions that are used in the GWSCREEN analysis are as follows:

- All infiltration is assumed to occur through contaminated areas of the site.
- GWSCREEN uses a plug flow model for contaminant transport through the unsaturated zone. This model does not take any credit for contaminant dispersion in the unsaturated zone.
- Groundwater flow through fractured basalt in the unsaturated zone is assumed to occur very rapidly in comparison to flow through sedimentary material. This assumption is incorporated into the GWSCREEN modeling by using a depth to the aquifer that is only $1/10^{th}$ of the total unsaturated zone thickness beneath the site. Using this small depth results in a relatively short unsaturated zone travel time in which decomposition can occur.
- All COPC mass contained in surface soils is assumed to contribute to groundwater contamination. For the purposes of the GWSCREEN modeling, no credit is taken for loss of COPC mass caused by mechanisms such as wind erosion, surface water erosion, or contaminant uptake into plants.
- Estimates of COPC mass that may be transported to groundwater are based on upper limit estimates of COPC soil concentrations.

Two other conservative assumptions that are included in the groundwater analysis, but not limited to the GWSCREEN modeling, are as follows:

- The groundwater receptor is assumed to take all drinking water from a well, located at the center of the equivalent rectangle's downgradient edge, for 30 years.

- All contaminants are assumed to be uniformly distributed within the groundwater modeling source volume.

B-1.2.5.1 Dermal Absorption From Groundwater Methodology. Exposures to COPCs through dermal absorption of groundwater are controlled by a given contaminants permeability coefficient of water through skin (K_p^w). According to EPA guidance (EPA 1992a), if the permeability coefficient for a given COPC is less than 0.1 cm/hour, then the dermal absorption from the groundwater exposure route produces hazardous effects that are less harmful than the hazardous effects produced by the groundwater ingestion exposure route for the COPC. In this assessment, the default permeability coefficient for inorganic COPCs of 1E–03 cm/hour was used.

Contaminant intakes for this exposure route are calculated using Equation B-15 shown below.

$$\text{Intake}_{\text{residential, absorption groundwater}} = \frac{C_{water} * SA_{aw} * ETW_a * EF_a * ED_a * DP * CF}{BW_a * AT} \qquad \text{(B-15)}$$

where:

C_{water} = concentration of COPC in groundwater, calculated from the GW Screens (mg/L)

SA_{aw} = Skin surface area available for contact with groundwater, (20,000 cm^2/event) from EPA Region 9 preliminary remediation goal (PRG) tables (EPA 1999a)

ETW_a = exposure time for bathing (0.25 hours per day)

DP = dermal permeability, COPC specific (cm/hr)

CF = conversion factor (1 L/1000 cm^3).

Absorbed dose for the dermal absorption exposure route is similar to contaminant intakes for other exposure routes. However, oral toxicity numbers are more available than the dermal toxicity numbers. Therefore, the HQs are calculated using the reference doses and adjusted with a gastrointestinal absorption efficiency factor (GI). The new guidance (EPA 2001) provides a recommended GI absorption value for those compounds with chemical-specific dermal absorption factors from soil. For mercury salts it is recommended to use the RfD with a 7% adjustment. For methyl mercury it is recommended to use the RfD without adjustment.

HQs for dermal absorption exposures are calculated using Equation B-16 below.

$$HQ = \frac{\text{Intake Rate}}{RfD} \qquad \text{(B-16)}$$

where:

HQ = contaminant specific noncarcinogenic hazard quotient (unitless)

RfD = contaminant specific dermal reference dose (mg/kg-d).

Dermal pathway assumptions are included in Section 6 of the OU 4-13 Comprehensive RI/FS (DOE-ID 2000). These were compared to the latest EPA dermal guidance (EPA 2001) and are still applicable.

B-1.2.5.2 Ingestion of Groundwater Methodology. The groundwater ingestion exposure route is very similar to the soil ingestion exposure route. The equation used to calculate the intake of groundwater is presented in Equation B-17 below.

$$\text{Intake residential, groundwater ingestion} = \frac{C_{water} * IRW_a * EF_a * ED_a * FI}{BW_a * AT} \quad \text{(B-17)}$$

where:

C_{water} = COPC concentration in the groundwater (mg/L or pCi/L)

IRW_a = Intake rate of water, adult (2 L/day).

EF_a = exposure frequency, adult (350 days/year)

ED_a = exposure duration, adult (24 years) (DOE-ID 1994)

FI = fraction ingested from contaminated source (assumed = 100 pecent)

BW_a = body weight, adult (75 kg) (EPA 1991, DOE-ID 1994)

AT = averaging time, noncarcinogenic (30 years * 350 days/year = 10,500 days [EPA 1991, DOE-ID 1994]).

HQs for ingestion of groundwater exposures are calculated using Equation B-18 below.

$$HQ = \frac{\text{Intake Rate}}{RfD} \quad \text{(B-18)}$$

where:

HQ = contaminant specific noncarcinogenic hazard quotient (unitless)

RfD = contaminant specific oral reference dose (mg/kg-d).

To assess the accumulative effects of all exposure pathways of concern, the HQs may be summed across all applicable pathways. For the FRG calculation, HQs were summed from ingestion of soil, groundwater, and homegrown produce, inhalation of fugitive dust, and absorption of soil and groundwater for a total hazard index (HI). HIs can be used as a measure to assess the potential hazardous effects of the contaminants of concern or in this case methyl mercury and mercury.

B-2. ECOLOGICAL RISK CALCULATIONS

The original OU 4-13 Comprehensive RI/FS (DOE-ID 2000) approach to performing screening level ecological risk assessments (ERA) incorporated significant conservatism due to the use of functional grouping (and the associated parameters). This approach was also used to support the development of the final remediation goal (ten times background to protect ecological receptors). The functional grouping approach used at the INEEL was developed for screening to ensure that all possible receptors were protected. The ERA process, as developed by the EPA (1992b, 1997, 1998) and implemented at the INEEL (VanHorn, Hampton, Morris 1995), has evolved. Currently, a more realistic approach is preferred for subsequent assessments. Recent guidance from EPA (1999b) presents a documented approach that is consistent with the previous work at the INEEL and current ERA practices. Several species were selected as receptors to evaluate the pathways presenting the most likely route of exposure from potential contaminants at the CFA-04 pond. Realistic input parameters were input into the exposure equations and toxicity values as documented in EPA (1999b) were used.

B-2.1 Terrestrial Receptors

Species were selected to develop a new final remediation goal for the CPA-04 pond. The deer mouse, mule deer, coyote, Townsend's western big-eared bat, mourning dove, sage grouse, red-tailed hawk, and bald eagle were selected as receptors. These species were selected to be representative of trophic levels and associated functional groups. Although they are not as extensive as the listing for OU 10-04 RI/FS (DOE-ID 2001) they are considered comprehensive for this analysis. Due to the lack of toxicity data for reptiles, reptiles were not evaluated quantitatively. It is presumed that risk estimates for birds and mammals are protective of reptiles.

B-2.1.1 Coyote

The coyote (*Canis latrans*) represents terrestrial carnivores. Although this species is also listed as an omnivore it can be modeled to represent risks to other carnivores that could occur in the area. The coyote controls prey populations. Toxicity values are readily available from the literature for related animals such as domestic dogs and other mammalian species.

B-2.1.2 Deer Mouse

The deer mice (*Peromyscus maniculatus*) represents terrestrial omnivores. Omnivores consume both plant and animal matter. Deer mice are a major component of the food web at the INEEL and are consumed by many larger animals. Risks to deer mice are assumed to be representative of risks to other rodents. Toxicity values are readily available from the literature for related animals such as laboratory rats and mice.

B-2.1.3 Townsend's Big-Eared Bat

This mammal (*Plecotus townsendii*) is an insectivore and a State and Federal species of concern. Risks to this species could represent risks to other bats or insectivorous species. Bats consume large numbers of insects, and so are beneficial to man. Toxicity values for bats can be estimated from those for laboratory rats and mice.

B-2.1.4 Mule Deer

The mule deer (*Odocoileus hemionus*) is representative of large herbivores. Herbivores consume only plant material and are exposed to plant and soil ingestion. Mule deer are considered prey for large carnivores. Toxicity values can be obtained from the literature for mule deer or related mammalian species.

B-2.1.5 Red-Tailed Hawk

The red-tailed hawk (*Buteo jamaicenis*) is a large, carnivorous raptor and can represent other avian carnivores such as eagles, and falcons. This bird has social significance as raptors are of interest to birdwatchers, and they play an ecological role in the control of vertebrate pests. They are susceptible to contaminants that biomagnify within food chains due to their position at the top of the food web. Toxicity values for other avian species can be used to estimate potential adverse effects in this receptor.

B-2.1.6 Bald Eagle

The bald eagle (*Haliaeetus leucocephalus*) is also included in the evaluation of the terrestrial habitats. The bald eagle is federally listed as threatened. As a large raptor that feeds on birds and small mammals (e.g., grouse, mourning doves, and deer mice), the bald eagle represents avian carnivores feeding in terrestrial environments. This bird has social significance as raptors are of interest to birdwatchers, and they play an ecological role in the control of vertebrate pests. They are susceptible to contaminants that biomagnify within food chains due to their position at the top of the terrestrial food web. Toxicity values for other avian species can be used to estimate potential adverse effects to this receptor. Eagles would be expected to have lower soil ingestion fractions than other birds or mammals due to their behavioral habits of roosting in trees and limited contact with the ground. Most of the soil ingested by eagles would be soil within the gastrointestinal tract, or adhering to its prey's surface. For the purpose of calculation, it is assumed that ingestion of solid matter should be similar to that of any other predator consuming pretty of a similar size and type. In the absence of a value for this receptor in Beyer et al. (1994), 1.4% was selected as the soil fraction ingested which represents on-half the soil ingestion fraction (2.8%) for the fox which is in the same feeding guild as this avian species.

B-2.1.7 Sage Grouse

Sage grouse (*Centrocercus urophasianus*) are omnivorous, ground-feeding birds that represent terrestrial avian insectivores. Although the sage grouse adults are primarily herbivorous, the chicks consume large quantities of insects (especially beetles and ants) and then gradually incorporate larger quantities of forbs into their diet. Many other grouse and ground-feeding birds are also omnivorous, however, the sage grouse was modeled exclusively as an insectivore.

B-2.1.8 Mourning Dove

Mourning doves (*Zenaida macroura*) are ground-feeding, herbivorous birds which consume only plant material. They are thus likely to be more highly exposed to contaminants depositing on soils than arboreal-feeding species. They are a game species. Risks to this receptor are considered protective of other herbivorous birds. Toxicity values for various avian species can be used to estimate adverse effects in the mourning dove.

B-2.1.9 Plant Community

The plant community provides food and habitat for animals and humans. Representative receptors in the facility area include big sagebrush and thick-spiked wheatgrass. Toxicity values for some contaminants are available from the literature with which to estimate adverse effects to plants.

B-2.1.10 Soil Community

The soil community is composed of invertebrates such as ants, beetles, and worms, as well as microbes. One Federal species of concern invertebrate, the Idaho dunes tiger beetle (*Cicindela arenicola*), could potentially occur in the assessment area. The soil community provides food for other animals. Detritivores break down dead animal and plant matter, which enrich soils and make them more productive. Toxicity values for soil community receptors are available for some constituents.

B-2.2 Complete Exposure Pathways

A complete exposure pathway is the process by which a receptor is exposed to contaminants in the environment. A complete exposure pathway consists of the following items:

- A source of contamination,
- A receptor,
- A mechanism of release and often of transport of the contamination from the source,
- An exposure point (i.e., point of contact) between the receptor and the contaminants, and
- A route of exposure by which the contaminant acts with the target organ to produce toxicity.

If the exposure pathway is incomplete, (i.e., one of the components is lacking) the receptor is not exposed to the contamination, and the pathway is not quantitatively addressed in the risk assessment. Exposure pathways can be direct (i.e., the receptor is exposed directly to the contaminated abiotic media as in soil ingestion or surface water ingestion). Exposure pathways can also be indirect (i.e., the contaminant migrates from abiotic to biotic media and the receptor is exposed by ingestion of diet).

Exposure pathways in the terrestrial environment to be examined in this assessment are (indicated in **bold**):

- **Ingestion of soil by mammals,**
- Ingestion of surface water by mammals (surface water not present at site),
- **Ingestion of soil by birds,**
- **Ingestion of surface water by birds,**
- **Ingestion of diet by mammals,**
- **Ingestion of diet by birds,**
- **Direct contact with soil by plant roots,**
- **Direct contact with soil by invertebrates.**

Inhalation of dusts or vapors and dermal contact with soils by birds and mammals are considered insignificant contributors to total risk (EPA 1999b).

B-2.3 Exposure Analysis

Exposure analysis consists of quantifying potential exposure of an ecological receptor to a contaminant. Exposure to community-level (e.g., the plant community) and species-specific receptors selected to represent different feeding guilds (e.g., bird or mammalian receptors) is assessed using different approaches. For the risk characterization of community-level receptors, the toxicity reference values (TRVs) used are media specific. Therefore, for community-level receptors (e.g., plant, invertebrate), the exposure assessment consists of determining the contaminant concentration in the media that the particular community inhabits. For example, the contaminant concentration in soil is determined during the exposure assessment for comparison to the TRVs for terrestrial plants and soil invertebrates.

In contrast, TRVs for species-specific receptors representing different trophic levels or functional groups are provided in terms of dose ingested. For class-specific receptors representing different avian and mammalian trophic levels, exposure is assessed by quantifying the daily dose ingested of contaminated media as well as contaminated prey or forage items. Exposure for species-specific receptors is expressed as the mass of contaminant ingested per kilogram of body weight per day (mg/kg bw/d).

B-2.3.1 Concentrations of COPCs in Terrestrial Plants

The uptake of COPCs by the root system is modeled with the following equation (EPA 1999b):

$$P_r = C_S * BCF_r * 0.12$$

where:

P_r	=	Plant concentration due to root uptake (mg COPC/kg WW)
BCF_r	=	Plant-soil biotransfer factor (unitless)
C_s	=	COPC concentration in soil (mg COPC/kg soil) – site and COPC specific
0.12	=	Dry weight to wet weight conversion factor (unitless).

The dry weight to wet weight conversion factor of 0.12 is based on the average rounded value from the range of 80 to 95 percent water content in herbaceous plants and nonwoody plant parts (Taiz and Geiger 1991). The BCF_r parameters are presented in Table B-2. An area use factor (AUF) may be incorporated into the equation.

B-2.3.2 Concentrations of Contaminant in Herbivorous Birds, Mammals, and Amphibians

Herbivores consume only plants. The equation used to predict uptake from plants, soil/sediment, and surface water into herbivores is simplified from EPA (1999b) by conservatively assuming that the contaminated fraction of water (C_{sw}), herbivorous diet (C_p), and soils or sediments ($C_{s/sed}$) is equal to 1 (i.e., no uncontaminated material is contacted). Also, because the data are inadequate to distinguish between uptake by different plant species, only one component is required to account for the dietary contribution to exposure; thus, there is no parameter for proportion of each item in the diet. It is also noted that FCMs for all TL2 herbivore are equal to one. The equation below is generalized to address the tissue concentrations of COPCs in herbivores from either an aquatic or terrestrial environment. The equation is the sum of the uptake from diet, soil or sediment, and surface water as follows:

$$C_H = \left(C_p * P_p * BCF_{p-H}\right) + \left(C_{s/sed} * P_{s/sed} * BCF_{s/sed-H}\right) + \left(C_W * P_W * BCF_{W-H}\right)$$

where:

C_H	=	COPC concentration of herbivore (mg/kg)
C_p	=	COPC concentration in plant (mg/kg)
P_p	=	Proportion of plant food item in diet that is contaminated (unitless)
BCF_{p-H}	=	Bioconcentration factor between plants to herbivore (fresh-weight basis [fwb], unitless)
$C_{s/sed}$	=	Concentration in soil/sediment (mg/kg)
$P_{s/sed}$	=	Proportion of soil or bed sediment in diet that is contaminated (unitless)
C_w	=	COPC concentration in surface water (mg/L)
P_w	=	Proportion of water in diet (unitless)
BCF_{w-H}	=	Bioconcentration factor between surface water and herbivore (unitless).

Table B-2. Transfer factors (EPA 1999b).

	Communities			Mourning Dove			Mule Deer			Deer Mouse		
Contaminant	**BCF_{SI}**	**BCF_r**	**Bv**	**$BCF_{p\text{-}H}$**	**$BCF_{w\text{-}H}$**	**$BCF_{s/sed\text{-}H}$**		**$BCF_{p\text{-}H}$**	**$BCF_{s/sed\text{-}H}$**	**$BCF_{p\text{-}Om}$**	**$BCF_{w\text{-}Om}$**	**$BCF_{s/sed\text{-}Om}$**
Mercuric chloride	4.0E-02	3.75E-02	1.8E+03	2.12E-03	3.31E-04	4.99E-05	8.36E-02	2.37E-02	1.00E-04	6.74E-05	1.17E-05	1.48E-07
Mercury	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methyl mercury	8.50E+00	1.37E-01	NA	3.17E-04	4.96E-05	7.48E-06	1.25E-02	3.53E-03	1.50E-05	1.74E-06	1.74E-06	2.21E-08

	Bald Eagle		Red-tailed Hawk		Coyote		Sage Grouse		Big-eared Bat		Biotransfer factors (Ba)	
Contaminant	**$BCF_{w\text{-}C}$**	**$BCF_{s/sed\text{-}C}$**	**$BCF_{w\text{-}C}$**	**$BCF_{s/sed\text{-}C}$**	**$BCF_{w\text{-}C}$**	**$BCF_{s/sed\text{-}C}$**	**$BCF_{w\text{-}C}$**	**$BCF_{s/sed\text{-}C}$**	**$BCF_{w\text{-}C}$**	**$BCF_{s/sed\text{-}C}$**	**Mammal**	**Avian**
Mercuric chloride	2.94E-03	8.23E-05	1.37E-03	3.49E-05	2.98E-03	8.46E-05	1.41E-03	1.20E-04	7.45E-06	8.52E-08	5.22E-03	2.39E-02
Mercury	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methyl mercury	4.41E-04	1.23E-04	2.05E-04	5.23E-06	4.45E-04	1.26E-05	2.11E-04	1.79E-05	1.11E-06	1.27E-08	7.80E-04	3.58E-03

BCF_{SI} = Soil to soil invertebrate

BCF_r = Soil to plant/sediment to plant

B_v = COPC-specific soil-to-plant uptake coefficient (mass of COPC/dry mass plant material per mass of COPC/dry mass soil)

$BCF_{p\text{-}H}$ = Bioconcentration factor between plants to herbivore (fresh-weight basis [fwb], unitless)

$BCF_{w\text{-}H}$ = Bioconcentration factor between water and herbivore (unitless)

$BCF_{s/sed\text{-}H}$ = Bioconcentration factor between soil/sediment to herbivore (unitless)

$BCF_{p\text{-}Om}$ = Bioconcentration factor for plant-to-omnivore (unitless)

$BCF_{w\text{-}Om}$ = Bioconcentration factor between water and omnivore (unitless)

$BCF_{s/sed\text{-}Om}$ = Bioconcentration factor for soil- or bed sediment-to-omnivore (unitless)

$BCF_{s/sed\text{-}C}$ = Bioconcentration factor for soil- or bed sediment-to-carnivore (unitless)

$BCF_{w\text{-}C}$ = Bioconcentration factor between water and carnivore (unitless)

Ba = Biotransfer factor between soil or sediment to herbivore (d/kg, fwb), COPC-specific.

BCFs for uptake from diet, soil or sediment, and water were estimated according to EPA (1999b). To estimate a BCF from food, the biotransfer factor (Ba) for the COPC was multiplied by the dietary ingestion rate (IR_F) for that receptor according to the generalized equation:

$$BCF_F = Ba * IR_F$$

where:

BCF_F	=	Uptake factor between herbivore and plants (unitless)
Ba	=	COPC-specific biotransfer factor (day(d)/kg fresh weight)
IR_F	=	Dietary ingestion rate (kg fresh weight/d).

To estimate a BCF from soil or sediment, the Ba for the COPC was multiplied by the media ingestion rate for soil or sediment ($IR_{s/sed}$) or for surface water (IR_W) for that receptor:

$$BCF_{s/sed-H} = Ba * IR_{sed\ or\ soil} \qquad BCF_{w-H} = Ba * IR_w$$

where:

$BCF_{s/sed-H}$	=	Uptake factor between soil/sediment to herbivore (unitless)
Ba	=	Biotransfer factor between soil or sediment to herbivore (d/kg, fwb), COPC-specific
$IR_{s/sed}$	=	Soil or sediment ingestion rate (kg/d, fwb)

BCF_{w-H}	=	Bioconcentration factor between water and herbivore (unitless)
Ba	=	Biotransfer factor between water and herbivore (d/L, fwb)
IR_w	=	Water ingestion rate (L/d).

Although presented here for completeness, there is no water ingestion or associated exposure at the CFA-04 site. Receptor-specific parameters are presented in Table B-3. An area use factor (AUF) may be incorporated into the equation.

B-2.3.3 Concentrations of Contaminants in Omnivorous Birds and Mammals

Omnivores consume both plant and animal material. Since plants and invertebrates or other animals are not accumulate contaminants at the same rate or to the same level, the contribution from each type of diet must be summed to obtain total dietary exposure. Plants were not broken into separate types of modeling due to the uncertainty; thus, there is only one plant component. The equation as follows:

$$C_{OM} = \sum\left(C_{Ai} * \frac{FCM_{TL3}}{FCM_{TLAi}} * P_{Ai} * F_{Ai}\right) + \sum\left(C_{tp} * BCF_{p-om} * P_p * F_p\right) + \left(C_{s/sed} * P_{s/sed} * BCF_{s/sed}\right) + \left(C_w * P_w * BCF_{w-om}\right)$$

where:

C_{OM}	=	COPC concentration in omnivore (mg/kg)
C_{Ai}	=	COPC concentration in *i*th animal food item (mg/kg)
FCM_{TL3}	=	Food chain multiplier for trophic level 3 (unitless)

FCM_{Ai}	=	Food chain multiplier for trophic level of *i*th animal food item (unitless)
F_{Ai}	=	Fraction of diet consisting of *i*th animal food item (unitless)
$BCF_{p\text{-}om}$	=	Bioconcentration factor for plant-to-omnivore (unitless)
C_p	=	COPC concentration in plants (mg/kg)
F_p	=	Fraction of diet consisting of plants (unitless)
P_{Ai}	=	Proportion of *i*th animal food item in diet that is contaminated (unitless)
P_p	=	Proportion of plant food item in diet that is contaminated (unitless)
$P_{s/sed}$	=	Proportion of soil or bed sediment in diet that is contaminated (unitless)
P_w	=	Proportion of water in diet that is contaminated (unitless)
$C_{s/sed}$	=	COPC concentration in soil or bed sediment (mg/kg)
$BCF_{s/sed}$	=	Bioconcentration factor for soil- or bed sediment-to-omnivore (unitless)
C_w	=	Total COPC concentration in water column (mg/L)
$BCF_{w\text{-}OM}$	=	Bioconcentration factor for water-to-omnivore (L/kg).

Transfer factors are presented in Table B-2 and receptor-specific parameters are presented in Table B-3. An AUF may be incorporated into the equation.

B-2.3.4 Concentrations of COPCs in Carnivorous Birds and Mammals

Carnivores consume animal matter. The equation used to predict uptake from animal tissue, soil, sediment, and surface water into carnivores was obtained from EPA (1999b). The equation is the sum of the uptake from diet, soil or sediment, and surface water as follows:

$$C_c = \sum\left(C_{Ai} * \left(FCM_{TL4} / FCM_{Ai}\right) * P_{Ai} * F_{Ai}\right) + \left(C_{s/sed} ** P_{s/sed} * BCF_{s/sed}\right) + \left(C_w * P_w * BCF_{w-c}\right)$$

where:

C_c	=	COPC concentration in carnivore (mg/kg)
C_{Ai}	=	COPC concentration in *i*th animal food item (mg/kg)
FCM_{TL4}	=	Food chain multiplier for trophic level 4 (unitless)
FCM_{Ai}	=	Food chain multiplier for trophic level of *i*th animal food item (unitless)
P_{Ai}	=	Proportion of *i*th animal food item in diet that is contaminated (unitless)
$P_{s/sed}$	=	Proportion of soil or bed sediment in diet that is contaminated (unitless)
P_w	=	Proportion of water in diet that is contaminated (unitless)
F_{Ai}	=	Fraction of diet consisting of *i*th animal food item (unitless)
$C_{s/sed}$	=	COPC concentration in soil or bed sediment (mg/kg)
$BCF_{s/sed}$	=	Bioconcentration factor for soil- or bed sediment-to-carnivore (unitless)
C_w	=	Total COPC concentration in water column (mg/L)
$BCF_{w\text{-}c}$	=	Bioconcentration factor for water-to-carnivore (L/kg).

Transfer factors are presented in B-2 and receptor-specific parameters are presented in Table B-3. An AUF may be incorporated into the equation.

B-2.4 Exposure Parameters for Mammals and Birds

Exposure parameters are values used to estimate the daily dose for each of the species-specific receptors that represent the different feeding guilds. Parameters for each of the receptors were obtained from various sources, and are presented in Table B-3. The lowest mean body weight value from EPA (1993) was used for each receptor to derive ingestion rates using allometric equations from EPA 1993. Animals were assumed to inhabit the exposure area year-round; risk estimates therefore are conservative enough to be protective of the area's numerous migrants.

B-2.4.1 Exposures to Mammals

Risk to animals in the taxonomic class *Mammalia* is addressed by selecting several species of mammals from different feeding guilds (e.g., herbivores and carnivores) and evaluating exposure for each species. Exposure is assessed by quantifying the daily dose (DD) ingested from consuming contaminated food items (i.e., plant and animal), and abiotic media. The COPC daily dose ingested (expressed as the mass of COPC ingested per kilogram of body weight per day) depends on the COPC concentration in plant and animal food items and media, the measurement receptor's trophic level (i.e., consumer), the trophic level of animal food items (i.e., prey), and the measurement receptor's ingestion rate for each food item and media. The complexity of the daily dose equation is dependent on (1) the number of food items in a measurement receptor's diet, and (2) the trophic level of each food item and of the measurement receptor. The daily dose of COPC ingested by a receptor, considering all food items and media ingested, can be calculated from the following generic equation (EPA 1999b):

$$DD = \sum IR_F * Ci * Pi * Fi + \sum IR_M * C_M * P_M$$

where:

DD	=	Daily dose of COPC ingested (mg COPC/kg bw-day),
IR_F	=	Measurement receptor plant or animal food item ingestion rate (kg/kg bw-day),
Ci	=	COPC concentration in *i*th plant or animal food item (mg COPC/kg),
Pi	=	Proportion of *i*th food item that is contaminated (unitless)
Fi	=	Fraction of diet consisting of plant or animal food item *i* (unitless)
IR_M	=	Measurement receptor media ingestion rate (kg/kg bw-day [soil or bed sediment] or L/kg bw-day [water]),
C_M	=	COPC concentration in media (mg/kg [soil or bed sediment] or mg/L [water]),
P_M	=	Proportion of ingested media that is contaminated (unitless).

Table B-3. Input parameters for terrestrial receptors.

Units	Description		Terrestrial Receptors								
			DM	COY	MD	BEB	MDV	BE	SG	RTH	MDK
Kg	Body weight	BW	0.0148	7	70	0.009	0.115	3	1	0.957	1.043
kg/kg bw-day, wwb	Food ingestion rate	FIR	0.872	0.258	0.229	0.567	0.770	0.128	0.168	0.170	0.24
L/kg bw-day	Water ingestion rate	WIR	0.151	0.081	0.06	0.159	0.120	0.041	0.059	0.060	0.058
kg/kg bw-day, dwb	Soil/sediment ingestion rate	SIR	0.002	0.002	0.0003	0.0018	0.018	0.001	0.005	0.002	0.0018
Unitless	Fraction plant in diet	PPLNT	0.5	0	1	0	1	0	0	0	0.5
Unitless	Fraction invertebrate in diet	PINVERT	0.5	0	0	1	0	0	1	0	0.5
Unitless	Fraction prey in diet	PPREY	0	1	0	0	0	1	0	1	0
Unitless	Fraction soil/sediment in diet	PS	0.01	0.028	0.01	0.01	0.093	0.014	0.093	0.028	0.033
Hectares	Home range	RANGE	1	8000	243	4928	5480	3750	2590	1300	283
Unitless	Area use factor	AUF	1.0	1.0	1.0	1.0	1.0	TBD	1.0	TBD	0.1

Note: Ingestion rate values were obtained from allometric equations as appropriate; other values as per EPA 1999b.

The daily dose of COPC ingested by a receptor is determined by summing the contributions from each contaminated plant, animal, and media food item. The parameters accounting for 100 percent of the measurement receptor's diet or total daily mass of potentially contaminated food items ingested are presented in Table B-3. However, if a food item or media at an actual site location is not contaminated (i.e., the measured or modeled COPC concentration in the media or resulting food item is zero), then the daily mass of that food item or media ingested does not contribute to the daily dose of COPC ingested. Also, the equation does not directly include a term for home range. However, the term accounting for the proportion of plant or animal food item that is contaminated, *Pi*, numerically accounts for the fraction of a respective food item that may potentially be obtained from outside the geographical limits of the impacted habitat (i.e., outside the area of contamination). The P_i and P_m are usually initially set to 1.

For receptors ingesting more than one plant or animal food item (i.e., omnivore), EPA (1999b) recommends that exposure be separately quantified assuming that the measurement receptor ingests both "equal" and "exclusive" diets. Not only does this constitute the most complete evaluation of exposure potential for a measurement receptor; if warranted, it also identifies which pathways are driving risk specific to a COPC and measurement receptor, and allows risk management efforts to be prioritized. These two separate dietary exposure scenarios are modeled as follows:

Equal Diet – The daily dose of COPC ingested is calculated assuming that the fraction of daily diet consumed by the measurement receptor is equal among food item groups. This is computed by setting the value for fraction of diet consisting of plant and/or animal food items, *Fi*, equal to 1.0 divided by the total number of plant and animal food item groups ingested. Therefore, *Fi* values within the specific *DD* equation would be the same numerically.

Exclusive Diet – The daily dose of COPC ingested is calculated assuming that the fraction of daily diet consumed by the measurement receptor is exclusively (100 percent) of one food item group. This is computed by setting the value of Fi equal to 1.0 for each food item group at a time, while the Fi values for the remaining food item groups are set equal to zero. The food item designated as exclusive is alternated to each respective food item represented in the DD equation to obtain a numeric range of exposure values based on exclusive diets. If the daily diet of a food item (i.e., prey) of a measurement receptor (i.e., consumer) also consists of more than one plant or animal food item, then an equal diet was assumed for the food item being consumed while evaluating exposure to the measurement receptor (EPA 1999b).

EPA (1999b) recommends that the following assumptions be applied in a screening level risk assessment:

- The contaminant concentrations estimated to be in food items and media ingested are completely bioavailable, as opposed to reducing the estimated dose to account for lack of gastrointestinal uptake.
- The measurement receptor's most sensitive life stage is present in the assessment area being evaluated in the risk assessment. This can vary for each contaminant, depending on if the contaminant has maternal effects, effects on male reproductive capabilities, or is more toxic to juveniles. Often this is not clear from the toxicity information.
- The body weights and food ingestion rates for measurement receptors are conservative. This is assured by using the lowest mean adult body weight for each receptor. These body weights are then used to obtain ingestion rates from the allometric equations provided in EPA (1999b) and the Wildlife Exposures Handbook (EPA 1993).
- Each individual species in a community or class-specific guild is equally exposed.
- The proportion of ingested food items and ingested media that is contaminated is assumed to be 100 percent (i.e., *Pi* is assigned a value of 1.0) which assumes that a measurement receptor feeds only in the assessment area.

B-2.4.2 Exposures to Birds

The same procedure listed above was applied to avian species.

B-2.4.3 Exposures to the Terrestrial Plant and Invertebrate Communities

Exposure to the plant and soil invertebrate communities as ecological receptors was assessed by determining the contaminant concentration in soil (*Cs*) and direct comparison.

B-2.5 Effects Analysis

The toxicity values are presented in Table B-4 and were obtained from EPA 1999b or as noted.

B-2.6 Hazard Quotient Assessment

Hazard quotients are used as a measure of risk. To estimate the hazard quotient, the chemical and receptor-specific ratios of the calculated intakes (or daily exposures) and the appropriate TRVs for each contaminant are calculated as follows:

$$HQ = EEL / TRV$$

where:

HQ	=	Hazard quotient (unitless)
EEL	=	COPC estimated exposure level (mass COPC/mass media [communities] or DD (mg COPC/kg bw-day [species-specific receptors]), and
TRV	=	COPC toxicity reference value (mass COPC/mass media [communities] or mass daily dose COPC ingested/mass body weight-day [species-specific receptors]).

When multiple contaminants are present the HQs are summed to develop a HI. A HI of less than 10 is considered to pose minimal risk to ecological receptors. The final remediation goal concentration (8.4 mg/kg) was obtained by back calculating risk iteratively until the HIs were less than 10.0.

Table B-4. Toxicity reference values from EPA (1999b) except as noted.

CPOC	Mammalian TRV (mg/kg bw-day)	Endpoint and Duration	Eco TRVs (mg/kg-d)[a]	Avian TRV (mg/kg bw-day)	Endpoint and Duration	Eco TRVs (mg/kg-d)[a]	Terrestrial Plant TRV (mg/kg)	Endpoint and Duration	Soil Fauna TRV (mg/kg)	Endpoint and Duration
Mercuric chloride	1.01	Chronic NOAEL; UF=1	NA	3.25	Acute LOAEL; UF=0.01	NA	0.349	Acute NOEC; UF=0.01	2.50E+00	Methyl mercury
Mercury	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methyl mercury	0.03	Subchronic NOAEL; UF=1	NA	0.0064	Chronic LOAEL; UF=0.1	NA	NA	NA	2.50E+00	Chronic NOEC

a. EPA, 2000, *Ecological Soil Screening Level Guidance, Draft, Eco-SSL-Ecological Soil Screening Levels*, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC, July 10, 2000.

LOAEL = Lowest observable effects level

NA = Not available

NOEC = No observed effects concentration

SSL = Soil screening level

TRV = Toxicity reference value

UF = Uncertainty factor

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Appendix C

Human Health Risk Assessment Parameters

Appendix C

Human Health Risk Assessment Parameters

C-1. HUMAN HEALTH RISK ASSESSMENT

This Appendix presents the exposure point concentrations, masses, and input parameters used in the human health risk assessment and for development of the remediation goals for the CFA-04 site in the OU 4-13 Comprehensive RI/FS (DOE-ID 2000). With the exception of the updated input parameters as presented in Section 4 of this document and updated per new EPA dermal guidance (EPA 2001), the parameters in this appendix were also used to develop an updated remediation goal. Table C-1 identifies the exposure parameters used in the human health risk assessment for the future residential scenario.

Table C-1. Input parameters for future residential scenario.

Exposure Parameter	Future Adult Resident[a]	Future Child Resident[a]
Soil ingestion rate (mg/day)	100	200
Skin surface area available for soil contact (cm^2/event)	3,000[b]	—
Soil-to-skin adherence factor (mg/cm^2)	0.5	—
Inhalation rate (m^3/hr)	0.83	—
Homegrown produce ingestion rate, nonradionuclide-contaminated (g/kg-day)	0.276[c]	—
Groundwater ingestion rate (L/day)	2	1
Skin surface area available for groundwater contact	17,000	—
Inhalation exposure time (hr/day)	24	—
Dermal contact exposure time (hr/day)	0.25	—
Exposure frequency (days/year)	350	350
Exposure duration (years)	24	6
Body Weight (kg)	70	15

a. Value from DOE-ID (1994), unless otherwise noted.

b. Value from EPA (1992)

c. Derivation based on Burns (1996).

For the OU 4-13 Comprehensive RI/FS (DOE-ID 2000) human health risk assessment a 95% upper confidence limit (UCL) exposure point concentration was calculated. A 95% UCL of 7.34E+01 mg/kg in the 0 to 10 ft depth range for the future residential scenario was calculated for mercury.

Table C-2 identifies the volume of contaminated soil present at this site. The mass and volume of contaminated soil is an important input for the development of concentrations of the contamination in the groundwater. The calculation of the mass of contaminated soil (5.53E+09 mg) as related to volumes presented in the OU 4-13 Comprehensive RI/FS (DOE-ID 2000) could not be recalculated from this volume. For evaluation of an updated remediation goal, a mass was calculated from the volume as follows:

Table C-2. Volume of before and after remediation of contaminated soil at CFA-04.

CFA-04	Site Characteristics
Area of the site	6.88E+03 m^2
Contamination thickness	5.5 m
Total volume of contaminated soil	3.78E+04 m^3

9.5 mg/kg x 1,500 kg/m^3 (soil density) x 3.78E+04 m^3 (vol. of contaminated soil)= 5.4E+08 mg

This provides a conservative assumption of volume in the assessment for calculation of a mass for input into the GWSCREEN analysis. It is assumed that although contaminated soil will have been removed during the remediation process the volume is assumed to remain the same. To calculate the mass of meHg in the soil, the total Hg mass was multiplied by either 0.5% or 0.005%. The masses used for the GWSCREEN analysis are presented in Table C-3. The concentrations in the groundwater and soil used in the development of the remediation goal are presented in Table C-4. The GWSCREEN runs are presented in Appendix D.

Table C-3. Mass of Hg and meHg[a] used in the GWSCREEN assessment.

	Calculated Mass in Soil (mg)	
Contaminant	Assuming 0.5% meHg	Assuming 0.005% meHg
Hg	1.30E+09	1.30E+09
MeHg	6.52E+06	6.52E+04

a. Assuming a volume of 3.78E+04 m^3 and a concentration of Hg of 9.5 mg/kg.

Table C-4. Concentration of Hg and meHg[a] in groundwater and soil (used in FRG assessment).

	Concentration in Soil (mg/kg)		Calculated Concentration in Groundwater (mg/L)	
Contaminant	Assuming 0.005% meHg	Assuming 0.5% meHg	Assuming 0.005% meHg	Assuming 0.5% meHg
Hg	9.5E+00	9.5E+00	1.01E-04	1.01E-04
MeHg	4.75E-04	4.75E-02	7.2E-10	7.2E-08

a. Assuming the mass from Table C-3.

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Appendix D

GWSCREEN Runs

Appendix D

GWSCREEN Runs

This is the GWSCREEN run with Hg at 9.5 mg/kg and meHg percentage at 0.5%

```
GWSCREEN Version 2.5 - Test Problems                    (Card 1)
 TIME OF RUN: 08:19:56.40  DATE OF RUN: 04/18/02
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                    GWSCREEN                     *
   *                   Version 2.5a                  *
   *    A semi-analytical model for the assessment   *
   *    of the groundwater pathway from the leaching *
   *    of surficial and buried contamination and    *
   *  release of contaminants from percolation ponds *
   *                   04/05/2001                    *
   *                  Arthur S. Rood                 *
   *         Idaho National Engineering and          *
   *            Environmental Laboratory             *
   *                   PO Box 1625                   *
   *              Idaho Falls, Idaho 83415           *
   ***************************************************
  ==============================================================================
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  ==============================================================================

 OUTPUT FILE NAME:
CFA-04s.out
 INPUT FILE NAME:
CFA-04s.PAR
 Title: CFA-04 GWSCREEN Ver 2.5 25 m vert avg source  (Card 1)
 ------------------------------------------------------------------------------
 Model Run Options
 ------------------------------------------------------------------------------
 IMODE Contaminant Type and Impacts:                                    6
 ITYPE (1) Vert Avg (2) 3D Point (3) 3d Avg:                            1
 IDISP (0) Fixed Dispersivity (1-3) Spatially Varying:                  0
 KFLAG (1) Max Conc (2) Conc vs Time (3) Grid Output:                   1
 IDIL (1) No dilution factor (2) Include Dilution Factor:               1
 IMOIST Source Moisture Content Option:                                 1
 IMOISTU Unsaturated Moisture Content Option:                           1
```

```
IMODEL (1) Surface/Burried Src (2) Pond (3) Usr Def:            1
ISOLVE (1) Gaussian Quarature (2) Simpsons Rule: (Aquifer)      1
ISOLVEU (1) Gaussian Quarature (2) Simpsons Rule: (Unsat Zone)  1
Health Effects: Non-carcinogenic effects for non-radiological contaminants
Output mass/activity units:   mg
Output concentration units:   mg/m**3
Dose/Risk Conversion Units:   mg-g/kg
Output health effects units:  hazard quotient
-------------------------------------------------------------------------------
Exposure Parameters
-------------------------------------------------------------------------------
Body Mass (kg):               70.       Averaging Time (days):      25550.
Water Ingestion (L/d):        2.000E+00 Exposure Freq (day/year):   3.500E+02
Exposure Duration (y):        3.000E+01 Limiting Dose:              1.000E+00
-------------------------------------------------------------------------------
Site Parameters
-------------------------------------------------------------------------------
X Coordinate:                 0.000E+00  Y Coordinate:                0.000E+00
Source Length (m):            1.507E+02  Source Width (m):            4.561E+01
Percolation Rate (m/y):       1.000E-01
Source Thickness (m):         5.500E+00  Src Bulk Density (g/cc):     1.500E+00
Source Moisture Content:      3.000E-01
-------------------------------------------------------------------------------
Unsaturated Zone Parameters
-------------------------------------------------------------------------------
Unsat Zone Thickness (m):     1.400E+01  Unsat Bulk Density:          1.500E+00
Unsat Dispersivity (m):       0.000E+00  Unsat Moisture Content:      3.000E-01
-------------------------------------------------------------------------------
Aquifer Zone Parameters
-------------------------------------------------------------------------------
Longitudinal Disp (m):        9.000E+00  Transverse Disp (m):         4.000E+00
Aquifer Thickness (m):        1.500E+01  Well Screen Thickness (m):   1.500E+01
Darcy Velocity (m/y):         5.700E+01  Aquifer Porosity:            1.000E-01
Bulk Density (g/cc):          1.900E+00
-------------------------------------------------------------------------------
Calculated Flow Parameters
-------------------------------------------------------------------------------
Percolation Water Flux (m3/y):  6.8734E+02
Unsat Pore Velocity (m/y):      3.3333E-01
Aquifer Pore Velocity (m/y):    5.7000E+02
Longitudinal Disp (m**2/y):     5.1300E+03
Transverse Disp (m**2/y):       2.2800E+03
-------------------------------------------------------------------------------
Contaminant Data
-------------------------------------------------------------------------------
 Contaminant Name:                Mercury
 Half Life (y):                   9.000E+09
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                1.000E+03
 Solubility Limit (mg/L):         6.000E-02
 Molecular Weight (mg/L):         2.006E+02
 Initial mass/activity:           5.390E+08
 Kd Unsat (ml/g):                 1.000E+03
 Kd Aquifer (ml/g):               1.000E+03
 Risk/Dose Conversion Factor:     3.000E-04
-------------------------------------------------------------------------------
Calculated Contaminant Values
```

```
-----------------------------------------------------------------------------
Decay Constants (1/y):                      7.7016E-11
Leach Rate Constant (1/y):                  1.2119E-05
Initial Pore Water Conc (Ci or mg/m**3):    9.5033E+00
Solubility Limited Mass (mg):               3.4030E+09
Unsaturated Retardation Factor:             5.0010E+03
Mean Unsaturated Transit Time (y):          2.1004E+05
Aquifer Retardation Factor:                 1.900E+04
Minimum Peak Window Time (y):               2.1004E+05
Maximum Peak Window Time (y):               7.8701E+05
-----------------------------------------------------------------------------
Results for Receptor X =  7.50000E+01 Y = 0.00000E+00
-----------------------------------------------------------------------------
Peak Concentration (mg/m**3):             1.012E-01
Time of Peak (y):                         2.1793E+05
Concentrations Averaged Between:        2.1792E+05 and  2.1795E+05 years
Average Concentration (mg/m**3):          1.012E-01
Maximum Dose:                             3.960E-03
Maximum Allowable Inventory (mg):         1.361E+11
WARNING: PORE WATER CONCENTRATION OF THE MAXIMUM ALLOWABLE INVENTORY
         EXCEEDS THE SOLUBILITY LIMIT OF THE CONTAMINANT
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:                MethylMercury
 Half Life (y):                   9.000E+09
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                7.000E+03
 Solubility Limit (mg/L):         1.000E+06
 Molecular Weight (mg/L):         2.160E+02
 Initial mass/activity:           2.690E+06
 Kd Unsat (ml/g):                 7.000E+03
 Kd Aquifer (ml/g):               7.000E+03
 Risk/Dose Conversion Factor:     1.000E-04
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                      7.7016E-11
Leach Rate Constant (1/y):                  1.7316E-06
Initial Pore Water Conc (Ci or mg/m**3):    6.7766E-03
Solubility Limited Mass (mg):               3.9695E+17
Unsaturated Retardation Factor:             3.5001E+04
Mean Unsaturated Transit Time (y):          1.4700E+06
Aquifer Retardation Factor:                 1.330E+05
Minimum Peak Window Time (y):               1.4700E+06
Maximum Peak Window Time (y):               5.5082E+06
-----------------------------------------------------------------------------
Results for Receptor X =  7.50000E+01 Y = 0.00000E+00
-----------------------------------------------------------------------------
Peak Concentration (mg/m**3):             7.214E-05
Time of Peak (y):                         1.5253E+06
Concentrations Averaged Between:        1.5252E+06 and  1.5253E+06 years
Average Concentration (mg/m**3):          7.214E-05
Maximum Dose:                             8.471E-06
Maximum Allowable Inventory (mg):         3.176E+11
Execution Time (Seconds):    0
```

This is the GWSCREEN run with Hg at 9.5 mg/kg and meHg percentage at 0.005%

```
GWSCREEN Version 2.5 - Test Problems                    (Card 1)
 TIME OF RUN: 08:21:05.06  DATE OF RUN: 04/18/02
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                    GWSCREEN                     *
   *                  Version 2.5a                   *
   *    A semi-analytical model for the assessment   *
   *    of the groundwater pathway from the leaching *
   *    of surficial and buried contamination and    *
   *  release of contaminants from percolation ponds *
   *                  04/05/2001                     *
   *                 Arthur S. Rood                  *
   *         Idaho National Engineering and          *
   *            Environmental Laboratory             *
   *                  PO Box 1625                    *
   *             Idaho Falls, Idaho 83415            *
   ***************************************************
  ==============================================================================
          ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND
                   LIMITATION OF LIABILITY

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  DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
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  ==============================================================================

 OUTPUT FILE NAME:
CFA-04t.out
 INPUT FILE NAME:
CFA-04t.PAR
 Title: CFA-04 GWSCREEN Ver 2.5 25 m vert avg source  (Card 1)
 ------------------------------------------------------------------------------
 Model Run Options
 ------------------------------------------------------------------------------
 IMODE Contaminant Type and Impacts:                                    6
 ITYPE (1) Vert Avg (2) 3D Point (3) 3d Avg:                            1
 IDISP (0) Fixed Dispersivity (1-3) Spatially Varying:                  0
 KFLAG (1) Max Conc (2) Conc vs Time (3) Grid Output:                   1
```

```
IDIL (1) No dilution factor (2) Include Dilution Factor:        1
IMOIST Source Moisture Content Option:                          1
IMOISTU Unsaturated Moisture Content Option:                    1
IMODEL (1) Surface/Burried Src (2) Pond (3) Usr Def:            1
ISOLVE (1) Gaussian Quarature (2) Simpsons Rule: (Aquifer)      1
ISOLVEU (1) Gaussian Quarature (2) Simpsons Rule: (Unsat Zone)  1
Health Effects: Non-carcinogenic effects for non-radiological contaminants
Output mass/activity units:   mg
Output concentration units:   mg/m**3
Dose/Risk Conversion Units:   mg-g/kg
Output health effects units:  hazard quotient
-------------------------------------------------------------------------
Exposure Parameters
-------------------------------------------------------------------------
Body Mass (kg):              70.       Averaging Time (days):      25550.
Water Ingestion (L/d):       2.000E+00 Exposure Freq (day/year):   3.500E+02
Exposure Duration (y):       3.000E+01 Limiting Dose:              1.000E+00
-------------------------------------------------------------------------
Site Parameters
-------------------------------------------------------------------------
X Coordinate:                0.000E+00  Y Coordinate:                0.000E+00
Source Length (m):           1.507E+02  Source Width (m):            4.561E+01
Percolation Rate (m/y):      1.000E-01
Source Thickness (m):        5.500E+00  Src Bulk Density (g/cc):     1.500E+00
Source Moisture Content:     3.000E-01
-------------------------------------------------------------------------
Unsaturated Zone Parameters
-------------------------------------------------------------------------
Unsat Zone Thickness (m):    1.400E+01  Unsat Bulk Density:          1.500E+00
Unsat Dispersivity (m):      0.000E+00  Unsat Moisture Content:      3.000E-01
-------------------------------------------------------------------------
Aquifer Zone Parameters
-------------------------------------------------------------------------
Longitudinal Disp (m):       9.000E+00  Transverse Disp (m):         4.000E+00
Aquifer Thickness (m):       1.500E+01  Well Screen Thickness (m):   1.500E+01
Darcy Velocity (m/y):        5.700E+01  Aquifer Porosity:            1.000E-01
Bulk Density (g/cc):         1.900E+00
-------------------------------------------------------------------------
Calculated Flow Parameters
-------------------------------------------------------------------------
Percolation Water Flux (m3/y):  6.8734E+02
Unsat Pore Velocity (m/y):      3.3333E-01
Aquifer Pore Velocity (m/y):    5.7000E+02
Longitudinal Disp (m**2/y):     5.1300E+03
Transverse Disp (m**2/y):       2.2800E+03
-------------------------------------------------------------------------
Contaminant Data
-------------------------------------------------------------------------
 Contaminant Name:                Mercury
 Half Life (y):                   9.000E+09
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                1.000E+03
 Solubility Limit (mg/L):         6.000E-02
 Molecular Weight (mg/L):         2.006E+02
 Initial mass/activity:           5.390E+08
 Kd Unsat (ml/g):                 1.000E+03
 Kd Aquifer (ml/g):               1.000E+03
```

```
 Risk/Dose Conversion Factor:    3.000E-04
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                          7.7016E-11
Leach Rate Constant (1/y):                      1.2119E-05
Initial Pore Water Conc (Ci or mg/m**3):        9.5033E+00
Solubility Limited Mass (mg):                   3.4030E+09
Unsaturated Retardation Factor:                 5.0010E+03
Mean Unsaturated Transit Time (y):              2.1004E+05
Aquifer Retardation Factor:                     1.900E+04
Minimum Peak Window Time (y):                   2.1004E+05
Maximum Peak Window Time (y):                   7.8701E+05
-----------------------------------------------------------------------------
Results for Receptor X =  7.50000E+01 Y = 0.00000E+00
-----------------------------------------------------------------------------
Peak Concentration (mg/m**3):                 1.012E-01
Time of Peak (y):                             2.1793E+05
Concentrations Averaged Between:            2.1792E+05 and  2.1795E+05 years
Average Concentration (mg/m**3):              1.012E-01
Maximum Dose:                                 3.960E-03
Maximum Allowable Inventory (mg):             1.361E+11
WARNING: PORE WATER CONCENTRATION OF THE MAXIMUM ALLOWABLE INVENTORY
         EXCEEDS THE SOLUBILITY LIMIT OF THE CONTAMINANT
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:                MethylMercury
 Half Life (y):                   9.000E+09
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                7.000E+03
 Solubility Limit (mg/L):         1.000E+06
 Molecular Weight (mg/L):         2.160E+02
 Initial mass/activity:           2.690E+04
 Kd Unsat (ml/g):                 7.000E+03
 Kd Aquifer (ml/g):               7.000E+03
 Risk/Dose Conversion Factor:     1.000E-04
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                          7.7016E-11
Leach Rate Constant (1/y):                      1.7316E-06
Initial Pore Water Conc (Ci or mg/m**3):        6.7766E-05
Solubility Limited Mass (mg):                   3.9695E+17
Unsaturated Retardation Factor:                 3.5001E+04
Mean Unsaturated Transit Time (y):              1.4700E+06
Aquifer Retardation Factor:                     1.330E+05
Minimum Peak Window Time (y):                   1.4700E+06
Maximum Peak Window Time (y):                   5.5082E+06
-----------------------------------------------------------------------------
Results for Receptor X =  7.50000E+01 Y = 0.00000E+00
-----------------------------------------------------------------------------
Peak Concentration (mg/m**3):                 7.214E-07
Time of Peak (y):                             1.5253E+06
Concentrations Averaged Between:            1.5252E+06 and  1.5253E+06 years
Average Concentration (mg/m**3):              7.214E-07
Maximum Dose:                                 8.471E-08
```

```
Maximum Allowable Inventory (mg):        3.176E+11
Execution Time (Seconds):    0
```