DEPARTMENT OF THE ARMY
BADGER ARMY AMMUNITION PLANT
2 BADGER ROAD
BARABOO, WISCONSIN 53913-5000

November 16, 2009

SUBJECT: Draft Revised Remediation Goals Proposal for the Alternative Feasibility Study
Final Creek, Settling Ponds, and Spoils Disposal Areas
Badger Army Ammunition Plant

Mr. Harlan Kuehling, P.G.
Hydrogeologist
Wisconsin Department of Natural Resources
South Central Region
3911 Fish Hatchery Road
Fitchburg, WI 53711-5397

Dear Mr. Kuehling:

The purpose of this letter is to propose updated alternative site-specific remediation goals for the Final Creek, Settling Ponds, and Spoils Disposal Areas (Site) at the Badger Army Ammunition Plant (BAAAP) using Section NR 720.19, Wisconsin Administrative Code (Wis. Adm. Code). This section of code provides the procedures for determining site-specific residual contaminant levels. The site-specific residual contaminant levels will be established that are protective of public health, safety, and welfare, and the environment, and will be developed using scientifically valid procedures, toxicological values, and alternative assumptions specifically approved by the Wisconsin Department of Natural Resources (WDNR) per Section NR 720.19(5)(b), Wis. Adm. Code.

Remediation goals for the Final Creek, Settling Ponds and Spoils Disposal Areas soils, initially proposed in 1994 and approved in 1995 by the WDNR, need to be modified utilizing the most up-to-date information, e.g., toxicological data, soil and groundwater data, exposure pathways, and land use. Therefore, the Department of the Army (Army) is requesting review and approval of the proposed methodology, default values, and exposure assumptions to be used to derive site-specific residual contaminant levels for the Site. Once these remediation goals are established, the Army can move forward with an alternative feasibility study for the Site.

Background Information

The BAAAP (currently about 7,275 acres) was constructed in 1942 to manufacture small arms and ordnance propellants as part of the United States military manufacturing effort during the Second World War. BAAAP also operated as a propellant manufacturing facility during the Korean conflict and the Vietnam era. The installation, inactive since 1977, was declared "excess" in 1999.

ABB Environmental Services, Inc. submitted a *Final Feasibility Study* report to the WDNR in August 1994 on behalf of the Army. Specific remediation goals were established in the report and remedial alternatives were evaluated for five target areas of concern at the BAAAP. One of these areas was the Settling Ponds and Spoils Disposal Areas, which included Final Creek, four Settling Ponds, and five Spoils Disposal Areas. This area encompasses approximately 70 acres of land. The WDNR subsequently approved the remediation goals and selected remedial options in their *Approval of Corrective Measures Selected in the Final Feasibility Study Report/Corrective Measures Study Report* letter dated June 1, 1995. The WDNR-approved remedy for the Site was modified in-situ soil stabilization with a soil cover. Since that time, further investigation work has been completed at the Site to fully delineate the extent of contamination and further characterize the degree of contamination in the soil and groundwater. In addition, a baseline ecological risk assessment (BERA) has been conducted at the Site to determine the effect of residual contamination on terrestrial ecosystem pathways of exposure.

Land Use

At the time the *Final Feasibility Study* was written in 1994, the Army's intention for future land use was continued government ownership in "standby" status. Since that time, the Army has deemed the installation "excess", which means the Army no longer has any use for the property. The Army has been in the process of decommissioning the BAAAP and transferring parcels to other government agencies over the past few years. Three parcels encompass the Site: T, T1, and M1. Parcels T and T1 contain Final Creek and Settling Pond 1. The Army intends to transfer these parcels to the Bluffview Sanitary District (Bluffview), as they contain the Wastewater Treatment Plant (WWTP) servicing the Bluffview community directly west of BAAAP and land for possible future expansion.

Parcel M1 contains Settling Ponds 2, 3, and a portion of Settling Pond 4, Spoils Disposal Areas I, II, III, IV, and V. The Army has plans to transfer this parcel to the National Park Service (NPS)/WDNR. It should be noted a portion of Settling Pond 4 is contained in parcels transferred or intended to transfer to the United Stated Department of Agriculture and the Wisconsin Department of Transportation. The WDNR granted closure for this portion of Settling Pond 4 in the December 12, 2008, *Final Case Closure for the BAAP – WDOT Projects Area Within Settling Pond 4* letter.

Currently, the BAAAP is zoned "governmental-agricultural conservation" by the Town of Merrimac and "exclusive agriculture" by the Town of Sumpter. However, during years of operation, the BAAAP would have been considered an industrial facility. It should be noted, deed restrictions are imposed to prohibit residential use when BAAAP parcels are transferred to other government agencies.

The current and future land use in Parcels T and T1 would be most similar to industrial in that they contain a wastewater treatment facility and a groundwater treatment system. Potential exposure rates to impacted soil would be similar to a worker at an industrial facility.

The current and future land use in Parcel M1 is anticipated to be somewhat similar in that human contact with soil is of a short duration (a few hours) and only on occasion (1 to 10 days per year) per individual. As stated above, the Army plans to transfer Parcel M1 to the NPS/WDNR for recreational use (e.g., hunting, hiking) as an extension of Devil's Lake State

Park (Park). Currently, the only people allowed access to this area are employees contracted by the government conducting demolition and environmental restoration work. Therefore, the exposure rate for this type of land use would be even less than an industrial setting.

Current and future land use must be considered in order to determine the appropriate potential human exposure risk. Chapter NR 720, Wis. Adm. Code (NR 720), identifies two types of land uses, industrial and non-industrial. Industrial use default value for human exposure is 250 days per year. This equates to the days that a worker at an industrial facility would be exposed working at a jobsite five days per week. Non-industrial default exposure value is 350 days per year. This value is based on a residential exposure rate where a person could potentially be exposed every day.

Other factors to consider when evaluating exposure rates in these areas is the fact that the ground is frozen and snow-covered for approximately four months per year from December through March, thus reducing the potential for direct contact with the impacted soil. In addition, the Park, which would manage this area after transfer, has limited hours of access for the public except for camping areas. The deed restriction language would prohibit camping on these parcels.

Established Limits

The August 1994 *Final Feasibility Study* originally established remediation goals for surface soils for the Final Creek and Settling Ponds and the Spoils Disposal Areas. These remediation goals, e.g., 2,4-DNT at 2.5 milligrams per kilogram (mg/kg), 2,6-DNT at 4.29 mg/kg, lead at 30 mg/kg, and nitroglycerin at 3.6 mg/kg, will be revised in a plan modification of the In-Field Conditions Report based on the forthcoming alternative feasibility study.

It should be noted BAAAP sites, not identified in the August 1994 *Final Feasibility Study*, use established background concentrations, NR 720 residual contaminant levels, or United States Environmental Protection Agency (USEPA) regional screening levels to set cleanup objectives. The contaminants of concern for the Site and their respective limits are listed in the Table on page 5. The USEPA regional screening level for 2,4-DNT is the most stringent of all the contaminants of concern at the Site at 1.6 milligrams mg/kg for residential and 5.5 mg/kg for industrial. Concentrations of 2,4-DNT range up to 660 mg/kg in Final Creek and 470 mg/kg in Spoils Disposal Area I. Considering the limited exposure risk at the Site, remediating the soil to this level may not be warranted.

In addition, USEPA regional screening levels are screening levels used when a site is initially investigated to determine if potentially significant levels of contamination are present to warrant further investigation such as a RI/FS. In order to set chemical-specific regional screening levels in a site-specific context, information must be evaluated on the chemicals that are present on-site, the specific contaminated media, land-use assumptions, and the exposure assumptions behind pathways of individual exposure (direct-contact).

Exposure Frequency

As previously stated, the current and future land use for Parcels T and T1 is industrial. The WDNR exposure frequency value is 250 days per year per NR 720. However, a worker would only be potentially exposed during working hours, which is eight hours out of a 24-hour day. If the number of days is adjusted based on actual exposure hours, the number of days is reduced

from 250 to 83 days per year. This exposure rate is still considered conservative in that a worker at the WWTP would not likely be exposed to the soil outside the WWTP as part of their regular work-related duties.

Considering Parcel M1, the future land use will be recreational. The Park would restrict uses to only those recreational activities allowed in the area. Considering an estimate of seven hours per day for recreational use, and that the ground is frozen four months out of the year, limiting exposure to eight months during a year, a maximum exposure frequency would be equivalent to 72 days per year. This is a very conservative estimate, as most recreational users would not visit the Park every day. A Park employee (Ranger for instance) might come close to this estimate; however, it is unlikely that an employee would be stationed in this area year-round and come in contact with the soil on a daily basis.

The average of the two exposure frequencies (83 days per year for modified industrial and 72 days per year for recreational/Park employee) yields an average exposure frequency of 77 days per year for the entire Site. It should be noted, the USEPA Risk Assessment Information System (RAIS) website, used to calculate a preliminary remediation goal, uses 75 days per year as the default value for a recreational user.

Cancer Risk

The WDNR has established a cancer risk level of one in 1,000,000 (10^{-6}) as an appropriate cancer risk level in NR 720. This value has the most significant impact on the result of the calculation for site-specific residual contaminant levels as it can change the value by an order of magnitude. California Environmental Protection Agency states in *A Guide to Health Risk Assessment*:

> "Actual regulatory standards for chemicals or hazardous waste cleanups may be set at less stringent risk levels, such as one in 100,000 or 10^{-5} (not more than one additional cancer case per 100,000 people) or one in 10,000 or 10^{-4} (not more than one additional cancer case per 10,000 people). These less stringent risk levels are often due to economic or technological considerations. Regulatory agencies generally view these higher risk levels to be acceptable if there is no feasible way to reduce the risks further."

Parcels T, T1, and M1 encompass over 320 acres, and the Site consists of approximately 70 of those acres. Considering the expansive area, setting remedial goals at the WDNR standard one in 1,000,000 risk level for some contaminants of concern could be impracticable.

Ingestion Factor

The ingestion factor is a value used in calculating site-specific residual contaminant levels that is expressed in milligrams per day (mg/day) of soil that could potentially adhere to human hands and be ingested by hand-to-mouth transfer. For an adult, this value is typically in the range of 10 to 50 mg/day, based on a low exposure type of activity (recreational). In scenarios where there is greater possibility of exposure to the soil (e.g., agricultural use/farmer, construction worker), this value would increase to a range of 100 to 200 mg/day.

The Site is currently thickly vegetated with prairie grasses, trees, and shrubs. The root systems of these plants bind the soil particles beneath the surface and prevent them from becoming airborne or exposed. As stated above, it is not anticipated that the vegetative cover

will be disturbed with future land use. Therefore, the potential for human ingestion of soil is low. The WDNR default value for age adjusted soil ingestion factor is 100 milligrams-year per kilograms-day (mg-yr/kg-d) and the USEPA default value is 114 mg-yr/kg-d.

Proposed Remediation Goals for Alternative Feasibility Study

Using a cancer risk factor of one in 1,000,000 (10^{-6}), an age adjusted ingestion factor of 114 mg-yr/kg-d, and an exposure frequency of 77 days per year, the direct contact site-specific residual contaminant level for 2,4-DNT would be 25.7 mg/kg. The USEPA RAIS Contaminated Media Calculator for determining the direct contact site-specific residual contaminant level was used to derive this result (http://rais.ornl.gov/cgi-bin/prg/PRG_search). The summary of the soil/sediment pathway equation input data, soil/sediment pathway results, and exposure pathway equations are included in Attachment A.

The remediation goals for all other contaminants of concern at the Site (see Table 1) would be the industrial residual contaminant levels, regional screening levels, or the respective background concentration. Bold values are the proposed remediation goals.

Table 1
Settling Ponds, Spoils Disposal Areas and Final Creek
Established and Proposed Remediation Goals

Contaminant of Concern	NR 720 Table 2 Residual Contaminant Level		BAAAP	USEPA Regional Screening Levels		NR 720-based
	Non-Industrial (mg/kg)	Industrial (mg/kg)	Background (mg/kg)	Residential (mg/kg)	Industrial (mg/kg)	Site-Specific Residual Contaminant Level (mg/kg)
Lead (Pb)	50/250	**500**	NA	400	800	NA
Arsenic (As)	0.039	1.6	**10**	0.39	1.6	NA
Chromium (Cr)	14/16,000	200/NA	**35.5+**	280	1,400	NA
Tin (Sn)	NA	NA	NA	47,000	**610,000**	NA
2,4-DNT	NA	NA	NA	1.6	5.5	**25.7**
2,6-DNT	NA	NA	NA	61	**620**	NA
Nitroglycerin	NA	NA	NA	6.1	**62**	NA

Bold values indicate proposed remediation goals – Shaded values are provided for comparison
NA = Not Applicable
+ = Total Chromium
DNT = Dinitrotoluene

It should be noted, contaminants of concern identified in the plan modification approved in 1995 also included 2n-nitrodiphenylamine (or possibly 2-nitrodiphenylamine), carcinogenic polycyclic aromatic hydrocarbons, diethyl phthalate, diphenylamine, nitrocellulose, aluminum, and zinc. These contaminants of concern either have no applicable cleanup standard or were not identified in any Site soil samples exceeding USEPA regional screening levels.

The Army is confident, based on sound scientific principles, that these remediation goals will be protective of human health and the environment. The Army respectfully requests the WDNR review and comments regarding the methodology and proposed cleanup objectives presented in this draft document.

Please do not hesitate to contact us with any questions at 608-643-3361.

Sincerely,

Joan M. Kenney

Joan M. Kenney
Commander's Representative

Attachment
Copy furn: SpecPro, Inc.

Attachment A

Summary of Soil/Sediment Pathway Equation Input Data, Soil/Sediment Pathway Results and Exposure Pathway Equations

Risk Assessment Information System Preliminary Remediation Goals Calculator

Recreational Exposure to Soil or Sediment (2,4-Dinitrotoluene)

Soil/Sediment Pathway Equation Input Data

Variable	Value
TR (target cancer risk) unitless	0.000001
THQ (target hazard quotient) unitless	1
EF_r (exposure frequency) d/yr	***77***
ED_r (exposure duration - recreator) years	30
$ED_{0\text{-}2}$ (exposure duration first phase) years	2
$ED_{2\text{-}6}$ (exposure duration second phase) years	4
$ED_{6\text{-}16}$ (exposure duration third phase) years	10

Variable	Value
$ED_{16\text{-}30}$ (exposure duration fourth phase) years	14
LT (lifetime - recreator) yr	70
ET_r (exposure time - recreator) hours	1
BW_a (body weight - adult) kg	70
BW_c (body weight - child) kg	15
ED_c (exposure duration - child) years	6
IRS_a (soil intake rate - adult) mg/day	100

Variable	Value
IRS_c (soil intake rate - child) mg/day	200
SA_a (skin surface area - adult) cm^2/day	5,700
SA_c (skin surface area - child) cm^2/day	2,800
AF_a (skin adherence factor - adult) mg/cm^2	0.07
AF_c (skin adherence factor - child) mg/cm^2	0.2
IFS_{adj} (age-adjusted soil ingestion factor) mg-yr/kg-day	114
DFS_{adj} (age-adjusted soil dermal factor) mg-yr/kg-day	361

All input values to the soil/sediment pathway equations are Risk Assessment Information System defaults with the exception of EFr (exposure frequency) d/yr

Results for Soil/Sediment Pathway

Chemical	Chronic RfD (mg/kg-day)	RfD Ref	Ingestion SF $(mg/kg\text{-}day)^{-1}$	SFO Ref	ABS_{gi}	Inhalation Unit Risk $(\mu g/m^3)^{-1}$	IUR Ref	Chronic RfC (mg/m^3)	RfC Ref
Dinitrotoluene, 2,4-	0.002	I	0.31	C	1	0.000089	C	-	-

ABS_{derm}	Volatilization Factor (m^3/kg)	Particulate Emission Factor (m^3/kg)	Ingestion PRG TR=1.0E-6 (mg/kg)	Dermal PRG TR=1.0E-6 (mg/kg)	Inhalation PRG TR=1.0E-6 (mg/kg)	**Carcinogenic PRG TR=1.0E-6 (mg/kg)**	Ingestion PRG HQ=1 (mg/kg)	Dermal PRG HQ=1 (mg/kg)	Inhalation PRG HQ=1 (mg/kg)	Noncarcinogenic PRG HI=1 (mg/kg)
0.102	-	1,360,000,000	225	29.1	4,050,000	**25.7**	17,100	2,490	-	2,170

Recreational Exposure to Soil or Sediment

Carcinogenic Dermal, Ingestion, and Inhalation Exposure Pathway Equations

Dermal

$$CDI_{rec\text{-}sol\text{-}ca\text{-}der}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{76\ days}{year}\right)\times DFS_{adj}\left(\frac{361\ mg\text{-}Year}{Kg\text{-}day}\right)\times ABS_{d}\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)}$$

where:

$$DFS_{adj}\left(\frac{361\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_{c}\left(6\ years\right)\times SA_{c}\left(\frac{2800\ cm^{2}}{day}\right)\times AF_{c}\left(\frac{0.2\ mg}{cm^{2}}\right)}{BW_{c}\left(16\ Kg\right)}+\frac{ED_{r}\text{-}ED_{c}\left(24\ years\right)\times SA_{a}\left(\frac{6700\ cm^{2}}{day}\right)\times AF_{a}\left(\frac{0.07\ mg}{cm^{2}}\right)}{BW_{a}\left(70\ Kg\right)}$$

Ingestion

$$CDI_{rec\text{-}sol\text{-}ca\text{-}ing}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times IFS_{adj}\left(\frac{114\ mg\text{-}Year}{Kg\text{-}day}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)}$$

where:

$$IFS_{adj}\left(\frac{114\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_{c}\left(6\ years\right)\times IRS_{c}\left(\frac{200\ mg}{day}\right)}{BW_{c}\left(15\ Kg\right)}+\frac{ED_{r}\text{-}ED_{c}\left(24\ years\right)\times IRS_{a}\left(\frac{100\ mg}{day}\right)}{BW_{a}\left(70\ Kg\right)}$$

Inhalation

$$CDI_{rec\text{-}sol\text{-}ca\text{-}inh}\left(\mu g/m^{3}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{76\ days}{year}\right)\times\left(\frac{1}{VF_{a}\left(\frac{m^{3}}{Kg}\right)}+\frac{1}{PEF_{w}\left(\frac{m^{3}}{Kg}\right)}\right)\times ED_{r}\left(30\ years\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)\times\left(\frac{1\ mg}{1000\ \mu g}\right)}$$

Recreational Exposure to Soil or Sediment

Mutagenic Dermal, Ingestion, and Inhalation Exposure Pathway Equations

Dermal

$$CDI_{rec\text{-}sol\text{-}mu\text{-}der}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{76\ days}{year}\right)\times DFSM_{adj}\left(\frac{1446\ mg\text{-}Year}{Kg\text{-}day}\right)\times ABS_{d}\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)}$$

where:

$$DFSM_{adj}\left(\frac{1446\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_{0\text{-}2}\left(yr\right)\times AF_{c}\left(\frac{0.2\ mg}{cm^{2}}\right)\times SA_{c}\left(\frac{2800\ cm^{2}}{day}\right)\times 10}{BW_{c}\left(16\ Kg\right)}+\frac{ED_{2\text{-}8}\left(yr\right)\times AF_{c}\left(\frac{0.2\ mg}{cm^{2}}\right)\times SA_{c}\left(\frac{2800\ cm^{2}}{day}\right)\times 3}{BW_{c}\left(16\ Kg\right)}+$$
$$\frac{ED_{8\text{-}16}\left(yr\right)\times AF_{a}\left(\frac{0.07\ mg}{cm^{2}}\right)\times SA_{a}\left(\frac{6700\ cm^{2}}{day}\right)\times 3}{BW_{a}\left(70\ Kg\right)}+\frac{ED_{16\text{-}30}\left(yr\right)\times AF_{a}\left(\frac{0.07\ mg}{cm^{2}}\right)\times SA_{a}\left(\frac{6730\ cm^{2}}{day}\right)\times 1}{BW_{a}\left(70\ Kg\right)}$$

Ingestion

$$CDI_{rec\text{-}sol\text{-}mu\text{-}ing}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{76\ days}{year}\right)\times IFSM_{adj}\left(\frac{489.6\ mg\text{-}Year}{Kg\text{-}day}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)}$$

where:

$$IFSM_{adj}\left(\frac{489.6\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_{0\text{-}2}\left(yr\right)\times IRS_{c}\left(\frac{200\ mg}{day}\right)\times 10}{BW_{c}\left(16\ Kg\right)}+\frac{ED_{2\text{-}8}\left(yr\right)\times IRS_{c}\left(\frac{200\ mg}{day}\right)\times 3}{BW_{c}\left(16\ Kg\right)}+$$
$$\frac{ED_{8\text{-}16}\left(yr\right)\times IRS_{a}\left(\frac{100\ mg}{day}\right)\times 3}{BW_{a}\left(70\ Kg\right)}+\frac{ED_{16\text{-}30}\left(yr\right)\times IRS_{a}\left(\frac{100\ mg}{day}\right)\times 1}{BW_{a}\left(70\ Kg\right)}$$

Inhalation

$$CDI_{rec\text{-}sol\text{-}mu\text{-}inh}\left(\mu g/m^{3}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times}{\left(\left(ED_{0\text{-}2}\left(yrs\right)\times 10\right)+\left(ED_{2\text{-}6}\left(yrs\right)\times 3\right)+\left(ED_{6\text{-}16}\left(yrs\right)\times 3\right)+\left(ED_{16\text{-}30}\left(yrs\right)\times 1\right)\right)\times\left(\frac{1}{VF_{s}\left(\frac{m^{3}}{Kg}\right)}+\frac{1}{PEF_{w}\left(\frac{m^{3}}{Kg}\right)}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)\times\left(\frac{1\ mg}{1000\ \mu g}\right)}$$

Recreational Exposure to Soil or Sediment

Non-Carcingenic Dermal, Ingestion, and Inhalation Exposure Pathway Equations

Dermal

$$CDI_{rec\text{-}soil\text{-}nc\text{-}der}\left(\frac{mg}{kg\text{-}day}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ED_c\ (6\ years)\times SA_c\left(\frac{2800\ cm^2}{day}\right)\times AF_c\left(\frac{0.2\ mg}{cm^2}\right)\times ABS_d\times\frac{10^{-6}Kg}{1mg}}{AT_{rec}\left(\frac{365\ days}{year}\times ED_c\ (6\ years)\right)\times BW_c\ (15\ Kg)}$$

Ingestion

$$CDI_{rec\text{-}soil\text{-}nc\text{-}ing}\left(\frac{mg}{kg\text{-}day}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ED_c\ (6\ years)\times IRS_c\left(\frac{200\ mg}{day}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\frac{10^{-6}Kg}{1mg}}{AT_{rec}\left(\frac{365\ days}{year}\times ED_c\ (6\ years)\right)\times BW_c\ (15\ Kg)}$$

Inhalation

$$CDI_{rec\text{-}soil\text{-}nc\text{-}inh}\left(mg/m^3\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ED_c\ (6\ years)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\frac{1}{VF_s\left(\frac{m^3}{Kg}\right)}+\frac{1}{PEF_w\left(\frac{m^3}{Kg}\right)}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times ED_c\ (6\ years)\right)}$$

Source of equations: http://rais.ornl.gov/

Recreational Exposure to Soil or Sediment

Carcinogenic Dermal, Ingestion, and Inhalation Exposure Pathway Equations

Dermal

$$CDI_{rec\text{-}sol\text{-}ca\text{-}der}\left(\frac{mg}{kg\text{-}day}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{76\ days}{year}\right)\times DFS_{adj}\left(\frac{361\ mg\text{-}Year}{Kg\text{-}day}\right)\times ABS_d\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\ (70\ years)\right)}$$

where:

$$DFS_{adj}\left(\frac{361\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_c\ (6\ years)\times SA_c\left(\frac{2800\ cm^2}{day}\right)\times AF_c\left(\frac{0.2\ mg}{cm^2}\right)}{BW_c\ (16\ Kg)}+\frac{ED_f\text{-}ED_c\ (24\ years)\times SA_a\left(\frac{5700\ cm^2}{day}\right)\times AF_a\left(\frac{0.07\ mg}{cm^2}\right)}{BW_a\ (70\ Kg)}$$

Ingestion

$$CDI_{rec\text{-}sol\text{-}ca\text{-}ing}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times IFS_{adj}\left[\frac{114\ mg\text{-}Year}{Kg\text{-}day}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\ (70\ years)\right)}$$

where:

$$IFS_{adj}\left(\frac{114\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_c\ (6\ years)\times IRS_c\left(\frac{200\ mg}{day}\right)}{BW_c\ (15\ Kg)}+\frac{ED_f\text{-}ED_c\ (24\ years)\times IRS_a\left(\frac{100\ mg}{day}\right)}{BW_a\ (70\ Kg)}$$

Inhalation

$$CDI_{rec\text{-}sol\text{-}ca\text{-}inh}\left(\mu g/m^3\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{76\ days}{year}\right)\times\left(\frac{1}{VF_s\left(\frac{m^3}{Kg}\right)}+\frac{1}{PEF_w\left(\frac{m^3}{Kg}\right)}\right)\times ED_f\ (30\ years)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\ (70\ years)\right)\times\left(\frac{1\ mg}{1000\ \mu g}\right)}$$

Recreational Exposure to Soil or Sediment

Mutagenic Dermal, Ingestion, and Inhalation Exposure Pathway Equations

Dermal

$$CDI_{rec\text{-}sol\text{-}mu\text{-}der}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times DFSM_{adj}\left(\frac{1445\ mg\text{-}Year}{Kg\text{-}day}\right)\times ABS_d\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)}$$

where:

$$DFSM_{adj}\left(\frac{1445\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_{0\text{-}2}\left(yr\right)\times AF_c\left(\frac{0.2\ mg}{cm^2}\right)\times SA_c\left(\frac{2800\ cm^2}{day}\right)\times 10}{BW_c\left(16\ Kg\right)}+\frac{ED_{2\text{-}6}\left(yr\right)\times AF_c\left(\frac{0.2\ mg}{cm^2}\right)\times SA_c\left(\frac{2800\ cm^2}{day}\right)\times 3}{BW_c\left(16\ Kg\right)}+$$
$$\frac{ED_{6\text{-}16}\left(yr\right)\times AF_a\left(\frac{0.07\ mg}{cm^2}\right)\times SA_a\left(\frac{5700\ cm^2}{day}\right)\times 3}{BW_a\left(70\ Kg\right)}+\frac{ED_{16\text{-}30}\left(yr\right)\times AF_a\left(\frac{0.07\ mg}{cm^2}\right)\times SA_a\left(\frac{5730\ cm^2}{day}\right)\times 1}{BW_a\left(70\ Kg\right)}$$

Ingestion

$$CDI_{rec\text{-}sol\text{-}mu\text{-}ing}\left(mg/kg\text{-}day\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times IFSM_{adj}\left(\frac{489.6\ mg\text{-}Year}{Kg\text{-}day}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\frac{10^{-6}Kg}{mg}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)}$$

where:

$$IFSM_{adj}\left(\frac{489.6\ mg\text{-}Year}{Kg\text{-}day}\right)=\frac{ED_{0\text{-}2}\left(yr\right)\times IRS_c\left(\frac{200\ mg}{day}\right)\times 10}{BW_c\left(16\ Kg\right)}+\frac{ED_{2\text{-}6}\left(yr\right)\times IRS_c\left(\frac{200\ mg}{day}\right)\times 3}{BW_c\left(16\ Kg\right)}+$$
$$\frac{ED_{6\text{-}16}\left(yr\right)\times IRS_a\left(\frac{100\ mg}{day}\right)\times 3}{BW_a\left(70\ Kg\right)}+\frac{ED_{16\text{-}30}\left(yr\right)\times IRS_a\left(\frac{100\ mg}{day}\right)\times 1}{BW_a\left(70\ Kg\right)}$$

Inhalation

$$CDI_{rec\text{-}sol\text{-}mu\text{-}inh}\left(\mu g/m^3\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\begin{array}{l}\left(ED_{0\text{-}2}\left(yrs\right)\times 10\right)+\left(ED_{2\text{-}6}\left(yrs\right)\times 3\right)+\\ \left(ED_{6\text{-}16}\left(yrs\right)\times 3\right)+\left(ED_{16\text{-}30}\left(yrs\right)\times 1\right)\end{array}\right)\times\left(\frac{1}{VF_s\left(\frac{m^3}{Kg}\right)}+\frac{1}{PEF_w\left(\frac{m^3}{Kg}\right)}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times LT\left(70\ years\right)\right)\times\left(\frac{1\ mg}{1000\ \mu g}\right)}$$

Recreational Exposure to Soil or Sediment

Non-Carcingenic Dermal, Ingestion, and Inhalation Exposure Pathway Equations

Dermal

$$CDI_{rec\text{-}sol\text{-}nc\text{-}der}\left(\frac{mg}{kg\text{-}day}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ED_c\ (6\ years)\times SA_c\left(\frac{2800\ cm^2}{day}\right)\times AF_c\left(\frac{0.2\ mg}{cm^2}\right)\times ABS_d\times\frac{10^{-6}Kg}{1mg}}{AT_{rec}\left(\frac{365\ days}{year}\times ED_c\ (6\ years)\right)\times BW_c\ (15\ Kg)}$$

Ingestion

$$CDI_{rec\text{-}sol\text{-}nc\text{-}ing}\left(\frac{mg}{kg\text{-}day}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ED_c\ (6\ years)\times IRS_c\left(\frac{200\ mg}{day}\right)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\frac{10^{-6}Kg}{1mg}}{AT_{rec}\left(\frac{365\ days}{year}\times ED_c\ (6\ years)\right)\times BW_c\ (15\ Kg)}$$

Inhalation

$$CDI_{rec\text{-}sol\text{-}nc\text{-}inh}\left(\frac{mg}{m^3}\right)=\frac{C_{soil}\left(\frac{mg}{kg}\right)\times EF_{rec}\left(\frac{75\ days}{year}\right)\times ED_c\ (6\ years)\times ET_{rec}\left(\frac{1\ hr}{day}\right)\times\left(\frac{1\ day}{24\ hours}\right)\times\left(\frac{1}{VF_s\left(\frac{m^3}{Kg}\right)}+\frac{1}{PEF_w\left(\frac{m^3}{Kg}\right)}\right)}{AT_{rec}\left(\frac{365\ days}{year}\times ED_c\ (6\ years)\right)}$$

Source of equations: http://rais.ornl.gov/