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Appendices

APPENDIX TABLE OF CONTENTS

APPENDIX A

INITIAL DEFAULT TARGET LEVELS (IDTLs)

APPENDIX TABLE OF CONTENTS

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INITIAL DEFAULT TARGET LEVELS (IDTLs)

CHEMICALS OF CONCERN	SOIL			GROUNDWATER		
	IDTL [mg/kg]	Critical Pathway	Critical Receptor	IDTL [mg/L]	Critical Pathway	Basis for Ingestion Target/ Inhalation Critical Receptor$_i$
1,1,1,2-Tetrachloroethane	4.09E-02	GWP[a]	GWP	2.15E-03	Ingestion	Risk-Based
1,1,1-Trichloroethane	2.00E+00	GWP	GWP	2.00E-01	Ingestion	MCL[b]
1,1,2,2-Tetrachloroethane	9.15E-04	GWP	GWP	2.79E-04	Ingestion	Risk-Based
1,1,2-Trichloroethane	1.41E-02	GWP	GWP	5.00E-03	Ingestion	MCL
1,1-Dichloroethane	3.48E+00	GWP	GWP	1.04E+00	Ingestion	Risk-Based
1,1-Dichloroethene	3.88E-02	GWP	GWP	7.00E-03	Ingestion	MCL
1,2,3-Trichloropropane	2.45E-04	GWP	GWP	2.79E-05	Ingestion	Risk-Based
1,2,4-Trichlorobenzene	6.92E-01	Subsurface Soil	Child	7.00E-02	Ingestion	MCL
1,2,4-Trimethylbenzene (pseudocumene)	1.93E-01	Subsurface Soil	Child	4.39E-01	Indoor Inhalation	Child
1,2-Dibromo-3-chloropropane	9.75E-04	GWP	GWP	2.00E-04	Ingestion	MCL
1,2-Dichlorobenzene	5.25E+00	GWP	GWP	6.00E-01	Ingestion	MCL
1,2-Dichloroethane	7.67E-03	Subsurface Soil	Child	5.00E-03	Ingestion	MCL
1,2-Dichloroethene-(cis)	1.93E-01	GWP	GWP	7.00E-02	Ingestion	MCL
1,2-Dichloroethene-(trans)	3.65E-01	GWP	GWP	1.00E-01	Ingestion	MCL
1,2-Dichloropropane	8.90E-03	Subsurface Soil	Child	5.00E-03	Ingestion	MCL
1,2-Diphenylhydrazine	9.48E-04	GWP	GWP	6.98E-05	Ingestion	Risk-Based
1,3,5-Trimethylbenzene	1.45E-01	Subsurface Soil	Child	3.04E-01	Indoor Inhalation	Child
1,3-Dichlorobenzene	2.29E-01	Subsurface Soil	Child	9.39E-03	Ingestion	Risk-Based
1,3-Dichloropropene-(cis)	2.45E-03	GWP	GWP	5.59E-04	Ingestion	Risk-Based
1,3-Dichloropropene-(trans)	2.45E-03	GWP	GWP	5.59E-04	Ingestion	Risk-Based
1,4-Dichlorobenzene	7.55E-02	Subsurface Soil	Child	7.50E-02	Ingestion	MCL
2,3,7,8-TCDD[h]	3.91E-06	Surficial Soil	Age-Adjusted	3.00E-08	Ingestion	MCL
2,4,5 TP (silvex)[i]	2.37E+00	GWP	GWP	5.00E-02	Ingestion	MCL
2,4,5-Trichlorophenol	7.38E+00	GWP	GWP	1.04E+00	Ingestion	Risk-Based
2,4,6-Trichlorophenol	4.36E-03	GWP	GWP	1.04E-03	Ingestion	Risk-Based
2,4,6-Trinitrotoluene	1.34E-02	GWP	GWP	1.86E-03	Ingestion	Risk-Based
2,4-Dichlorophenol	9.78E-02	GWP	GWP	3.13E-02	Ingestion	Risk-Based
2,4Dichlorophenoxyacetic acid	1.84E+00	GWP	GWP	1.04E-01	Ingestion	Risk-Based
2,4-Dimethylphenol	8.19E-01	GWP	GWP	2.09E-01	Ingestion	Risk-Based
2,4Dinitro-6-sec-butylphenol (Dinoseb)	1.63E-01	GWP	GWP	7.00E-03	Ingestion	MCL

INITIAL DEFAULT TARGET LEVELS (IDTLs)

CHEMICALS OF CONCERN	SOIL			GROUNDWATER		
	IDTL [mg/kg]	Critical Pathway	Critical Receptor	IDTL [mg/L]	Critical Pathway	Basis for Ingestion Target/ Inhalation Critical Receptor$_i$
2,4-Dinitrophenol	3.84E-02	GWP	GWP	2.09E-02	Ingestion	Risk-Based
2,4-Dinitrotoluene	2.90E-04	GWP	GWP	8.22E-05	Ingestion	Risk-Based
2,6-Dinitrotoluene	2.12E-04	GWP	GWP	8.22E-05	Ingestion	Risk-Based
2-Butanone (Methyl Ethyl Ketone)	1.18E+01	GWP	GWP	6.26E+00	Ingestion	Risk-Based
2-Chloronaphthalene	1.28E+02	GWP	GWP	8.34E-01	Ingestion	Risk-Based
2-Chlorophenol	3.65E-01	GWP	GWP	5.21E-02	Ingestion	Risk-Based
2-Chlorotoluene	1.56E+00	Subsurface Soil	Child	2.09E-01	Ingestion	Risk-Based
2-Methylnaphthalene	3.31E+00	GWP	GWP	4.17E-02	Ingestion	Risk-Based
2-Methylphenol	1.80E+00	GWP	GWP	5.21E-01	Ingestion	Risk-Based
2-Nitroaniline	7.25E-02	GWP	GWP	3.13E-02	Ingestion	Risk-Based
3,3-Dichlorobenzidine	1.83E-03	GWP	GWP	1.24E-04	Ingestion	Risk-Based
3-Nitroaniline	3.18E-03	GWP	GWP	1.47E-03	Ingestion	Risk-Based
4- Bromophenylphenylether	5.45E-03	GWP	GWP	3.72E-06	Ingestion	Risk-Based
4-Chloroaniline	1.26E-01	GWP	GWP	4.17E-02	Ingestion	Risk-Based
4-Methyl-2-pentanone	1.76E+01	GWP	GWP	8.97E+00	Ingestion	Risk-Based
4-Methylphenol	1.41E-01	GWP	GWP	5.21E-02	Ingestion	Risk-Based
4-Nitroaniline	2.99E-03	GWP	GWP	1.47E-03	Ingestion	Risk-Based
4-Nitrophenol	2.26E-01	GWP	GWP	8.34E-02	Ingestion	Risk-Based
Acenaphthene	5.23E+01	GWP	GWP	6.26E-01	Ingestion	Risk-Based
Acenaphthylene	7.80E+01	GWP	GWP	6.26E-01	Ingestion	Risk-Based
Acetochlor	1.12E+00	GWP	GWP	2.09E-01	Ingestion	Risk-Based
Acetone	1.74E+01	GWP	GWP	9.39E+00	Ingestion	Risk-Based
Acrolein	9.65E-03	GWP	GWP	5.21E-03	Ingestion	Risk-Based
Acrylonitrile	1.94E-04	GWP	GWP	1.03E-04	Ingestion	Risk-Based
Alachlor	1.05E-02	GWP	GWP	2.00E-03	Ingestion	MCL
Aldicarb	4.14E-02	GWP	GWP	1.04E-02	Ingestion	Risk-Based
Aldrin	2.11E-02	Surficial Soil	Age-Adjusted	3.29E-06	Ingestion	Risk-Based
Ammonia	4.15E+00	Subsurface Soil	Child	NA	NA	NA
Aniline	1.96E-02	GWP	GWP	9.80E-03	Ingestion	Risk-Based
Anthracene	1.04E+03	GWP	GWP	3.13E+00	Ingestion	Risk-Based
Antimony	4.77E+00	GWP	GWP	6.00E-03	Ingestion	MCL

INITIAL DEFAULT TARGET LEVELS (IDTLs)

CHEMICALS OF CONCERN	SOIL			GROUNDWATER		
	IDTL [mg/kg]	Critical Pathway	Critical Receptor	IDTL [mg/L]	Critical Pathway	Basis for Ingestion Target/ Inhalation Critical Receptor$_i$
Aroclor 1016	2.33E+00	GWP	GWP	7.30E-04	Ingestion	Risk-Based
Aroclor 1221	2.94E-03	GWP	GWP	2.79E-05	Ingestion	Risk-Based
Aroclor 1242	3.18E-03	GWP	GWP	2.79E-05	Ingestion	Risk-Based
Aroclor 1248	1.37E-01	GWP	GWP	2.79E-05	Ingestion	Risk-Based
Aroclor 1254	7.40E-01	Surficial Soil	Child	2.09E-04	Ingestion	Risk-Based
Aroclor 1260	1.47E-01	Surficial Soil	Age-Adjusted	2.79E-05	Ingestion	Risk-Based
Arsenic	3.91E-01	Surficial Soil	Age-Adjusted	1.00E-02	Ingestion	MCL
Atrazine	1.39E-02	GWP	GWP	3.00E-03	Ingestion	MCL
Azobenzene	1.30E-02	GWP	GWP	5.08E-04	Ingestion	Risk-Based
Barium	8.96E+02	GWP	GWP	2.00E+00	Ingestion	MCL
Benzene	1.78E-02	GWP	GWP	5.00E-03	Ingestion	MCL
Benzidine	5.37E-07	GWP	GWP	2.43E-07	Ingestion	Risk-Based
Benzo(a)anthracene	4.22E-01	Surficial Soil	Age-Adjusted	7.65E-05	Ingestion	Risk-Based
Benzo(a)pyrene	4.22E-02	Surficial Soil	Age-Adjusted	2.00E-04	Ingestion	MCL
Benzo(b)fluoranthene	4.22E-01	Surficial Soil	Age-Adjusted	7.65E-05	Ingestion	Risk-Based
Benzo(g,h,i)perylene	1.18E+03	Surficial Soil	Child	3.13E-01	Ingestion	Risk-Based
Benzo(k)fluoranthene	4.22E+00	Surficial Soil	Age-Adjusted	7.65E-04	Ingestion	Risk-Based
Benzoic acid	7.71E+01	GWP	GWP	4.17E+01	Ingestion	Risk-Based
Benzyl Alcohol	6.43E+00	GWP	GWP	3.13E+00	Ingestion	Risk-Based
Beryllium	1.63E+00	GWP	GWP	4.00E-03	Ingestion	MCL
BHC-alpha[c]	2.10E-04	GWP	GWP	8.87E-06	Ingestion	Risk-Based
BHC-beta	7.51E-04	GWP	GWP	3.10E-05	Ingestion	Risk-Based
BHC-gamma(Lindane)	8.96E-04	GWP	GWP	4.30E-05	Ingestion	Risk-Based
Bis(2-chloroethyl)ether	1.08E-04	GWP	GWP	5.08E-05	Ingestion	Risk-Based
Bis(2-chloroisopropyl)ether	3.11E+00	GWP	GWP	4.17E-01	Ingestion	Risk-Based
Bis(2-ethylhexyl)phthalate	1.18E+01	GWP	GWP	6.00E-03	Ingestion	MCL
Bromodichloromethane	2.68E-03	GWP	GWP	9.01E-04	Ingestion	Risk-Based
Bromoform	2.92E-02	GWP	GWP	7.07E-03	Ingestion	Risk-Based
Bromomethane	5.01E-02	GWP	GWP	1.46E-02	Ingestion	Risk-Based
Butyl benzyl phthalate	5.11E+02	GWP	GWP	2.09E+00	Ingestion	Risk-Based
Cadmium	1.35E+00	GWP	GWP	5.00E-03	Ingestion	MCL

INITIAL DEFAULT TARGET LEVELS (IDTLs)

CHEMICALS OF CONCERN	SOIL			GROUNDWATER		
	IDTL [mg/kg]	Critical Pathway	Critical Receptor	IDTL [mg/L]	Critical Pathway	Basis for Ingestion Target/ Inhalation Critical Receptor$_i$
Carbofuran	9.42E-02	GWP	GWP	4.00E-02	Ingestion	MCL
Carbon disulfide	5.97E+00	GWP	GWP	1.04E+00	Ingestion	Risk-Based
Carbon Tetrachloride	1.14E-02	Subsurface Soil	Child	4.56E-03	Indoor Inhalation	Age-Adjusted
Chlordane	1.53E+00	Surficial Soil	Age-Adjusted	2.00E-03	Ingestion	MCL
Chlorobenzene	6.18E-01	GWP	GWP	1.00E-01	Ingestion	MCL
Chloroethane	5.33E-02	GWP	GWP	1.93E-02	Ingestion	Risk-Based
Chloroform	5.64E-03	GWP	GWP	1.80E-03	Ingestion	Risk-Based
Chloromethane	2.31E-02	GWP	GWP	4.30E-03	Ingestion	Risk-Based
Chlorpyrifos	2.84E+00	GWP	GWP	3.13E-02	Ingestion	Risk-Based
Chromium (III) total Cr	2.13E+03	GWP	GWP	1.00E-01	Ingestion	MCL
Chromium (VI)	7.90E+00	GWP	GWP	3.13E-02	Ingestion	Risk-Based
Chrysene	3.34E+01	GWP	GWP	7.65E-03	Ingestion	Risk-Based
Copper	9.21E+02	GWP	GWP	1.30E+00	Ingestion	MCL
Cyanide (as Sodium Cyanide)	3.68E-01	GWP	GWP	2.00E-01	Ingestion	MCL
Dacthal	1.58E+01	Subsurface Soil	Child	1.04E-01	Ingestion	Risk-Based
Dalapon (2,2-dichloropropionic acid)	4.57E-01	GWP	GWP	2.00E-01	Ingestion	MCL
DDD[d]	2.44E+00	Surficial Soil	Age-Adjusted	2.33E-04	Ingestion	Risk-Based
DDE[e]	1.72E+00	Surficial Soil	Age-Adjusted	1.64E-04	Ingestion	Risk-Based
DDT[f]	4.03E-01	GWP	GWP	1.64E-04	Ingestion	Risk-Based
Demeton	1.29E-03	GWP	GWP	4.17E-04	Ingestion	Risk-Based
Dibenzo(a,h)anthracene	4.22E-02	Surficial Soil	Age-Adjusted	7.65E-06	Ingestion	Risk-Based
Dibenzofuran	6.10E+00	GWP	GWP	4.17E-02	Ingestion	Risk-Based
Dibromochloromethane	2.02E-03	GWP	GWP	6.65E-04	Ingestion	Risk-Based
Dichlorodifluoromethane	2.96E+00	Subsurface Soil	Child	1.95E-01	Indoor Inhalation	Child
Dieldrin	1.33E-03	GWP	GWP	3.49E-06	Ingestion	Risk-Based
Diethylphthalate	2.75E+01	GWP	GWP	8.34E+00	Ingestion	Risk-Based
Dimethylphthalate	2.71E+02	GWP	GWP	1.04E+02	Ingestion	Risk-Based
Di-n-butyl phthalate	3.10E+01	GWP	GWP	1.04E+00	Ingestion	Risk-Based
Di-n-octyl phthalate	1.83E+03	Surficial Soil	Child	4.17E-01	Ingestion	Risk-Based
Diquat	1.09E-01	GWP	GWP	2.00E-02	Ingestion	MCL

INITIAL DEFAULT TARGET LEVELS (IDTLs)

CHEMICALS OF CONCERN	SOIL			GROUNDWATER		
	IDTL [mg/kg]	Critical Pathway	Critical Receptor	IDTL [mg/L]	Critical Pathway	Basis for Ingestion Target/ Inhalation Critical Receptor$_i$
Disulfoton	6.68E-02	GWP	GWP	4.17E-04	Ingestion	Risk-Based
Diuron	2.16E-01	GWP	GWP	2.09E-02	Ingestion	Risk-Based
Endosulfan	2.49E+00	GWP	GWP	6.26E-02	Ingestion	Risk-Based
Endothall	3.35E-01	GWP	GWP	1.00E-01	Ingestion	MCL
Endrin	3.35E-01	GWP	GWP	2.00E-03	Ingestion	MCL
Eptam	1.39E+00	GWP	GWP	2.61E-01	Ingestion	Risk-Based
Ethylbenzene	1.02E+01	GWP	GWP	7.00E-01	Ingestion	MCL
Ethylene dibromide(EDB)	1.43E-04	GWP	GWP	5.00E-05	Ingestion	MCL
Fluoranthene	3.64E+02	GWP	GWP	4.17E-01	Ingestion	Risk-Based
Fluorene	5.48E+01	GWP	GWP	4.17E-01	Ingestion	Risk-Based
Fluoride (as Sodium Fluoride)	7.36E+00	GWP	GWP	4.00E+00	Ingestion	MCL
Glyphosate	4.48E+01	GWP	GWP	7.00E-01	Ingestion	MCL
Heptachlor	1.06E-03	Subsurface Soil	Age-Adjusted	4.00E-04	Ingestion	MCL
Heptachlor epoxide	2.61E-02	GWP	GWP	2.00E-04	Ingestion	MCL
Hexachlorobenzene	4.27E-02	Subsurface Soil	Age-Adjusted	1.00E-03	Ingestion	MCL
Hexachlorobutadiene	3.78E-02	Subsurface Soil	Age-Adjusted	7.16E-04	Ingestion	Risk-Based
Hexachlorocyclopentadiene	1.16E-02	Subsurface Soil	Child	7.01E-03	Indoor Inhalation	Child
Hexachloroethane	1.38E-01	GWP	GWP	3.99E-03	Ingestion	Risk-Based
Hexazinone	8.84E-01	GWP	GWP	3.44E-01	Ingestion	Risk-Based
Hydrogen Sulfide	2.96E-02	Subsurface Soil	Child	1.75E-02	Indoor Inhalation	Child
Indeno(1,2,3-cd)pyrene	4.22E-01	Surficial Soil	Age-Adjusted	7.65E-05	Ingestion	Risk-Based
Iron (as Iron Oxide)	5.76E+00	GWP	GWP	3.13E+00	Ingestion	Risk-Based
Isophorone	1.40E-01	GWP	GWP	5.88E-02	Ingestion	Risk-Based
Isopropylbenzene (Cumene)	3.46E+00	GWP	GWP	1.04E+00	Ingestion	Risk-Based
Lead	4.96E+01	GWP	GWP	1.50E-02	Ingestion	MCL
Manganese	2.23E+02	GWP	GWP	2.50E-01	Ingestion	Risk-Based
Mercury	5.09E-03	GWP	GWP	2.00E-03	Ingestion	MCL
Methoxychlor	5.52E+01	GWP	GWP	4.00E-02	Ingestion	MCL
Methylene Chloride	1.69E-02	GWP	GWP	7.45E-03	Ingestion	Risk-Based
Metolachlor	8.43E+00	GWP	GWP	1.56E+00	Ingestion	Risk-Based
Metribuzin	7.21E-01	GWP	GWP	2.61E-01	Ingestion	Risk-Based

INITIAL DEFAULT TARGET LEVELS (IDTLs)

CHEMICALS OF CONCERN	SOIL			GROUNDWATER		
	IDTL [mg/kg]	Critical Pathway	Critical Receptor	IDTL [mg/L]	Critical Pathway	Basis for Ingestion Target/ Inhalation Critical Receptor$_i$
MTBE[g]	3.64E-02	GWP	GWP	1.69E-02	Ingestion	Risk-Based
Naphthalene	1.14E+00	Subsurface Soil	Child	2.09E-01	Ingestion	Risk-Based
Nickel	5.91E+01	GWP	GWP	2.09E-01	Ingestion	Risk-Based
Nitrate (as Sodium Nitrate)	1.84E+01	GWP	GWP	1.00E+01	Ingestion	MCL
Nitrite (as Sodium Nitrite)	1.84E+00	GWP	GWP	1.00E+00	Ingestion	MCL
Nitrobenzene	2.18E-02	GWP	GWP	5.21E-03	Ingestion	Risk-Based
N-Nitrosodimethylamine	2.09E-06	GWP	GWP	1.10E-06	Ingestion	Risk-Based
N-Nitrosodi-n-propylamine	1.81E-05	GWP	GWP	7.98E-06	Ingestion	Risk-Based
N-Nitrosodiphenylamine	8.80E-02	GWP	GWP	1.14E-02	Ingestion	Risk-Based
Oxamyl (Vydate)	3.86E-01	GWP	GWP	2.00E-01	Ingestion	MCL
Pentachlorophenol	9.07E-03	GWP	GWP	1.00E-03	Ingestion	MCL
Phenanthrene	7.90E+01	GWP	GWP	3.13E-01	Ingestion	Risk-Based
Phenol	7.36E+00	GWP	GWP	3.13E+00	Ingestion	Risk-Based
Picloram	2.95E+00	GWP	GWP	5.00E-01	Ingestion	MCL
Prometon	7.04E-01	GWP	GWP	1.56E-01	Ingestion	Risk-Based
Pyrene	3.59E+02	GWP	GWP	3.13E-01	Ingestion	Risk-Based
sec-Butylbenzene	1.17E+00	Subsurface Soil	Child	1.04E-01	Ingestion	Risk-Based
Selenium	2.03E+00	GWP	GWP	5.00E-02	Ingestion	MCL
Silver	1.89E-01	GWP	GWP	5.21E-02	Ingestion	Risk-Based
Simazine	1.08E-02	GWP	GWP	4.00E-03	Ingestion	MCL
Styrene	1.83E+00	GWP	GWP	1.00E-01	Ingestion	MCL
Terbutryn	3.21E-01	GWP	GWP	1.04E-02	Ingestion	Risk-Based
tert-Butylbenzene	8.52E-01	Subsurface Soil	Child	1.04E-01	Ingestion	Risk-Based
Tetrachloroethene	2.88E-02	Subsurface Soil	Child	5.00E-03	Ingestion	MCL
Thallium	1.55E+00	GWP	GWP	2.00E-03	Ingestion	MCL
Toluene	4.89E+00	GWP	GWP	1.00E+00	Ingestion	MCL
Total Xylenes	1.67E+00	Subsurface Soil	Child	4.34E+00	Indoor Inhalation	Child
Toxaphene	3.26E-01	Surficial Soil	Age-Adjusted	3.00E-03	Ingestion	MCL
Trichloroethene	2.88E-03	Subsurface Soil	Child	3.32E-03	Indoor Inhalation	Age-Adjusted
Trichlorofluoromethane	1.04E+01	Subsurface Soil	Child	2.05E+00	Indoor Inhalation	Child
Vinyl Chloride	9.63E-03	GWP	GWP	2.00E-03	Ingestion	MCL
Zinc	8.86E+02	GWP	GWP	3.13E+00	Ingestion	Risk-Based

[a]Ground Water Protection Via Soils Leaching to Groundwater

[b]Maximum contaminant level

[c] Benzene hexachloride

[d] Dichloro diphenyl dichloroethylene

[e] 1,1-Dichloro-2,2-bis(p-chlorophenyl) ethane

[f] Dichloro diphenyl trichloroethane

[g] Methyl tert-butyl ether

[h] Tetrachloro di benzo-p-dioxin

[i] 4,5,-Trichlorophenoxy propionic acid

[j] For the ingestion pathway the source of the target level is indicated (MCL or a risk-based calculation); for the inhalation pathway the critical receptor is indicated (child or age-adjusted individual).

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APPENDIX B

SAMPLE DEED RESTRICTION LANGUAGE

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DECLARATION OF RESTRICTIONS

This Declaration of Restrictions to Run with the Land (Declaration) made by_____A_____, a _____ Corporation, ("_B_") its successors and assigns, and the State of Idaho Department of Environmental Quality ("Department"), its successors and assigns, sets forth protective provisions, covenants, restrictions, conditions (collectively referred to as "Restrictions") designed to protect natural resources and maintain air and water quality, upon and subject to which the Property (as identified below) and every portion thereof shall be improved, held, used, occupied, leased, sold, hypothecated, encumbered, and/or conveyed.

Each and all of the Restrictions are imposed Pursuant to the Idaho Uniform Conservation Easement Act, Idaho Code 55-2101 through 2109, and the Idaho Environmental Protection and Health Act, Idaho Code 39-101 through 39-130, and Idaho Code 39-7202(1)(Supp. 1996). For purposes of this Declaration, the Department shall be a "holder" as defined in Idaho Code 55-2101(2). ___B____ and the Department agree that each and all of the Restrictions are enforceable by the Department, against _____.

Ownership. __B__ is the fee owner of certain real property in the City of _____, County of _____, State of Idaho, described as _____lot and township_____ and is subject to this Declaration ("Property"). The Property is legally described as follows:

INSERT LEGAL DESCRIPTION HERE

Provisions to Run With the Land. Each and all of the Restrictions shall run with the land, and pass with each and every portion of the Property, and shall apply to and bind the respective successors in interest thereof. Each and all of the Restrictions are imposed upon the entire Property unless expressly stated as applicable to a specific portion of the Property.

Concurrence of Owners Presumed. All purchasers, lessees, or possessors of any portion of the Property shall be deemed by their purchase, leasing, or possession of such Property, to be in accord with the foregoing and to agree for and among themselves, their heirs, successors, and assignees, and the agents, employees, and lessees of such owners, heirs, successors, and assignees, that the Restrictions as herein established must be adhered to for the benefit of future Owners and Occupants and that their interest in the Property shall be subject to the Restrictions contained herein.

Recording/Filing of Declaration. This Declaration shall be recorded in the county recorder's office in the county where the Property is located within five (5) days of the effective date of this Declaration. __B__ shall provide to the Department a copy of this Declaration evidencing its recording in compliance with this provision within ten (10) days of the effective date of this Declaration. The Restrictions set forth herein shall be incorporated by reference in each and all deeds and leases of any portion of the Property.

Restricted Portion. A portion of the Property ("Restricted Portion") described and depicted in Exhibit "A" attached hereto and made a part hereof was previously used to operate _____ (a petroleum storage tank system), becoming contaminated with hazardous materials, including, without limitation, benzene, toluene, total xylenes, and petroleum hydrocarbons. On __date__, __B__ entered into a Consent Order with the Department to remediate the Restricted Portion. __B__ implemented a corrective action plan ("CAP") on the Restricted Portion. This Declaration is required because the CAP resulted in residual concentrations of petroleum constituents in soil and groundwater underlying the Restricted Portion. These concentrations may be at or above risk-based screening levels as determined by the Department and for which future use of the Restricted Portion shall be limited to protect human health and the environment.

Restrictions on Use. By acceptance and recordation of this Declaration, __B__, and any successors in interest, are hereby restricted from using the Restricted Portion, now or at any time in the future, as set forth below. __B__, and respective successors in interest, shall be solely responsible for demonstrating that use in the Restricted Portion is in conformity with the following:

1. No buildings of any kind or nature shall be constructed or located on the Restricted Portion.

2. The Restricted Portion, and any portion thereof, may be used for commercial and industrial uses only. The Restricted Portion shall not be used for residential purposes, agricultural purposes, or any permanently occupied human habitation (including hotels or motels), school, day care or hospital use.

3. There shall be no excavation of soil at, and there shall be no extraction of ground water under, the Restricted Area for any purpose, including, without limitation, drinking by animals or human beings, irrigation or an industrial or commercial use.

4. Any activity on the Restricted Portion that may result in the release or exposure to the environment of a petroleum constituent that remains on the Restricted Portion as part of the CAP, is prohibited without prior written approval from the Department.

The foregoing restrictions on use are herein referred to as the "Restricted Uses."

The Restricted Uses are imposed out of an abundance of caution due to the former use of the Restricted Portion and because certain environmental risk evaluations of the Restricted Portion indicate the presence of petroleum hydrocarbons at various locations in the soils which may present a risk to public health and the air and water quality at the Property. Further the Restrictions are imposed in furtherance of the public policy as stated in Idaho Code 39-7202(1)(Supp. 1996). __B__ intends further that the Property shall be used in such a manner as to avoid potential harm to persons or property which may result from releases or threatened release of hazardous substances or petroleum hydrocarbons.

Variance and Termination. The Restricted Uses set forth above shall apply to the Restricted Portion, or any subdivided portion thereof, unless:

A. the Restricted Portion or subdivided portion thereof is shown in a Department approved risk assessment not to contain petroleum hydrocarbons in the soils or groundwater;

B. contaminated soils and groundwater are remediated to levels the Department deems in writing to be adequate for the Restricted Portion to be developed for any of the Restricted Uses; or

C. __B__, or its successor in interest, applies to the Department to have this Declaration removed with respect to all or part of the Restricted Portion pursuant to laws, rules and regulations then in effect, and a formal determination is made by the Department in writing to remove the land-use restrictions.

Conveyance of Property. Within thirty (30) days of the closing of any sale, lease, or other conveyance of all or any portion of the Property, the former Owner (in the case of a sale) or Occupant (in the case of a lease) and the then current Owner or Occupant of the Property, or part thereof, conveyed shall provide written notice to the Department of the name and address of all the then Owners and/or Occupants of the Property, or part thereof, conveyed. The Department shall not, by reason of this Declaration, have authority to approve, disapprove, or otherwise affect any sale, lease, or other conveyance of the Property except as otherwise provided by law, or by administrative order.

Enforcement. Failure of __B__, or its successor in interest, to comply with any of the Restrictions set forth herein shall be grounds for the Department, or its successor, to require that the Owner modify or remove any improvements, including without limitation, all buildings, regradings and subsurface structures or wells, constructed in violation of this Agreement. Violation of this Declaration shall be grounds for the Department, or its successor, to file civil actions against the Owner as provided by law or in equity, including without limitation, the Uniform Conservation Easement Act, Idaho Code 55-2101, *et. seq*.

Notices. All notices required or permitted to be given hereunder shall be in writing and mailed in the United States Mail postage prepaid by certified or registered mail, return receipt requested, to the appropriate address indicated below or at such other place or places as either __B__, or its successors, or the Department, or its successors, may, from time to time, respectively, designate in a written notice given to the other. Notices which are deposited in the United States Mail in accordance with the terms of this provision shall be deemed received three (3) days after the date of mailing thereof.

__B__:

THE DEPARTMENT: _____
Idaho Department of Environmental Quality
(Regional office address)

Costs and Expenses. All costs of removing this Declaration, including the cost of any remediation or abatement of any environmental condition of or pertaining to the Property, regardless of mechanism used and the frequency thereof, shall be borne by the party seeking such removal. This Declaration shall run with the land and be binding on __B__ and its successors and assigns.

Partial Invalidity. If any portion of the Restrictions or terms set forth herein is determined to be invalid for any reason, the remaining portion shall remain in full force and effect as if such invalidated portion had not been included herein

Headings. Headings at the beginning of each section of this Declaration are solely for the convenience of the parties and are not a part of the Declaration.

Idaho Code References. All references to the Idaho Code sections include successor provisions.

Reservation of Rights. Notwithstanding any provision of this Declaration, the Department retains all of its access and enforcement authorities under any applicable statute or rule. Nothing in this Declaration shall affect the Department's ability to enforce the terms of any voluntary consent order or other agreement relating to remediation of the Property entered into between the Department and __B__ or any other responsible party. Nothing in this Declaration shall affect the obligations of __B__ or any other responsible party under such voluntary consent order or other agreement. The Department's acceptance hereunder is based upon the information presently known or available to the Department with respect to the environmental condition of the Property, and the Department reserves the right to take appropriate action under applicable authorities in the event the Department determines new information warrants such action.

Effective Date. The effective date of this Declaration shall be the date of signature by the Department.

Accepted:

Idaho Department of Environmental Quality- Holder

By: _____
Printed: _____
Its: _____
Date: _____

Property Owner

By: _____
Printed: _____
Its: _____
Date: _____

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APPENDIX C

EVALUATION OF THE INDOOR AIR INHALATION PATHWAY

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APPENDIX C TABLE OF CONTENTS

LIST OF FIGURES

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C.1 BACKGROUND

One pathway often complete at contaminated sites is exposure via inhalation of vapors in ambient or indoor air emitted from soil or ground water. Target levels for soil and groundwater, calculated to be protective of risks posed by indoor inhalation exposure, are often very low. This is attributed to the large uncertainty in input parameters used in emission/dispersion models, the simplification of complex processes by currently used models, the use of conservative assumptions, and the difficulties in assessing key processes and parameters in the field.

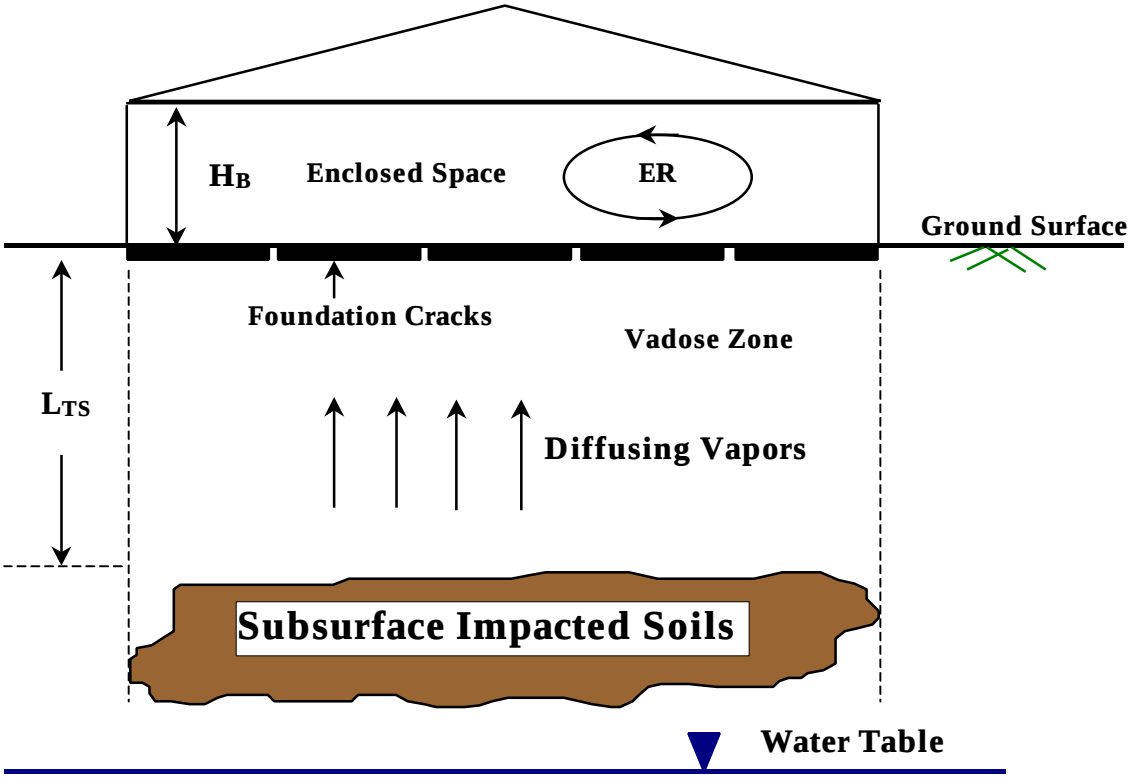
This appendix is intended to assist in the evaluation of this pathway within the tiered risk-based decision-making framework by describing a step-by-step characterization process and by providing general guidance on soil vapor and indoor air sampling. The focus of this document is on indoor inhalation only since experience suggests that outdoor inhalation from subsurface contamination rarely results in unacceptable risk. It is assumed that any imminent threats to human health via explosive levels of vapors have been mitigated prior to this evaluation.

Figure C-1 shows a schematic of the indoor inhalation pathway. Figure C-2 shows a step-by-step approach to evaluating the indoor inhalation pathway. This approach applies primarily to RE-1 and RE-2 evaluations, as described in the REM.

C.2 DETERMINATION OF WHETHER THE ROUTE OF EXPOSURE IS COMPLETE

One of the first steps in the evaluation of indoor inhalation is to determine whether the pathway is complete. Site-specific information and professional judgment should be used to determine this.

If chemicals of concern at the site are non-volatile (chemicals with a dimensionless Henry's Law constant of less than or equal to 1×10^{-4} and a molecular weight exceeding 200 are generally considered non-volatile [EPA, 1996]), the indoor inhalation pathway for both current and future conditions would be incomplete. Non-volatile chemicals



ER: Indoor air exchange rate
H_B: Height of Enclosed Space
L_{TS}: Source-Building Separation Distance

Figure C-1. Schematic of Indoor Inhalation Pathway

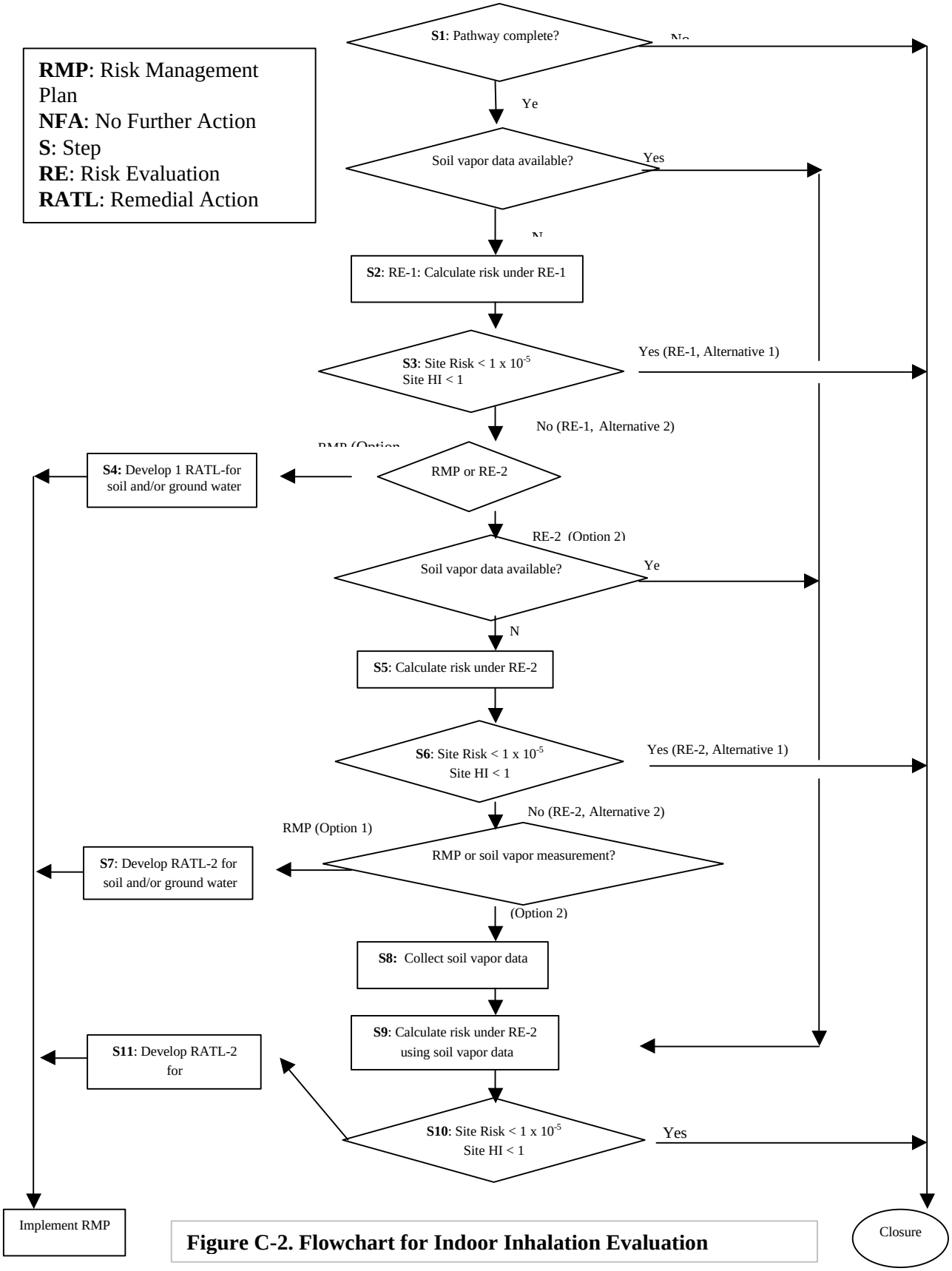


Figure C-2. Flowchart for Indoor Inhalation Evaluation

include polynuclear aromatic hydrocarbons such as benzo (a) pyrene and benzo (k) fluoranthene and pesticides such as atrazine and carbofuran.

Specific values for individual chemicals can be obtained from referring to the tables contained in Appendix D of the REM.

For current conditions, if the soil and ground water within 100 feet of the structure are not impacted, there are no preferential vapor pathways, and the area is paved, the pathway may be incomplete. Such conditions would be expected to occur in situations where the release occurred away from buildings and the buildings are located upgradient of the source.

For future conditions, many factors can affect the determination of completeness. These include the location of contamination and its relation to the likelihood that current structures will remain as-is for a sufficient time into the future, the nature and status of potential property transactions, current land use trends, and the location of contamination. For example, the pathway would be incomplete if conditions prohibit the construction of buildings on site or if a release occurred over a pipeline right of way or abuts a busy highway. Because of the great uncertainty in determining if the pathway will be complete for future conditions, the pathway is often considered complete since this is the most conservative option.

C.3 STEPS TO EVALUATE THE INDOOR INHALATION PATHWAY

Each of the steps illustrated in the flowchart in Figure C-2 is described below:

Step 1: Determine if the Pathway is Complete by Building a Site Conceptual Model

This first step is part of the general development of a site conceptual model, which is described in detail in Section 4. In general, it is necessary to determine which of the following two pathways are complete or potentially complete:

- Indoor inhalation of volatile emissions from subsurface soils
- Indoor inhalation of volatile emissions from ground water

The acceptable or target risk (individual excess lifetime cancer risk for carcinogens and hazard index [HI] for non-carcinogens) is defined in risk evaluations-1 and 2 (RE-1 and RE-2) as the cumulative risk and HI from all chemicals of concern and complete pathways. Pathways are not evaluated individually unless only one complete pathway exists at the site. See Section 3.7.1 for details on target risk and Sections 9 and 10 for details on developing target levels.

Section C.2 below provides guidance to determine if the indoor inhalation pathway is complete. When all the potentially complete pathways have been identified, proceed to Step 2.

Step 2: Calculate the Risk and HI Under RE-1

Step 2 involves calculating the risk and HI based on representative soil and ground water concentrations developed from default input parameters and soil and ground water samples gathered during the site characterization process. Calculation of risks using soil, ground water, or soil vapor data can typically be completed using the REM computational software or other models approved by DEQ.

Typically the type of soil vapor measurements needed for the risk-based decision-making process are not be available while an RE-1 is being performed. However, if appropriate soil vapor measurements are available, as described in Section C.4, go to Step 9 to perform a RE-2 using soil vapor data.

Step 3: Compare RE-1 Site Risk and HI with Target Risk and HI

Compare the site risk and HI estimated in Step 2 with the target risk ($<1 \times 10^{-5}$) and HI (<1). This comparison will lead the responsible party to one of the following two alternatives:

Alternative 1 - The site risk and site HI are within the target risk ($<1 \times 10^{-5}$) and HI (<1) levels and site closure is appropriate if all other closure requirements are met.

Alternative 2 - The site risk and/or site HI exceed the target risk ($<1 \times 10^{-5}$) and/or HI (<1) levels. Alternative 2 directs the responsible party to select one of the two following options:

Option 1: Develop soil and ground water target levels and develop and implement a risk management plan (RMP) to achieve these targets (go to Step 4)

Option 2: RE-2 (go to Step 5)

Step 4: Develop Remedial Action Target Levels-1 (RATL-) for Soil and Ground Water

The responsible party should develop RATL-1 as the cleanup levels, develop an RMP to achieve the cleanup levels, and submit the RMP to the Department of Environmental Quality (DEQ) for approval and implementation.

Step 5: Calculate Site Risk and HI under RE-2

Step 5 involves the calculating the risk and HI based on representative soil and ground water concentrations and site-specific input parameters. This step may require the collection of additional site-specific data including, but not limited to, soil bulk density, moisture content, organic carbon content, soil vapor permeability, soil porosity for various soil layers, aquifer and capillary fringe properties, soil vapor chemical concentrations, and building characteristics.

If appropriate soil vapor measurements are available while a RE-2 is being performed, they can be used in place of soil and ground water concentration data for evaluating the indoor air pathway (see Step 9). Also, if adequate site data are available the RE-1 step in the process can be bypassed and an RE-2 evaluation can be conducted immediately.

Step 6: Compare RE-2 Site Risk and HI with Target Risk and HI

Compare the risk and HI estimated in Step 5 with the target risk and HI. This comparison provides the responsible party with the following two alternatives:

Alternative 1 - Site risk and site HI are within the target risk ($<1 \times 10^{-5}$) and HI (<5) levels and site closure is appropriate if all other closure requirements are met.

Alternative 2 - Site risk and/or site HI exceed the target risk ($<1x\ 10^{-5}$) and/or HI (<5) levels. Alternative 2 leads the responsible party to one of two options as follows:

Option 1: Develop RATL-2 target levels for soil and/or ground water, develop an RMP, and perform and implement corrective action (go to Step 7)

Option 2: Collect soil vapor data for RE-2 re-evaluation (go to Step 8)

Step 7: Develop RATL-2 for Soil and Ground Water

The responsible party develops RATL-2 site-specific cleanup levels, an RMP to achieve those cleanup levels, and submits the RMP to DEQ for approval.

Step 8: Collect Soil Vapor Data

The responsible party develops a work plan for DEQ approval to collect the representative soil-vapor measurements as per the guidelines provided in Section C.4. After the data has been collected, it is evaluated as discussed in Step 9.

Step 9: Calculate Risk and HI Under RE-2 Using Soil Vapor Data

The soil vapor data collected in Step 8 (or the existing soil vapor data) is used to develop estimates of representative soil vapor concentrations at the site and estimate the sitewide cumulative risk from all pathways.

Step 10: Compare Site Risk and HI from Step 9 with Target Risk and HI

The estimated risk and HI from Step 9, including that from other complete pathways, is compared with the target risk and HI. This comparison provides the responsible party with the following alternatives:

Alternative 1 - The site risk and site HI are within the target risk ($<1 \times 10^{-5}$) and HI (<1) levels and site closure is appropriate if all other closure requirements are met.

Alternative 2a - The site risk and/or site HI exceed the target risk ($<1 \times 10^{-5}$) and/or HI (<1) levels. The responsible party must perform corrective action (Go to Step 11).

Alternative 2b - The site risk and/or site HI exceed the target risk ($<1 \times 10^{-5}$) and/or HI (<1) levels. The responsible party chooses to revise the RE-2 through by collecting appropriate indoor air sample data (Step 12). Prior to data collection a work plan describing the proposed sampling effort should be submitted to DEQ for approval. Data collected must meet the guidelines described in Section C.5.

Step 11: Develop RATL-2 for Soil Vapor

The responsible party develops RATL-2 for soil vapor, soil, and ground water (as necessary) as cleanup levels; develops an RMP to achieve the cleanup levels; and submits the RMP to DEQ for approval. After the implementation and completion of the RMP, confirmatory sampling is conducted. Confirmatory data must meet the appropriate site target levels for site closure.

Step 12: Evaluation of Pathway Risk Using Indoor Air Data

The responsible party develops and submits a work plan for DEQ approval describing the indoor air data collection effort. The results of the data collection are then used to calculate risk for the pathway. This risk calculation, is not supported by the REM software and should be performed manually. The risk estimate is then incorporated into a revised RE-2 to determine if the overall site target risk has been exceeded and if risk management is necessary.

C.4 PROTOCOL FOR THE MEASUREMENT OF SOIL VAPOR LEVELS

The intent of soil gas sample collection and analysis is to obtain spatially and temporally representative values that can be used to estimate the risk to the receptors. Soil vapor concentrations at a site are affected by a number of factors, including (1) atmospheric conditions (temperature, pressure, precipitation, etc.), (2) soil conditions (porosity, moisture content, vapor permeability, stratigraphy), (3) source characteristics, (4) age of the release, and (5) the capacity of the soil to attenuate or biodegrade the chemicals of concern.

To the extent that these factors exhibit spatial and temporal variations, the soil vapor concentrations can be variable. Thus a single soil gas sampling event is not adequate to characterize potential air exposure pathways. Measurements must be made over time to represent the range of possible site conditions. DEQ requires samples be collected at least twice (sometimes four times) per year during different times of the year. This may include taking measurements in winter and summer. At sites where there are significant seasonal water table fluctuations (> 5feet) measurements should be made when the water table is high and when it is low.

The responsible party should develop a work plan describing how representative soil gas data will be collected at the site for use in risk assessment and submit it for approval by DEQ prior to collecting the data. The work plan should include:

- The location where samples will be collected
- The depth where samples will be collected
- The number of samples to be collected
- The rationale for selecting all sampling locations
- The soil gas measurement technique and method of analysis
- Quality assurance/quality control procedures

Each of these is discussed below.

C.4.1 Location Where Samples Will be Collected

The following criteria should be considered when selecting the number and potential locations for collecting soil gas measurements:

- The size and location of the release area, soil contamination, and free phase product
- The location of highest ground water concentration
- The location of existing buildings on site and off site
- The location of potential future on site and off site buildings
- The location of paved and unpaved surfaces
- The location of potential preferential pathways for vapor migration such as utility trenches

It is recommended that samples be collected as close as possible around the footprint of an existing or potential future building. Installation of several probes per side on each side of the structure is recommended. Whenever possible, and particularly if contamination extends under an existing structure, one or more sampling points should be located within the structure, just below the concrete slab of a existing floor or within the earthen material of a crawl space. In all cases, at least one soil vapor probe shall be located in the source areas (the most impacted soil area and above the most impacted ground water area). Sampling at off-site locations will only be required if soil or ground water contamination associated with the release is known or suspected to have migrated off site. With the exception of source area sampling, avoid locating sample probes in unpaved areas or areas subject to impacts from water infiltration or surface volatilization.

Proposed locations of soil vapor borings on a site map and the rationale for the location must be included in the work plan submitted to DEQ for review and approval.

C.4.2 Depth Where Samples will be Collected

The depth at which samples are collected is a site-specific determination. For risk assessment purposes, sample depth should correspond with the characteristics of impacted or potentially impacted structures. Samples, whether taken from within or outside the building footprint, shall be collected as close as possible to the base of foundation floors and footings and other potential points of entry. Where feasible, probes installed adjacent to slab-on-grade structures shall be angled under the structure. Samples collected from within structures with earthen floors or crawl spaces shall be collected at depths below the soil surface to avoid effects of surficial drying, be representative of subsurface conditions, and minimize the potential for short-circuiting vapor flow.

Characterization of soil or ground water source areas, structures with basements, and natural attenuation capacities may require installation of nested soil gas probes located at multiple depths (Figure C-3). The impact of soil layers with dramatically different properties (such as moisture content, porosity, particle size, and vapor permeability) at the site shall be evaluated with appropriately located probes at multiple depths. For structures with basements, soil gas multiple depth probes shall be located below and adjacent to the basement wall. Possible locations of sampling points are shown in Figure C-2.

In ground water source areas, it is recommended that samples not be located and collected within the capillary fringe.

C.4.3 Number of Samples to be Collected

As in the case of site characterization, the number of soil gas samples to be collected will depend on site-specific conditions. For existing buildings, with soil or ground water contamination below them, a minimum of four probes, one on each side of the building, is recommended. If probes can be located within the building footprint, the number of probes will be dependent on the size and construction of the structure, and the location of contamination in relation to the building footprint. As stated previously, one or more probes must be located in the source area. As mentioned in Section C.4.2, multiple depth probe locations may be appropriate in selected areas to achieve specific objectives. The number of depth intervals at a given sampling location will be dependant on factors such as the total soil thickness being investigated and the degree of soil layering or heterogeneity present.

C.4.4 Soil Gas Measurement Technique and Analysis

Soil gas can be collected and analyzed in a number of ways. These methods include the use of flux chamber measurements to directly measure emission rates, passive sorbents, and active soil gas collection devices such as dedicated probes. DEQ recommends the use of permanently installed active soil gas probes for most applications where the data will be used for risk assessment. A typical single probe installation is presented in Figure C-4 and a nested multiple probe installation in Figure C-5.

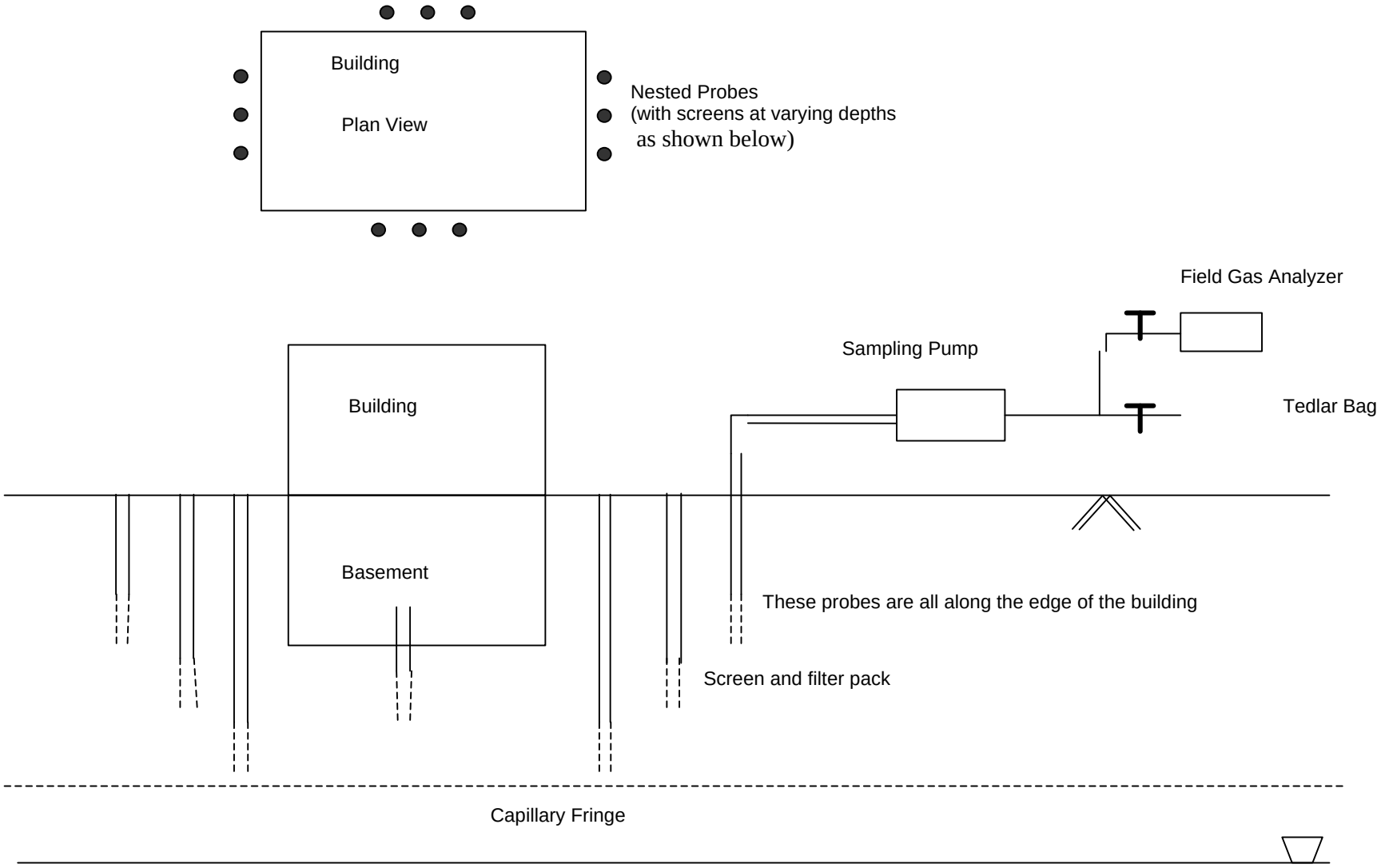


Figure C-3. Location of Nested Soil Gas Probes

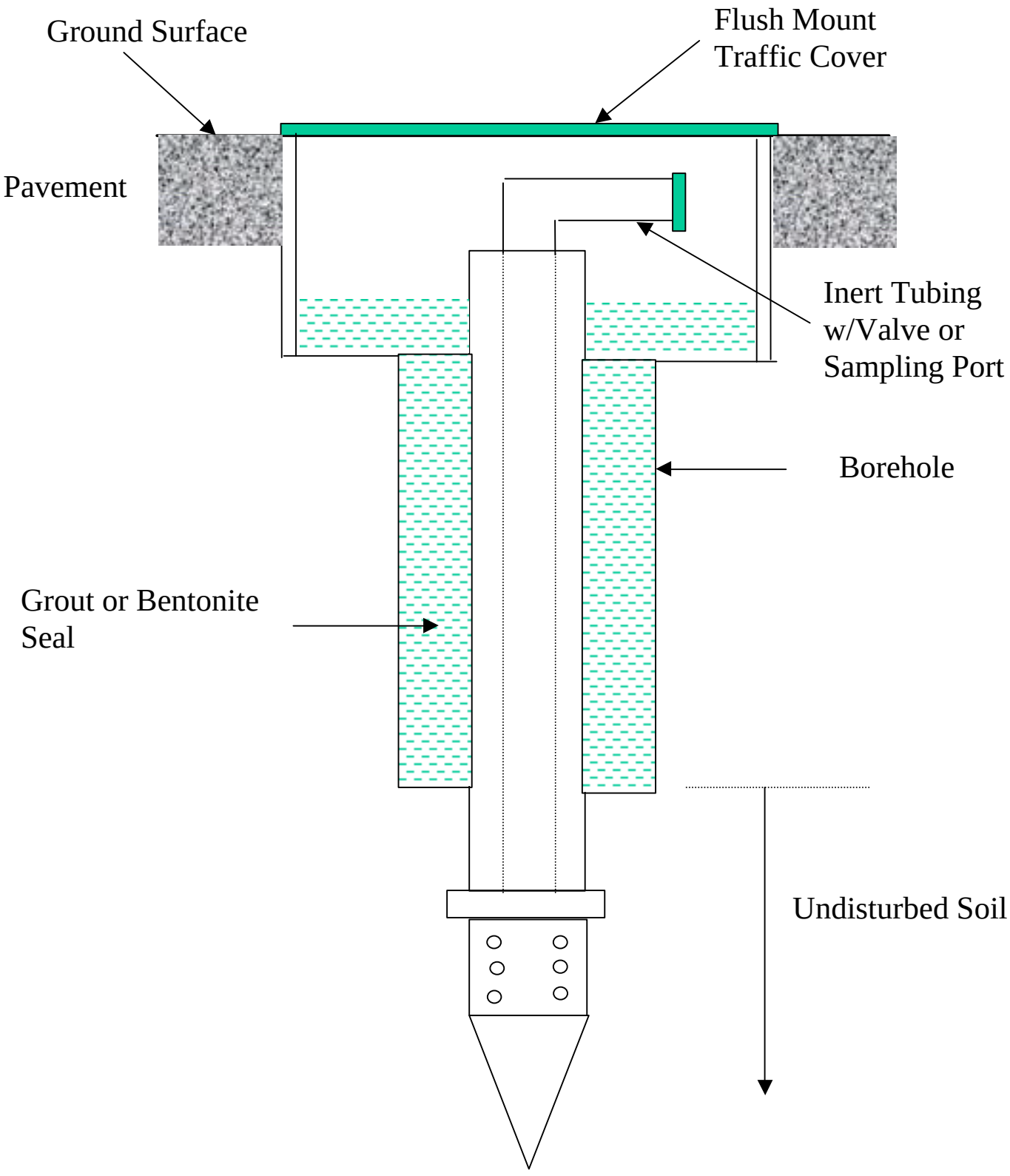


Figure C-4. Schematic of Soil Vapor Probe Installation

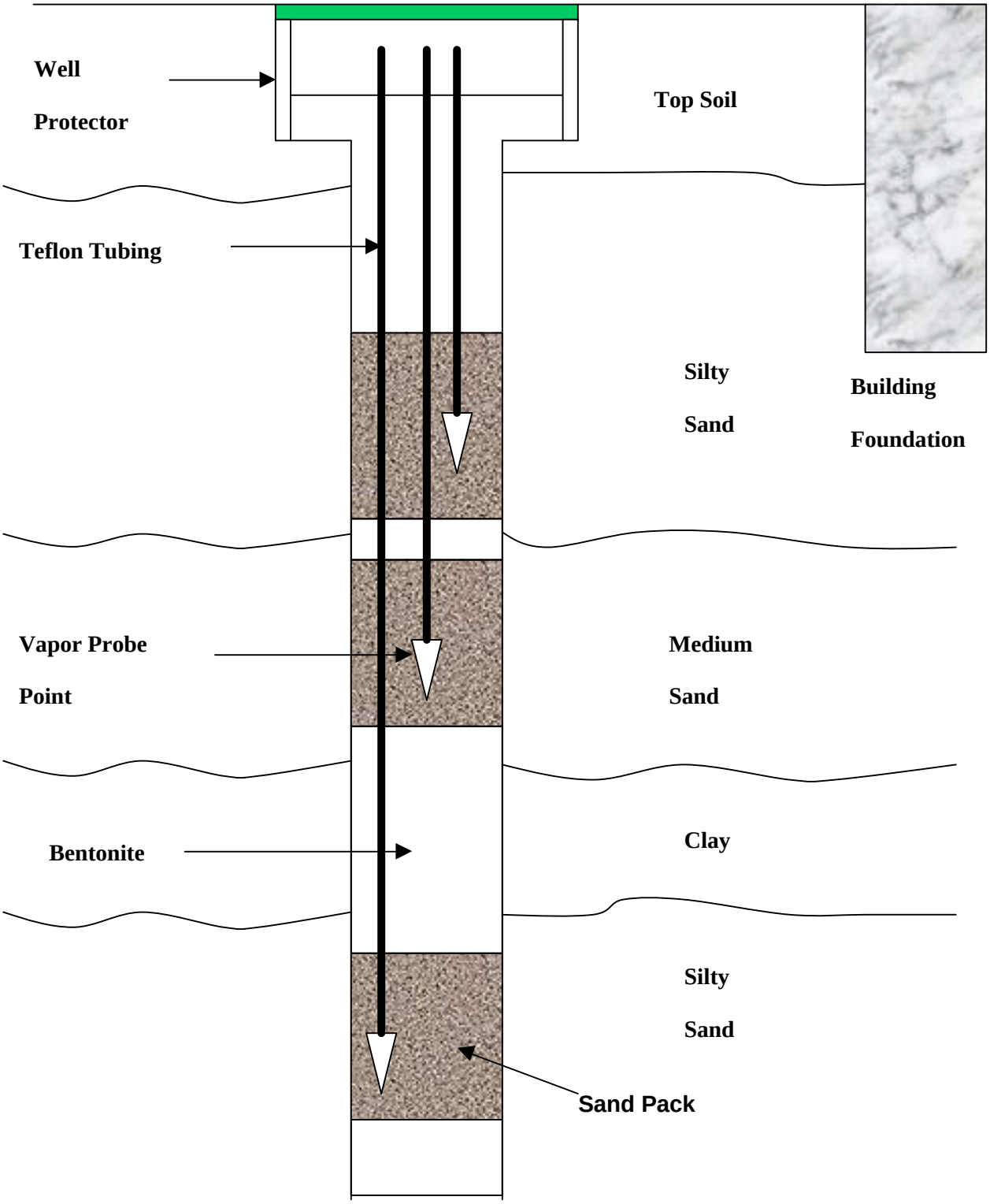


Figure C-5. Schematic of Multiple Completion Soil Vapor Probe Installation

Passive sorbent technology is not recommended since the data collected typically represents cumulative, relative chemical mass and not concentration. Flux chambers may have utility in specialized cases.

As mentioned above it will be necessary to collect soil vapor samples from soil probes at multiple times. Hence, probe installations should be treated similar to a ground water monitoring well in terms of their construction and expected longevity. Guidance on the installation and sampling of soil vapor monitoring probes is provided in the ASTM Standard Guide for Soil Gas Monitoring in the Vadose Zone, Designation: D 5314-92 (ASTM, 2001).

Soil vapor samples collected in a *Tedlar* bag, evacuated *Summa* canister, or granulated carbon must be analyzed for the volatiles of concern. Prior to collecting the sample, the probes and tubing shall be thoroughly purged to ensure that the sample sent for analysis is truly representative of the formation being sampled IDEQ recommends analysis of the vapor samples for oxygen and carbon dioxide. These measurements may be used to demonstrate the occurrence of natural attenuation over time.

C.5 INDOOR AIR SAMPLING

The intent of this section is not to provide exhaustive details on indoor air sampling protocols, but rather to outline a desired approach and issues to address when developing a work plan for these types of data collection efforts. Sampling details are well presented in other guidance documents.

Notable examples are those developed by the U.S. Environmental Protection Agency (EPA, 1990 and 1992), New Jersey Department of Environmental Protection (NJDEP, 2003) and the Massachusetts Department of Environmental Protection (MDEP, 2002).

While the collection of indoor air data may appear to offer the most direct evidence of exposure to chemicals of concern, the collection of such data is complex and presents significant challenges, and the interpretation of results is, with the exception of unambiguous negative results, often unclear. The ultimate goal of the data collection is to document unacceptable exposure to chemicals of concern resulting from a specific release. In order to achieve this goal, the contribution of other sources of the chemicals of concern, either from ambient, outdoor sources or sources within the building itself must be eliminated. Therefore, an integral part of any indoor air sampling campaign will be the collection of representative, contemporaneous outdoor air and soil gas data.

The significant influence of seasonal and diurnal meteorological changes on indoor air concentrations necessitates conducting multiple sampling events. The number of sampling events required is partly dependent on the goal of the collection efforts. In general, a minimum of two events, sufficiently separated in time, is necessary. If the goal is to identify “worst case” indoor air concentrations, then sampling should take place under those circumstances that will maximize indoor air concentrations. In many cases

this will entail sampling during winter or early spring because of the influences of building depressurization, lack of building ventilation, and frozen ground. Impacts from ground water sources may require sampling during periods of high water levels (for dissolved phase chemicals of concern) or low water levels (if separate phase product is suspected). If the goal is to characterize "average" conditions, more sampling events over longer times will be required.

Other important considerations in developing an indoor air sampling program include:

- Sampling duration
- Target detection limits
- Indoor sources
- Data analysis

These items should be addressed in the work plan.

C.6 SUGGESTED REFERENCES

ASTM (American Society for Testing and Materials), 2001. *Standard Guide for Soil Gas Monitoring in the Vadose Zone*. Designation D5314-92 (2001), West Conshohocken, PA.

EPA, 1990. *Compendium of Methods for the Determination of Air Pollutants in Indoor Air*. Atmospheric Research and Exposure Assessment Laboratory. EPA/600/S4-90/010, Washington, DC.

EPA, 1992. *Air/Superfund National Technical Guidance Study Series*. Assessing Potential Indoor Air Impacts for Superfund Sites. EPA-451/R-92-002. Office of Air Quality Planning and Standards, Washington, DC.

EPA, 1996. *Soil Screening Guidance: Technical Background Document*. EPA/540/R-95-128. Office of Solid Waste and Emergency Response, Washington, DC.

MDEP, 2002. *Indoor Air Sampling and Evaluation Guide*. WSC Policy #02-430. Office of Research and Standards, Massachusetts Department of Environmental Protection, Boston, MA.

NJDEP, 2003. *Indoor Air VOC Sampling and Analysis Requirements*. New Jersey Department of Enviromental Protection.
April 2003. http://www.state.nj.us/dep/srp/guidance/indoor_air/ia_sampling_req.htm

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APPENDIX D

DEFAULT TOXICITY VALUES FOR DEVELOPING IDTLs AND RATLs

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Default Toxicity Values For Developing IDTLs And RATLs

CHEMICALS	CAS Number[a]	Slope Factor				Reference Dose				Oral RA[b] Factor	Dermal RA Factor	Maximum Contaminant Level
		Oral (SFo) [kg-day/mg]		Inhalation (SFi*) [kg-day/mg]		Oral (RfDo) (mg/kg-day)		Inhalation (RfDi*) (mg/kg-day)		(RAFo)	(RAFd)	[mg/L]
Acenaphthene	83-32-9	NA		NA		0.06	l	0.06	o	1	0.13	NA
Acenaphthylene	208-96-8	NA		NA		0.06	p	NA		1	0.13	NA
Acetochlor	34256-82-1	NA		NA		0.02	l	0.02	o	1	0.1	NA
Acetone	67-64-1	NA		NA		0.9	l	0.9	o	1	0.0005	NA
Acrolein	107-02-8	NA		NA		0.0005	l	0.0000057	l	1	0.0005	NA
Acrylonitrile	107-13-1	0.54	l	0.24	l	NA	m	0.00057	l	1	0.03	NA
Alachlor	15792-60-8	0.081	m	0.08	o	0.01	l	0.01	o	1	0.1	0.002
Aldicarb	116-06-3	NA		NA		0.001	l	0.001	o	1	0.1	NA
Aldrin	309-00-2	17	l	17	l	0.00003	l	0.00003	o	1	0.1	NA
Ammonia	7664-41-7	NA		NA		NA		0.029	l	1	0.0005	NA
Aniline	62-53-3	0.0057	l	0.0057	o	0.007	n	0.00029	l	1	0.1	NA
Anthracene	120-12-7	NA		NA		0.3	l	0.3	o	1	0.13	NA
Antimony	7440-36-0	NA		NA		0.0004	l	NA		1	0.01	0.006
Aroclor 1016	12674-11-2	0.07	l	0.07	l	0.00007	l	0.00007	o	1	0.14	NA
Aroclor 1221	11104-28-2	2	l	2	l	NA		NA		1	0.14	NA
Aroclor 1242	53469-21-9	2	l	2	l	NA		NA		1	0.14	NA
Aroclor 1248	12672-29-6	2	l	2	l	NA		NA		1	0.14	NA
Aroclor 1254	11097-69-1	2	l	2	l	0.00002	l	0.00002	o	1	0.14	NA
Aroclor 1260	11096-82-5	2	l	2	l	NA		NA		1	0.14	NA
Arsenic	7440-38-2	1.5	l	15	l	0.0003	l	NA		1	0.03	0.01
Atrazine	1912-24-9	0.22	m	0.22	o	0.035	l	0.035	o	1	0.1	0.003
Azobenzene	103-33-3	0.11	l	0.11	l	NA		NA		1	0.0005	NA
Barium	7440-39-3	NA		NA		0.07	l	0.00014	m	1	0.01	2
Benzene	71-43-2	0.035	l	0.018	l	0.004	l	0.0086	l	1	0.0005	0.005
Benzidine	92-87-5	230	l	230	l	0.003	l	0.003	o	1	0.1	NA
Benzo(a)anthracene	56-55-3	0.73	n	0.73	n	NA		NA		1	0.13	NA
Benzo(a)pyrene	50-32-8	7.3	l	7.3	n	NA		NA		1	0.13	0.0002
Benzo(b)fluoranthene	205-99-2	0.73	n	0.73	n	NA		NA		1	0.13	NA
Benzo(g,h,i)perylene	191-24-2	NA		NA		0.03	p	NA		1	0.13	NA
Benzo(k)fluoranthene	207-08-9	0.073	n	0.073	n	NA		NA		1	0.13	NA
Benzoic Acid	65-85-0	NA		NA		4	l	4	o	1	0.1	NA
Benzyl Alcohol	100-51-6	NA		NA		0.3	m	0.3	o	1	0.1	NA
Beryllium	7440-41-7	NA		8.4	l	0.002	l	0.0000057	l	1	0.01	0.004
alpha-BHC[c]	319-84-6	6.3	l	6.3	l	NA		NA		1	0.1	NA
beta-BHC	319-85-7	1.8	l	1.8	l	NA		NA		1	0.1	NA
gamma-BHC (lindane)	58-89-9	1.3	m	1.3	o	0.0003	l	0.0003	o	1	0.1	NA
Bis(2-chloroethyl)ether	111-44-4	1.1	l	1.2	l	NA		NA		1	0.03	NA
Bis(2-chloroisopropyl)ether	108-60-1	NA		NA		0.04	l	0.04	o	1	0.03	NA

CHEMICALS	CAS Number[a]	Slope Factor				Reference Dose				Oral RA[b] Factor	Dermal RA Factor	Maximum Contaminant Level
		Oral (SFo) [kg-day/mg]		Inhalation (SFi*) [kg-day/mg]		Oral (RfDo) (mg/kg-day)		Inhalation (RfDi*) (mg/kg-day)		(RAFo)	(RAFd)	[mg/L]
Bis(2-ethylhexyl)phthalate	117-81-7	0.014	l	0.014	o	0.02	l	0.02	o	1	0.1	0.006
Bromodichloromethane	75-27-4	0.062	l	0.062	o	0.02	l	0.02	o	1	0.03	NA
Bromoform	75-25-2	0.0079	l	0.0039	l	0.02	l	0.02	o	1	0.03	NA
Bromomethane	74-83-9	NA		NA		0.0014	l	0.0014	l	1	0.0005	NA
4- Bromophenylphenylether	101-55-0	15	p	10.5	p	NA		NA		1	0.1	NA
2-Butanone (Methyl Ethyl Ketone)	78-93-3	NA		NA		0.6	l	0.29	l	1	0.03	NA
Butyl Benzyl Phthalate	85-68-7	NA		NA		0.2	l	0.2	o	1	0.1	NA
Cadmium	7440-43-9	NA		6.3	l	0.0005	l	NA		1	0.001	0.005
Carbofuran	1563-66-2	NA		NA		0.005	l	0.005	o	1	0.1	0.04
Carbon Disulfide	75-15-0	NA		NA		0.1	l	0.2	l	1	0.0005	NA
Carbon Tetrachloride	56-23-5	0.13	l	0.053	l	0.0007	l	0.0007	o	1	0.0005	0.005
Chlordane	57-74-9	0.35	l	0.35	l	0.0005	l	0.0002	l	1	0.04	0.002
4-Chloroaniline	106-47-8	NA		NA		0.004	l	0.004	o	1	0.1	NA
Chlorobenzene	108-90-7	NA		NA		0.02	l	0.017	n	1	0.03	0.1
Chloroethane	75-00-3	0.0029	n	0.0029	o	0.4	n	2.9	l	1	0.0005	NA
Chloroform	67-66-3	0.031	j	0.019	j	0.01	l	0.00086	n	1	0.0005	NA
Chloromethane	74-87-3	0.013	m	0.0063	m	NA		0.086	n	1	0.0005	NA
2-Chloronaphthalene	91-58-7	NA		NA		0.08	l	0.08	o	1	0.03	NA
2-Chlorophenol	95-57-8	NA		NA		0.005	l	0.005	o	1	0.03	NA
2-Chlorotoluene	95-49-8	NA		NA		0.02	l	0.02	o	1	0.03	NA
Chlorpyrifos	2921-88-2	NA		NA		0.003	l	0.003	o	1	0.1	NA
Chromium (III) total Chromium	7440-47-3	NA		NA		1.5	l	NA		1	0.01	0.1
Chromium (VI)	18540-29-9	NA		290	l	0.003	l	0.0000022	l	1	0.01	NA
Chrysene	218-01-9	0.0073	n	0.0073	n	NA		NA		1	0.13	NA
Copper	7440-50-8	NA		NA		0.037	m	NA		1	0.01	1.3
Cyanide (as Sodium Cyanide)	143-33-9	NA		NA		0.02	l	0.00086	l	1	0.01	0.2
Dacthal	1861-32-1	NA		NA		0.01	l	0.01	o	1	0.1	NA
Dalapon (2,2-dichloropropionic acid)	75-99-0	NA		NA		0.03	l	0.03	o	1	0.1	0.2
DDD[d]	72-54-8	0.24	l	0.24	o	NA		NA		1	0.03	NA
DDE[e]	72-55-9	0.34	l	0.34	o	NA		NA		1	0.03	NA
DDT[f]	50-29-3	0.34	l	0.34	l	0.0005	l	0.0005	o	1	0.03	NA
Demeton	8000-97-3	NA		NA		0.00004	l	0.00004	o	1	0.1	NA
Dibenzo(a,h)anthracene	53-70-3	7.3	n	7.3	n	NA		NA		1	0.13	NA
Dibenzofuran	132-64-9	NA		NA		0.004	n	0.004	o	1	0.03	NA
Dibromochloromethane	124-48-1	0.084	l	0.084	o	0.02	l	0.02	o	1	0.03	NA

CHEMICALS	CAS Number[a]	Slope Factor				Reference Dose				Oral RA[b] Factor	Dermal RA Factor	Maximum Contaminant Level
		Oral (SFo) [kg-day/mg]		Inhalation (SFi*) [kg-day/mg]		Oral (RfDo) (mg/kg-day)		Inhalation (RfDi*) (mg/kg-day)		(RAFo)	(RAFd)	[mg/L]
1,2-Dibromo-3-chloropropane	96-12-8	1.4	m	0.0024	m	0.000057	o	0.000057	l	1	0.1	0.0002
1,2-Dichlorobenzene	95-50-1	NA		NA		0.09	l	0.057	m	1	0.03	0.6
1,3-Dichlorobenzene	541-73-1	NA		NA		0.0009	n	0.0009	o	1	0.03	NA
1,4-Dichlorobenzene	106-46-7	0.024	m	0.022	n	0.03	n	0.23	l	1	0.03	0.075
3,3'-Dichlorobenzidine	91-94-1	0.45	l	0.45	o	NA		NA		1	0.1	NA
Dichlorodifluoromethane	75-71-8	NA		NA		0.2	l	0.057	m	1	0.0005	NA
1,1-Dichloroethane	75-34-3	NA		NA		0.1	m	0.14	m	1	0.0005	NA
1,2-Dichloroethane	107-06-2	0.091	l	0.091	l	0.03	n	0.0014	n	1	0.03	0.005
1,1-Dichloroethene	75-35-4	0.6	l	0.18	l	0.009	l	0.009	o	1	0.0005	0.007
1,2-Dichloroethene-(cis)	156-59-2	NA		NA		0.01	v	0.01	o	1	0.0005	0.07
1,2-Dichloroethene-(trans)	156-60-5	NA		NA		0.02	l	0.02	o	1	0.0005	0.1
1,2-Dichloropropane	78-87-5	0.068	m	0.068	o	0.0011	o	0.0011	l	1	0.03	0.005
1,3-Dichloropropene-(cis)	542-75-6	0.1	l	0.014	l	0.03	l	0.0057	l	1	0.03	NA
1,3-Dichloropropene-(trans)	542-75-6	0.1	l	0.014	l	0.03	l	0.0057	l	1	0.03	NA
2,4-Dichlorophenol	102-83-2	NA		NA		0.003	l	0.003	o	1	0.1	NA
2,4-Dichlorophenoxyacetic acid	94-75-7	NA		NA		0.01	l	0.01	o	1	0.05	NA
Dieldrin	60-57-1	16	l	16	l	0.00005	l	0.00005	o	1	0.1	NA
2,4-Dimethylphenol	105-67-9	NA		NA		0.02	l	0.02	o	1	0.1	NA
Diethylphthalate	84-66-2	NA		NA		0.8	l	0.8	o	1	0.1	NA
Dimethylphthalate	131-11-3	NA		NA		10	q	10	o	1	0.1	NA
Di-n-butyl Phthalate	84-74-2	NA		NA		0.1	l	0.0014	p	1	0.1	NA
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	88-85-7	NA		NA		0.001	l	0.001	o	1	0.1	0.007
2,4-Dinitrophenol	51-28-5	NA		NA		0.002	l	0.002	o	1	0.1	NA
2,4-Dinitrotoluene	121-14-2	0.68	l	0.68	o	0.002	l	0.002	o	1	0.1	NA
2,6-Dinitrotoluene	606-20-2	0.68	l	0.68	o	0.001	m	0.001	o	1	0.1	NA
Di-n-octyl Phthalate	117-84-0	NA		NA		0.04	v	0.04	o	1	0.1	NA
1,2-Diphenylhydrazine	122-66-7	0.8	l	0.77	l	NA		NA		1	0.1	NA
Diquat	85-00-7	NA		NA		0.0022	l	0.0022	o	1	0.1	0.02
Disulfoton	298-04-4	NA		NA		0.00004	l	0.00004	o	1	0.1	NA
Diuron	330-54-1	NA		NA		0.002	l	0.002	o	1	0.1	NA
Endosulfan	115-29-7	NA		NA		0.006	l	0.006	o	1	0.1	NA
Endothall	145-73-3	NA		NA		0.02	l	0.02	o	1	0.1	0.1
Endrin	72-20-8	NA		NA		0.0003	l	0.0003	o	1	0.1	0.002
Eptam	759-94-4	NA		NA		0.025	l	NA		1	0.1	NA
Ethylbenzene	100-41-4	NA		NA		0.1	l	0.29	l	1	0.03	0.7
Ethylene Dibromide	106-93-4	85	l	0.77	l	0.000057	o	0.000057	m	1	0.03	0.00005

CHEMICALS	CAS Number[a]	Slope Factor				Reference Dose				Oral RA[b] Factor	Dermal RA Factor	Maximum Contaminant Level
		Oral (SFo) [kg-day/mg]		Inhalation (SFi*) [kg-day/mg]		Oral (RfDo) (mg/kg-day)		Inhalation (RfDi*) (mg/kg-day)		(RAFo)	(RAFd)	[mg/L]
Fluoranthene	206-44-0	NA		NA		0.04	l	0.04	o	1	0.13	NA
Fluorene	86-73-7	NA		NA		0.04	l	0.04	o	1	0.13	NA
Fluoride (as Sodium Fluoride)	7681-49-4	NA		NA		0.06	l	NA		1	0.1	4
Glyphosate	1071-83-6	NA		NA		0.1	l	0.1	o	1	0.1	0.7
Heptachlor	76-44-8	4.5	l	4.6	l	0.0005	l	0.0005	o	1	0.1	0.0004
Heptachlor Epoxide	1024-57-3	9.1	l	9.1	l	0.000013	l	0.000013	o	1	0.1	0.0002
Hexachlorobenzene	118-74-1	1.6	l	1.6	l	0.0008	l	0.0008	o	1	0.1	0.001
Hexachlorobutadiene	87-68-3	0.078	l	0.078	l	0.0003	o	0.0003	o	1	0.1	NA
Hexachloroethane	67-72-1	0.014	l	0.014	l	0.001	l	0.001	o	1	0.1	NA
Hexachlorocyclopentadiene	77-47-4	NA		NA		0.006	l	0.000057	l	1	0.1	0.05
Hexazinone	51235-04-2	NA		NA		0.033	l	0.033	o	1	0.1	NA
Hydrogen Sulfide	7883-4-6	NA		NA		0.003	p	0.00057	l	1	0.0005	NA
Indeno(1,2,3-cd)pyrene	193-39-5	0.73	n	0.73	n	NA		NA		1	0.13	NA
Iron (as Iron Oxide)	1309-37-1	NA		NA		0.3	n	NA		1	0.01	NA
Isophorone	78-59-1	0.00095	l	0.00095	o	0.2	l	0.2	o	1	0.1	NA
Isopropylbenzene (Cumene)	98-82-8	NA		NA		0.1	l	0.11	l	1	0.03	NA
Lead	7439-92-1	NA		NA		NA		NA		1	0.01	0.015
Manganese	7439-96-5	NA		NA		0.024	l	0.000014	l	1	0.01	NA
Mercury	7439-97-6	NA		NA		0.0003	l	0.000086	l	1	0.01	0.002
Methoxychlor	72-43-5	NA		NA		0.005	l	0.005	o	1	0.1	0.04
Methylene Chloride	75-09-2	0.0075	l	0.00165	l	0.06	l	0.86	m	1	0.0005	NA
2-Methylnaphthalene	91-57-6	NA		NA		0.004	l	0.004	o	1	0.03	NA
4-Methyl-2-pentanone	108-10-1	NA		NA		0.86	o	0.86	l	1	0.03	NA
2-Methylphenol	95-48-7	NA		NA		0.05	l	0.05	o	1	0.1	NA
4-Methylphenol	106-44-5	NA		NA		0.005	m	0.005	o	1	0.1	NA
Metolachlor	51218-45-2	NA		NA		0.15	l	0.15	o	1	0.1	NA
Metribuzin	21087-64-9	NA		NA		0.025	l	0.025	o	1	0.1	NA
MTBE[g]	1634-04-4	0.0033	j	0.00035	j	0.86	o	0.86	l	1	0.0005	NA
Naphthalene	91-20-3	NA		NA		0.02	l	0.00086	l	1	0.03	NA
Nickel	7440-02-0	NA		NA		0.02	l	NA		1	0.01	NA
Nitrate (as Sodium Nitrate)	7631-99-4	NA		NA		1.6	l	NA		1	0.01	10
Nitrite (as Sodium Nitrite)	7632-00-0	NA		NA		0.1	l	NA		1	0.01	1
2-Nitroaniline	88-74-4	NA		NA		0.003	v	0.0000286	v	1	0.1	NA
3-Nitroaniline	99-09-2	0.038	n	NA		0.0003	n	0.00085	p	1	0.1	NA
4-Nitroaniline	100-01-6	0.038	n	NA		0.0003	n	0.00085	p	1	0.1	NA
Nitrobenzene	98-95-3	NA		NA		0.0005	l	0.00057	m	1	0.03	NA
4-Nitrophenol	100-02-7	NA		NA		0.008	n	0.008	o	1	0.1	NA

CHEMICALS	CAS Number[a]	Slope Factor				Reference Dose				Oral RA[b] Factor	Dermal RA Factor	Maximum Contaminant Level
		Oral (SFo) [kg-day/mg]		Inhalation (SFi*) [kg-day/mg]		Oral (RfDo) (mg/kg-day)		Inhalation (RfDi*) (mg/kg-day)		(RAFo)	(RAFd)	[mg/L]
N-Nitrosodimethylamine	62-75-9	51	l	49	l	NA		NA		1	0.1	NA
N-Nitrosodi-n-propylamine	621-64-7	7	l	7	o	NA		NA		1	0.1	NA
N-Nitrosodiphenylamine	86-30-6	0.0049	l	0.0049	o	NA		NA		1	0.1	NA
Oxamyl (Vydate)	23135-22-0	NA		NA		0.025	l	0.025	o	1	0.1	0.2
Pentachlorophenol	87-86-5	0.12	l	0.12	o	0.03	l	0.03	o	1	0.25	0.001
Phenanthrene	85-01-8	NA		NA		0.03	p	NA		1	0.13	NA
Phenol	108-95-2	NA		NA		0.3	l	0.3	o	1	0.1	NA
Picloram	1918-02-1	NA		NA		0.07	l	0.07	o	1	0.1	0.5
Prometon	1610-18-0	NA		NA		0.015	l	0.015	o	1	0.1	NA
Pyrene	129-00-0	NA		NA		0.03	l	0.03	o	1	0.13	NA
sec-Butylbenzene	135-98-8	NA		NA		0.01	n	0.01	o	1	0.03	NA
Selenium	7782-49-2	NA		NA		0.005	l	NA		1	0.01	0.05
Silver	7440-22-4	NA		NA		0.005	l	NA		1	0.01	NA
Simazine	122-34-9	0.12	m	0.12	o	0.005	l	0.002	o	1	0.1	0.004
Styrene	100-42-5	NA		NA		0.2	l	0.29	l	1	0.03	0.1
2,3,7,8-TCDD[h]	1746-01-6	150000	q	NA		NA		NA		1	0.03	3.00E-08
Terbutryn	886-50-0	NA		NA		0.001	l	0.001	o	1	0.1	NA
tert-Butylbenzene	98-06-6	NA		NA		0.01	n	0.01	o	1	0.03	NA
1,1,1,2-Tetrachloroethane	630-20-6	0.026	l	0.026	l	0.03	l	0.03	o	1	0.03	NA
1,1,2,2-Tetrachloroethane	79-34-5	0.2	l	0.2	l	0.06	n	0.06	o	1	0.03	NA
Tetrachloroethene	127-18-4	0.54	n	0.021	n	0.01	l	0.17	n	1	0.03	0.005
Thallium	7791-12-0	NA		NA		0.00008	l	NA		1	0.01	0.002
Toluene	108-88-3	NA		NA		0.2	n	2.86	n	1	0.03	1
Total Xylenes	1330-20-7	NA		NA		0.2	l	0.029	l	1	0.03	10
Toxaphene	8001-35-2	1.1	l	1.1	l	NA		NA		1	0.1	0.003
2,4,5 TPi (Silvex)	93-72-1	NA		NA		0.008	l	0.0028	p	1	0.1	0.05
1,2,4-Trichlorobenzene	120-82-1	NA		NA		0.01	l	0.00114	v	1	0.03	0.07
1,1,1-Trichloroethane	71-55-6	NA		NA		0.28	n	0.63	n	1	0.0005	0.2
1,1,2-Trichloroethane	79-00-5	0.057	l	0.056	l	0.004	l	0.004	o	1	0.03	0.005
Trichloroethene	79-01-6	0.21	n	0.21	n	0.0003	n	0.01	n	1	0.03	0.005
Trichlorofluoromethane	75-69-4	NA		NA		0.3	l	0.2	m	1	0.0005	NA
2,4,5-Trichlorophenol	95-95-4	NA		NA		0.1	l	0.1	o	1	0.1	NA
2,4,6-Trichlorophenol	88-06-2	0.011	l	0.011	l	0.0001	n	0.0001	o	1	0.1	NA
1,2,3-Trichloropropane	96-18-4	2	n	2	o	0.006	l	0.005	o	1	0.03	NA
1,2,4-Trimethylbenzene (Pseudocumene)	95-63-6	NA		NA		0.05	n	0.0017	n	1	0.03	NA
1,3,5-Trimethylbenzene	108-67-8	NA		NA		0.05	l	0.0017	o	1	0.03	NA
2,4,6-Trinitrotoluene	118-96-7	0.03	l	0.03	o	0.0005	l	0.0005	o	1	0.1	NA

CHEMICALS	CAS Number[a]	Slope Factor				Reference Dose				Oral RA[b] Factor	Dermal RA Factor	Maximum Contaminant Level
		Oral (SFo) [kg-day/mg]		Inhalation (SFi*) [kg-day/mg]		Oral (RfDo) (mg/kg-day)		Inhalation (RfDi*) (mg/kg-day)		(RAFo)	(RAFd)	[mg/L]
Vinyl Chloride	75-01-4	1.5	l	0.031	l	0.003	l	0.029	l	1	0.0005	0.002
Zinc	7440-66-6	NA		NA		0.3	l	NA		1	0.01	NA

Notes:

[a] Chemical Abstract Service

[b] Relative Absorption

[c] Benzene hexachloride

[d] Dichloro diphenyl dichloroethylene

[e] 1,1-Dichloro-2,2-bis(p-chlorophenyl) ethane

[f] Dichloro diphenyl trichloroethane

[g] Methyl tert-butyl ether

[h] Tetrachloro di benzo-p-dioxin

[i] 4,5,-Trichlorophenoxy propionic acid

Sources of Information:

j: Derived by CAL-EPA

l: IRIS

m: HEAST

n: NCEA

o: Route to route extrapolation

p: Derived by TNRCC

q: Withdrawn from IRIS or HEAST or under review
v: PPRTV

NA: No data available

APPENDIX E

JUSTIFICATION FOR DEFAULT EXPOSURE FACTORS USED FOR DEVELOPING IDTLs AND RATLs

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Risk assessment requires quantifying the magnitude, frequency and duration of exposure for the receptor populations and exposure pathways selected for analysis. In order to determine pathway-specific intake estimates, it is necessary to select values for a number of variables in the equations used to calculate intake. The selection of values for the following variables is based on an assessment of recommendations in various guidance documents, as well as the open scientific literature. When determining these values, it is often necessary to make assumptions, and in these cases the rationale for the assumption is provided.

AVERAGING TIME

The period over which exposure to chemicals is averaged depends on the type of toxic effect being assessed. For chronic exposure to noncarcinogenic toxicants, intakes are averaged over the period of exposure, so the averaging time is equal to the exposure duration. Intakes of carcinogens are calculated by prorating the total cumulative dose over a lifetime. The different approach is based on the idea that for carcinogens a higher dose received over a shorter period is equivalent to a corresponding lower dose spread over a lifetime. The averaging time selected for carcinogens, 70 years, is based on the U.S. Environmental Protection Agency's (EPA) *Risk Assessment Guidance for Superfund* (EPA, 1989).

BODY WEIGHT

It is appropriate to use an average value for this parameter. The default body weight for adult receptors is 70 kilograms (kg), and represents the EPA standard default exposure factor (EPA, 1991). There is evidence presented in the *Exposure Factors Handbook* (EPA, 1997) that Americans are getting slightly heavier, so currently the actual average adult body weight is 72 kg. However, the derivation of cancer slope factors assumes a body weight of 70 kg, so it is more appropriate to use this value. Also, using 70 kg rather than 72 kg results in a slightly more conservative assessment. Adolescent receptors are defined for the purpose of this document to be between the ages of 11 and 19 years. The body weight for adolescents, 55 kg, is the mean value for receptors between the ages of 11 and 19 taken from the *Exposure Factors Handbook* (EPA, 1997). The child body weight is 15 kg, and is the mean value for children aged six months to six years (EPA, 1997). It is also a standard default value in EPA's 1991 *Risk Assessment Guidance for Superfund*.

EXPOSURE DURATION

The age-adjusted exposure duration is the EPA standard default of 30 years (EPA, 1991). This period has traditionally been divided into 6 years of exposure as a child and 24 years as an adult. The approach followed here is to subdivide the 30-year exposure duration into 6 years as a child, 9 years as an adolescent, and 15 years as an adult. These same exposure periods are used for non-age adjusted exposures. For the non-residential adult receptor, the exposure duration is 6.6 years. This is a median value from the *Exposure Factors Handbook* (EPA, 1997). The exposure duration for the construction worker is 30 days (0.08 year); this is assumed to be a conservative estimate of exposure for most construction projects.

Exposure Frequency

The exposure frequency for residential receptors is 350 days per year for all exposure routes that do not involve direct contact with soil. This exposure frequency is the EPA standard default exposure factor (EPA, 1991). The non-residential scenario assumes an exposure frequency of 250 days per year. This is the EPA standard default for commercial or industrial scenarios (EPA, 1991), and so was considered appropriate for all non-residential receptors except for construction workers. For the construction worker scenario, the exposure frequency is 30 days per year.

Exposure Frequency for Direct Contact with Soil

For exposure routes involving direct contact with soil, including soil ingestion and dermal exposure, it is assumed that receptors have contact with soil primarily in warmer months, when the ground is not frozen or snow covered. For this reason, an exposure frequency of 270 days per year is used for these exposure routes for both residential and non-residential scenarios. The direct contact exposure frequency for construction workers is 30 days per year.

Daily Soil Ingestion Rate

The soil ingestion rate for residential child and adult receptors is 200 milligrams per day (mg/day) and 100 mg/day, respectively. These values were taken from EPA's *Risk Assessment Guidance for Superfund* (1991). A value of 100 mg/day is used for residential adolescent receptors, based on the assumption that their pattern of incidental soil ingestion is more similar to of adults than to that of children. Although both the *Risk Assessment Guidance for Superfund* (EPA, 1991) and the *Exposure Factors Handbook* (EPA, 1997) recommend a soil ingestion rate of 50 mg/day for workers other than

construction workers, it was decided to use a value of 100 mg/day to adequately address the potential soil exposures encountered by all non-residential adult receptors. For example, a value of 50 mg/day might be appropriate for office workers, but it would not adequately protect groundskeepers. The construction worker soil ingestion rate is 480 mg/kg. This value comes from a study by Hawley (1985), and it has been previously adopted in the Department of Environmental Quality (DEQ) *Idaho Risk Based Corrective Action Guidance Document for Petroleum Release* (1996).

Daily Water Ingestion Rate

The daily water ingestion rate used for children is 1.5 liters per day (L/day). This is the 90^{th} percentile value for children in the 3 to 5 year age group and the 95^{th} percentile value for all children aged 1 through 10 years (EPA, 1997). The adolescent water ingestion rate is 1.7 L/day, which is the 90^{th} percentile value for the 11 through 19-year age group. The residential adult receptor ingestion rate is 2 L/day, and the non-residential adult ingestion rate is 1 L/day. Both of these values are EPA standard default exposure factors (EPA, 1991).

Hourly Indoor Inhalation Rate

The hourly indoor inhalation rate for children is based on an assumption that the child rests for 8 hours, with an inhalation rate of 0.3 cubic meters per hour (m^3/hr) during that time. The remaining daily time spent indoors at the residence is evenly divided between sedentary activities (0.4 m^3/hr), light activities (1.0 m^3/hr), and moderate activities (1.2 m^3/hr). The average inhalation rate for the total time spent indoors by a child at the residence is 0.7 m^3/hr. All inhalation rates for the various activity levels are mean values recommended by the EPA in the *Exposure Factors Handbook* (EPA, 1997). A similar process was used to develop an hourly indoor inhalation rate, also 0.7 m^3/hr, for adult and adolescent residential receptors. The non-residential receptor is assumed to spend equal amounts of indoor time in sedentary, light, and moderate activities, for an average indoor inhalation rate of 1 m^3/hr. An indoor inhalation rate is not applied in the construction worker scenario, because it is assumed that all time is spent outdoors.

Exposure Time for Indoor Inhalation

The indoor exposure time for children is based on the 50^{th} percentile value of time spent indoors at the residence by children ages 1 through 4. This value is 21 hours per day. Although the time spent indoors for the 5 through 11 year age group is less (16.25 hours per day), it was decided to use the higher value in order to be protective of younger children. The adolescent value of 15.8 hours per day is the 50^{th} percentile for the 12 through 17 year age group, and the residential adult value, 15 hours per day, is the 50^{th}

percentile for the 18 through 64 year age group. Non-residential adult receptors are assumed to spend 7.5 hours per day indoors at the exposure site. All values are taken from the *Exposure Factors Handbook* (EPA, 1997).

Hourly Outdoor Inhalation Rate

For residential receptors, the hourly outdoor inhalation rates are based on the assumption that time spent outdoors at the residence is evenly divided between light and moderate activities. Based on this assumption and the mean hourly inhalation rates for different activities presented in the *Exposure Factors Handbook* (EPA, 1997), the hourly outdoor inhalation rates are 1.1 m^3/hr for children, 1.3 m^3/hr for adolescents, and 1.3 m^3/hr for adults. The outdoor inhalation rate for non-residential adult receptors, 1.6 m^3/hr, is based on an assumption of moderate activity. The construction worker is assumed to divide work between moderate and heavy activity, for an hourly average rate of 2.4 m^3/hr.

Exposure Time for Outdoor Inhalation

The exposure time for outdoor inhalation is based on the 50^{th} percentile of time spent outdoors at the residence. This value is two hours per day for residential receptors. Non-residential receptors are assumed to spend six hours per day outdoors at the site, and construction workers are assumed to spend 10 hours per day outdoors, as construction workers often work 10 hour days.

Dermal Relative Absorption Factor

The dermal relative absorption factor values are based primarily on recommendations contained in the draft EPA *Risk Assessment Guidance for Superfund, Part E, Supplemental Guidance for Dermal Risk Assessment* (EPA, 2001). In some cases, the values selected represent classes of chemicals; in other cases, chemical-specific values are used. For example, the default absorption factor for semivolatile organic compounds is 0.1, while the value for pentachlorophenol is 0.25. The EPA (EPA, 2001) does not provide dermal absorption factors for volatile organic compounds or default absorption factors for inorganics or pesticides. Values for these classes of chemicals are taken from EPA Region 3's *Risk Assessment: Technical Guidance Manual* (EPA, 1995). Two subgroups of volatile organic compounds (VOCs) are identified based on whether they have vapor pressures higher or lower than that of benzene (95 millimeters mercury). An absorption factor of 0.0005 is used for benzene and chemicals that are more volatile than benzene. An absorption factor of 0.03 is used for VOCs with a vapor pressure less than 95 millimeters mercury, such as toluene. The rationale for the higher absorption factor is that less volatile chemicals will remain in contact with the skin, and therefore be available for absorption, for a longer period of time than more volatile chemicals. Actual

absorption of VOCs may be less than that calculated using these absorption factors, so the values are considered conservative. The EPA Region 3 default absorption factor for inorganic chemicals is 0.01 and the value for pesticides is 0.1.

Soil-to Skin Adherence Factor

The soil-to-skin adherence factor was derived primarily from an analysis of soil adherence study data by the Massachusetts Department of Environmental Protection (MDEP, 2000). This analysis calculated body part weighted adherence factor values using studies involving upper end activities for soil-skin adherence and median values of body surface area. Whereas the Massachusetts Department of Environmental Protection used the median value from the resultant calculations, DEQ uses either 90^{th} or 95^{th} percentile estimates.

Skin Surface Area for Dermal Contact with Soil

Skin surface areas for dermal soil contact were developed by the Massachusetts Department of Environmental Protection (MDEP, 2000) based on studies by Holmes et al. (1999) and Kissel et al. (1998). All of the surface areas that are reported in these studies are median values for females. Body surface area is strongly correlated with body weight, and since a central tendency estimate is used for body weight, it would be inappropriate to use an upper bound estimate for surface area. The adult resident value of 5,657 square centimeters (cm^2) is based on a home gardening scenario, with an assumption of exposure to the face, hands, forearms, lower legs, and feet. The adult nonresidential value of 3,477 cm^2 is based on a groundskeeper scenario, with an assumption of exposure to the face, hands, forearms, and feet. It was decided that this value should be used for the construction worker receptor as well. It is based on exposure assumptions for a utility worker, which assume exposure to the face, hands, forearms, and feet. The child receptor surface area is 2,434 cm^2, based on a study of children ages one through eight years playing in wet soil (Kissel et al., 1998), and represents exposure to the face, hands, forearms, lower legs, and feet. For the adolescent receptor, the value of 5,657 cm^2 is based on a soccer-playing scenario, with exposure to the face, hands, forearms, lower legs, and feet.

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APPENDIX F

JUSTIFICATION FOR FATE AND TRANSPORT FACTORS FOR DEVELOPING IDTLs AND RATLs

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INTRODUCTION

Several routes of exposure evaluated in the *Idaho Risk Evaluation Manual* (REM) involve pathways where there is the transfer of chemicals across media. These pathways include inhalation of volatiles from soil or ground water in indoor air, ingestion of ground water containing chemicals leached from soil, and inhalation of volatiles and particulates from surficial soil. Models are used to simulate these cross-media transfer processes, estimate exposure point concentrations, and calculate target levels. This appendix describes the models and selection criteria for the default fate and transport parameter values used to develop the Idaho default target levels and to some degree the remedial action target levels. A list of the parameter values selected is presented in Table 3-2 of the REM.

SOIL PROPERTIES

Unsaturated Zone

Generic unsaturated zone soil properties were based on an assumed sandy loam soil textural class. Nielson and Rodgers (1990) and Hers (2002) present data on average soil physical and hydraulic properties for 12 Natural Resources Conservation Service soil textural classes. Data obtained from these compilations include mean particle diameter, total porosity, saturated moisture content, residual moisture content, van Genuchten parameters describing the shape of the moisture characteristic curve, and saturated hydraulic conductivity. Bulk density was calculated from total porosity. Soil vapor permeability was calculated using van Genuchten equations described in the U.S. Environmental Protection Agency's (EPA) *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (EPA, 2003), the hydraulic properties of the sandy loam soil noted above, and average moisture content conditions. Derivation of the average moisture contents is described below.

Infiltration rates for high and low precipitation areas of Idaho were developed and the value for high precipitation areas is used as the Idaho default target level value. The high precipitation area annual infiltration rate of 25 centimeters is based on field studies and water balance calculations done in northern Idaho on the Rathdrum Prairie (Hammel et al., 1995). This value represents about 40 percent of the total annual precipitation. The annual infiltration rate for low precipitation areas (1.4 centimeters) is based on investigations by Cecil et al. (1992). This latter work was conducted in areas of native

vegetation at the Idaho National Engineering and Environmental Laboratory in eastern Idaho. Using stable isotopes and other tracers, a long-term estimate of 1 centimeter per year infiltration was calculated.

This represents approximately five percent of total annual precipitation. This percentage was applied to the total annual precipitation in Boise (11.7 inches/year), with the assumption that Boise conditions represent average low precipitation conditions.

Average soil moisture content values for low and high precipitation conditions were derived by simulating infiltration into a homogeneous soil profile with the sandy loam hydraulic properties discussed above. The variably saturated flow and transport code HYDRUS-1D (Kool and van Genuchten, 1991) was used to conduct the simulations. The simulation was run until steady-state conditions were achieved and the moisture content at that time was noted.

The moisture content in the capillary fringe and the capillary fringe thickness were derived using methods and equations described in EPA (2003). The mean particle diameter of 0.03 centimeters used in these calculations is typical of a sandy loam soil type.

Saturated Zone

The default scenario selected to represent the saturated zone is a sandy, alluvial aquifer of moderate hydraulic conductivity. Selected saturated zone properties and ground water mixing zone thickness were taken from those developed for the soils protective of ground water pathway (Appendix A) in the *Risk Based Corrective Action Guidance Document for Petroleum Releases* (DEQ, 1996). The darcy velocity chosen (3,340 centimeters/year) is from ground water class 2. Total porosity, bulk density, and fraction organic carbon are similar to that of the unsaturated zone soil.

For inorganic chemicals such as metals, in order to model adsorption under saturated conditions for groundwater transport, an adsorption coefficient value was necessary. The default values selected for these chemicals are presented in Appendix G, the table of physical and chemical parameters. The values selected were taken from the technical support documentation for the USEPA soil screening guidance (USEPA, 1996) and a USEPA guidance on adsorption coefficients for selected metals (USEPA,1999). Many metals exhibit adsorption characteristics that vary with pH or other geochemical

parameters. In most cases the adsorption coefficient values chosen represent the lower end of the range.

ENCLOSED SPACE PARAMETERS

The enclosed space parameters are used in combination with soil and ground water properties to define the conditions controlling volatilization of vapors from soil or ground water into indoor spaces and to predict exposure point concentrations of chemicals in indoor air. Scenarios were developed for residential and nonresidential settings. Both the residential and nonresidential scenarios selected consist of one-story, slab-on-grade structures lying directly over the source of contamination. The primary differences between the two scenarios are the size of the structure and the number of air exchanges per time period. The nonresidential structure is larger and exchanges more air than the residential structure.

The size of structure for each scenario was based on residential and commercial building survey data collected by the U.S. Department of Energy (DOE, 1995, 2001). Data from the western census region of the 1993 housing survey (DOE, 1995) were used to further describe residential structures. Thirty-three percent of all homes in this region had heated floor space square footage between 1,000 and 1,599 square feet, constituting the largest proportion of all classes. Approximately 50 percent of all homes were one-story, single-family homes. The next largest category was multi-story apartment buildings, comprising with 29 percent of the homes. Homes with concrete slabs or crawl spaces each constituted about one-third of all homes, while 15 percent had basements. A sensitivity analysis evaluating the impact of concrete slabs vs. crawl spaces on target levels showed little difference.

For nonresidential structures, data from the mountain division of the western region of the 1999 commercial building energy consumption survey were used (DOE, 2001). The median square footage per building in this area was 5,000 square feet. Sixty-six percent of all buildings in this area were one-floor structures. A slab-on-grade foundation and indoor building height of 8 feet was assumed.

An analysis by the Michigan Department of Environmental Quality (MDEQ, 1998) of data evaluating air exchange rates in buildings was used for the default values selected. Values for other structural parameters, specifically the dimensions of foundation cracks, wall/foundation thickness, and pressure differentials between the space and the outdoors,

are based on data presented in the *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings* (EPA, 2003).

In the Johnson-Ettinger model equations, there is a dependent relationship between the width of foundation cracks (equivalent crack radius) and the fraction of the total floor space below grade occupied by cracks. It was decided to fix the equivalent crack width at 0.1 centimeters and allow the fraction of cracks to vary during the calculation of the total area of cracks in the default structure.

Source characteristics for calculation of indoor air pathways assumed a 1-foot separation distance between the top of the soil or ground water source and the building foundation.

For ground water sources, this soil separation distance includes the capillary fringe thickness of 25 centimeters. In making finite mass calculations the soil source was assumed to be 5 feet (153 centimeters) thick.

PARTICULATE EMISSION FACTOR PARAMETERS

All parameter values used in the calculation of the particulate emission factor are taken directly from the U.S. Environmental Protection Agency's soil screening guidance (EPA, 1996). Idaho specific values for the Q/C dispersion factor for a 0.5-acre size source and the average wind speed for Boise were selected as default values.

MODELS

The models selected to estimate the transport of chemicals between various media and within select media such as ground water include:

- The Johnson-Ettinger model (Johnson and Ettinger, 1991) for transport of volatile chemicals between soil or ground water and indoor air. This implementation of the model includes the effects of advection near the building and diffusion to the building from the source and infinite and finite source masses.
- The dilution attenuation factor model for the soil to ground water pathway implemented in the EPA *Soil Screening Guidance* (EPA, 1996). Soil leachate generated using the high infiltration rate is mixed with ground water having the darcy velocity described above. Target levels are estimated in ground water directly below the source.

- The Domenico model for transport of chemicals in the saturated zone. This is a steady-state model that includes advection, sorption, three dimensional dispersion, and decay (Domenico, 1990). Equations for calculating dispersivity values for use in the ground water transport model are those derived by Xu and Eckstein (1995).
- The Cowherd equation for transport and dispersion of particulates as described in the EPA *Soil Screening Guidance* (EPA, 1996).

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APPENDIX G

PHYSICAL-CHEMICAL PROPERTIES FOR DEVELOPING IDTLs AND RATLs

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Physical-Chemical Properties For Developing IDTLs And RATLs

CHEMICALS	CAS[a] Number	Molecular Weight	Water Solubility (mg/L)	Henry's Law Constant (L-air/L-water)	Octanol-Water Partition Coef. Kow (mL/g)	Org. Carbon Ads. Coef. Koc (mL/g)	Vapor Pressure mm Hg	Diffusion Coefficient in Air (cm^2/s)	Diffusion Coefficient in Water (cm^2/s)	log Kd
Acenaphthene	83-32-9	154.2	4.24	6.360E-03	8317.64	4600.00	3.750E-03	0.0421	7.69E-06	NA
Acenaphthylene	208-96-8	152.2	3.93	4.740E-03	8709.60	6918.30	2.900E-02	0.0439	7.07E-06	NA
Acetochlor	34256-82-1	269.8	223	2.860E-06	300.00	200.00	3.400E-08	0.0501	6.00E-06	NA
Acetone	67-64-1	58.8	1000000	1.590E-03	0.58	0.58	2.270E+02	0.1240	1.14E-05	NA
Acrolein	107-02-8	56.1	200000	1.830E-04	0.79	0.52	2.650E+02	0.1050	1.12E-05	NA
Acrylonitrile	107-13-1	53.1	75000	4.570E-03	1.62	1.10	1.100E+02	0.1220	1.34E-05	NA
Alachlor	15792-60-8	269.8	240	8.620E-07	2344.20	191.00	2.200E-05	0.0194	5.83E-06	NA
Aldicarb	116-06-3	190.3	6000	5.820E-08	22.91	120.00	2.900E-05	0.0305	7.20E-06	NA
Aldrin	309-00-2	365.0	0.18	6.970E-03	5620000.00	2450000.00	1.670E-05	0.0132	4.86E-06	NA
Ammonia	7664-41-7	17.0	531000	1.360E-02	1.69	0.49	7.470E+03	0.2590	6.93E-05	NA
Aniline	62-53-3	93.1	36000	5.820E-05	12.02	9.12	6.690E-01	0.0700	8.30E-06	NA
Anthracene	120-12-7	178.2	0.0434	2.670E-03	35481.34	18621.00	2.550E-05	0.0324	7.74E-06	NA
Antimony	7440-36-0	121.8	NA	NA	NA	NA	0.000E+00	NA	NA	1.65
Aroclor 1016	12674-11-2	257.6	0.42	1.190E-02	398110.00	180000.00	4.000E-04	0.0192	6.60E-06	NA
Aroclor 1221	11104-28-2	200.7	0.59	1.410E-01	50119.00	5800.00	6.700E-03	0.0285	7.00E-06	NA
Aroclor 1242	53469-21-9	266.5	0.34	2.100E-02	398110.00	6300.00	4.060E-04	0.0186	6.50E-06	NA
Aroclor 1248	12672-29-6	299.5	0.06	1.130E-01	1580000.00	277000.00	4.940E-04	0.0156	6.10E-06	NA
Aroclor 1254	11097-69-1	327.0	0.057	8.200E-02	3162300.00	530000.00	7.710E-05	0.0156	5.00E-06	NA
Aroclor 1260	11096-82-5	375.7	0.08	1.850E-01	6310000.00	6700000.00	4.050E-05	0.0116	6.00E-06	NA
Arsenic	7440-38-2	74.9	NA	NA	4.78	NA	0.000E+00	NA	NA	1.4
Atrazine	1912-24-9	215.7	30	1.090E-07	661.00	158.00	3.000E-07	0.0564	5.58E-06	NA
Azobenzene	103-33-3	182.2	0.000035	2.042E-04	6607.00	1338.00	1.683E+02	0.0315	7.45E-06	NA
Barium	7440-39-3	137.3	NA	NA	NA	NA	0.000E+00	NA	NA	1.4
Benzene	71-43-2	78.1	1750	2.280E-01	134.89	66.10	9.500E+01	0.0880	9.80E-06	NA
Benzidine	92-87-5	184.2	520	1.620E-09	21.87	20.89	8.360E-08	0.0340	1.50E-05	NA
Benzo(a)anthracene	56-55-3	228.3	0.0094	1.370E-04	501187.00	1380384.00	1.540E-07	0.0510	9.00E-06	NA
Benzo(a)pyrene	50-32-8	252.3	0.00162	4.630E-05	1288249.50	954000.00	4.890E-09	0.0430	9.00E-06	NA
Benzo(b)fluoranthene	205-99-2	252.3	0.015	4.550E-04	1584893.19	549541.00	8.060E-08	0.0226	5.56E-06	NA
Benzo(g,h,i)perylene	191-24-2	276.3	0.00026	5.700E-06	5011872.33	1584893.19	1.000E-10	0.0490	5.65E-05	NA
Benzo(k)fluoranthene	207-08-9	252.3	0.0008	3.400E-05	1584893.00	1024603.00	9.590E-11	0.0226	5.56E-06	NA
Benzoic Acid	65-85-0	122.1	3500	6.310E-05	72.44	0.50	6.510E-03	0.0536	7.97E-06	NA
Benzyl Alcohol	100-51-6	108.1	40000	1.620E-05	12.02	12.02	1.900E-01	0.0800	8.00E-06	NA
Beryllium	7440-41-7	9.0	NA	NA	0.57	NA	0.000E+00	NA	NA	1.36
alpha-BHC[b]	319-84-6	291.0	2	4.350E-04	18197.00	1230.00	4.260E-05	0.0142	7.34E-06	NA
beta-BHC	319-85-7	291.0	0.24	3.050E-05	18197.00	1260.00	4.900E-07	0.0142	7.34E-06	NA
gamma-BHC (lindane)	58-89-9	291.0	6.8	5.740E-04	18197.00	1070.00	3.720E-05	0.0142	7.34E-06	NA
Bis(2-chloroethyl)ether	111-44-4	143.0	17200	7.380E-04	16.22	15.48	1.340E+00	0.0692	7.53E-06	NA
Bis(2-chloroisopropyl)ether	108-60-1	171.1	1700	4.160E-03	380.19	316.22	8.500E-01	0.0600	6.40E-06	NA
Bis(2-ethylhexyl)phthalate	117-81-7	390.6	0.34	4.180E-06	19952623.10	111000.00	6.450E-06	0.0351	3.66E-06	NA
Bromodichloromethane	75-27-4	163.8	6740	6.560E-02	125.90	55.00	5.840E+01	0.0298	1.06E-05	NA

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Bromoform	75-25-2	252.7	3100	2.190E-02	223.87	126.00	5.600E+00	0.0149	1.03E-05	NA
Bromomethane	74-83-9	94.9	15200	5.900E-01	15.14	10.47	1.640E+03	0.0728	1.21E-05	NA
4- Bromophenylphenylether	101-55-0	249.1	4.8	4.800E-03	100000.00	82300.00	1.500E-03	0.0938	1.50E-05	NA
2-Butanone (Methyl Ethyl Ketone)	78-93-3	72.1	240000	1.940E-03	1.80	1.90	9.100E+01	0.0808	9.80E-06	NA
Butyl Benzyl Phthalate	85-68-7	312.4	2.69	5.170E-05	69183.10	13700.00	1.200E-05	0.0174	4.83E-06	NA
Cadmium	7440-43-9	112.4	NA	NA	0.85	NA	0.000E+00	NA	NA	1.18
Carbofuran	1563-66-2	221.3	700	1.620E-07	199.53	29.00	8.300E-06	0.0535	5.40E-06	NA
Carbon Disulfide	75-15-0	76.1	1190	1.240E+00	100.00	52.50	3.400E+02	0.1040	1.00E-05	NA
Carbon Tetrachloride	56-23-5	153.8	793	1.250E+00	537.03	152.00	1.120E+02	0.0780	8.80E-06	NA
Chlordane	57-74-9	409.8	0.056	1.990E-03	2089296.00	120226.00	1.000E-05	0.0118	4.37E-06	NA
4-Chloroaniline	106-47-8	127.6	5300	1.360E-05	67.68	66.00	2.350E-02	0.0483	1.01E-05	NA
Chlorobenzene	108-90-7	112.6	472	1.520E-01	724.44	224.00	1.210E+01	0.0730	8.70E-06	NA
Chloroethane	75-00-3	64.5	5700	3.650E-01	38.02	3.24	1.200E+03	0.8500	1.10E-05	NA
Chloroform	67-66-3	119.4	7920	1.500E-01	83.18	52.50	1.980E+02	0.1040	1.00E-05	NA
Chloromethane	74-87-3	50.5	7250	1.440E+00	12.30	5.99	3.770E+03	0.1260	6.50E-06	NA
2-Chloronaphthalene	91-58-7	162.6	6.74	2.540E-02	6456.54	8511.38	1.700E-02	0.0618	6.982-2	NA
2-Chlorophenol	95-57-8	128.6	22000	1.600E-02	144.54	288.40	1.420E+00	0.0501	9.46E-06	NA
2-Chlorotoluene	95-49-8	126.6	154	1.350E-01	1584.00	407.00	3.900E-03	0.0701	8.01E-06	NA
Chlorpyrifos	2921-88-2	350.6	0.9	1.730E-04	45708.81	5012.00	1.870E-05	0.0485	5.11E-06	NA
Chromium (III) total Chromium	7440-47-3	52.0	NA	NA	NA	NA	0.000E+00	NA	NA	3.08
Chromium (VI)	18540-29-9	52.0	NA	NA	NA	NA	0.000E+00	NA	NA	1.15
Chrysene	218-01-9	228.3	0.0016	3.880E-03	501187.12	245471.00	7.800E-09	0.0248	6.21E-06	NA
Copper	7440-50-8	63.6	NA	NA	-0.57	NA	0.000E+00	NA	NA	1.6
Cyanide (as Sodium Cyanide)	143-33-9	49.0	580000	NA	0.02	NA	0.000E+00	NA	6.64E-06	NA
Dacthal	1861-32-1	332.0	0.5	2.910E-01	25100.00	21200.00	3.300E-01	0.0149	4.27E-06	NA
Dalapon (2,2-dichloropropionic acid)	75-99-0	143.0	1.10E+06	6.300E-08	5.75	25.00	1.900E-01	0.0710	1.13E-05	NA
DDD[c]	72-54-8	320.0	0.09	1.640E-04	741310.00	1000000.00	8.660E-07	0.0169	4.76E-06	NA
DDE[d]	72-55-9	242.0	0.04	8.610E-04	1000000.00	4470000.00	5.660E-06	0.0137	4.95E-06	NA
DDT[e]	50-29-3	354.5	0.025	3.320E-03	3388441.00	138038.00	3.930E-07	0.0137	4.95E-06	NA
Demeton	8000-97-3	516.7	60	6.200E-05	1621.80	70.00	3.000E-04	0.1351	2.16E-05	NA
Dibenzo(a,h)anthracene	53-70-3	278.4	0.000249	6.030E-07	4897788.00	1905460.70	2.100E-11	0.0202	5.18E-06	NA
Dibenzofuran	132-64-9	168.2	2.86	5.280E-03	13182.00	8130.00	1.750E-02	0.0515	7.04E-06	NA
Dibromochloromethane	124-48-1	208.3	2600	3.250E-02	50.10	63.00	1.500E+01	0.0196	1.05E-05	NA
1,2-Dibromo-3-chloropropane	96-12-8	236.3	1000	8.310E-03	478.60	169.80	7.600E-01	0.0800	8.00E-06	NA
1,2-Dichlorobenzene	95-50-1	147.0	156	7.790E-02	2691.53	379.00	1.360E+00	0.0690	7.90E-06	NA
1,3-Dichlorobenzene	541-73-1	147.0	130	1.370E-01	1905.46	1700.00	2.300E+00	0.0642	7.10E-06	NA
1,4-Dichlorobenzene	106-46-7	147.0	73.8	9.960E-02	3235.94	616.00	1.060E+00	0.0690	7.90E-06	NA
3,3'-Dichlorobenzidine	91-94-1	253.1	3.11	1.640E-07	3235.93	724.43	2.200E-07	0.0194	6.74E-06	NA
Dichlorodifluoromethane	75-71-8	120.9	280	1.670E+01	66.00	128.80	4.800E+03	0.0520	1.05E-05	NA

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1,1-Dichloroethane	75-34-3	99.0	5060	2.300E-01	61.66	53.40	2.280E+02	0.0742	1.05E-05	NA
1,2-Dichloroethane	107-06-2	99.0	8520	4.010E-02	29.51	14.10	8.130E+01	0.1040	9.90E-06	NA
1,1-Dichloroethene	75-35-4	97.0	2250	1.070E+00	134.90	65.00	5.910E+02	0.0900	1.04E-05	NA
1,2-Dichloroethene-(cis)	156-59-2	96.9	3500	1.670E-01	72.44	28.84	1.750E+02	0.0736	1.13E-05	NA
1,2-Dichloroethene-(trans)	156-60-5	96.9	6300	3.850E-01	117.49	50.12	3.520E+02	0.0707	1.19E-05	NA
1,2-Dichloropropane	78-87-5	113.0	2800	1.150E-01	93.33	47.00	5.000E+01	0.0782	8.73E-06	NA
1,3-Dichloropropene-(cis)	542-75-6	111.0	2800	7.260E-01	100.00	45.70	3.700E+01	0.0626	1.00E-05	NA
1,3-Dichloropropene-(trans)	542-75-6	111.0	2800	7.260E-01	100.00	45.70	3.000E+01	0.0626	1.00E-05	NA
2,4-Dichlorophenol	102-83-2	163.0	4500	1.300E-04	630.96	72.44	7.150E-02	0.0346	8.77E-06	NA
2,4-Dichlorophenoxyacetic Acid	94-75-7	221.0	890	5.820E-09	416.87	891.00	2.400E-05	0.0590	6.50E-06	NA
2,4-Dimethylphenol	105-67-9	122.2	7870	8.200E-05	229.08	117.49	1.260E-01	0.0584	8.69E-06	NA
Dieldrin	60-57-1	381.0	0.195	6.190E-04	3160.00	21400.00	1.780E-07	0.0125	4.74E-06	NA
Diethylphthalate	84-66-2	222.2	1080	1.850E-05	316.23	82.20	1.650E-03	0.0256	6.35E-06	NA
Dimethylphthalate	131-11-3	194.2	4190	2.400E-05	45.71	42.60	9.120E-03	0.0568	6.30E-06	NA
Di-n-butyl phthalate	84-74-2	278.4	11.2	3.850E-08	40738.03	1570.00	4.250E-05	0.0438	7.86E-06	NA
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	88-85-7	240.2	52	2.080E-02	4680.00	1202.00	7.520E-02	0.0225	6.25E-06	NA
2,4-Dinitrophenol	51-28-5	184.1	2790	1.820E-05	53.70	0.01	1.140E-04	0.0273	9.06E-06	NA
2,4-Dinitrotoluene	121-14-2	182.1	270	3.600E-05	102.33	95.50	1.740E-04	0.2030	7.06E-06	NA
2,6-Dinitrotoluene	606-20-2	182.1	182	3.600E-05	74.13	41.69	5.700E-04	0.0327	7.26E-06	NA
Di-n-octyl phthalate	117-84-0	390.6	0.02	2.740E-03	114815362.00	83200000.00	4.470E-06	0.0151	3.58E-06	NA
1,2-Diphenylhydrazine	122-66-7	184.0	1840	1.420E-07	1148.00	661.00	2.600E-05	0.0562	5.70E-06	NA
Diquat	85-00-7	344.1	700000	2.690E-12	0.00	204.00	1.000E-07	0.0552	5.52E-06	NA
Disulfoton	298-04-4	274.4	16	2.580E-04	7240.00	8913.00	2.300E-04	0.0800	8.00E-06	NA
Diuron	330-54-1	233.1	42	2.060E-08	631.00	480.00	6.900E-08	0.0590	7.40E-06	NA
Endosulfan	115-29-7	423.0	0.51	4.590E-04	6918.00	2140.00	9.960E-06	0.0115	4.55E-06	NA
Endothall	145-73-3	230.1	100000	1.080E-08	77.60	85.00	1.800E-04	0.0800	8.00E-06	NA
Endrin	72-20-8	380.9	0.25	3.080E-04	114815.00	9333.00	5.840E-07	0.0125	4.74E-06	NA
Eptam	759-94-4	189.3	375	1.590E-05	1620.00	196.00	2.400E-02	0.0217	1.90E-05	NA
Ethylbenzene	100-41-4	106.2	169	3.230E-01	1380.38	676.00	9.600E+00	0.0750	7.80E-06	NA
Ethylene Dibromide	106-93-4	187.9	4320	2.930E-02	102.00	53.70	1.100E+01	0.0830	8.00E-06	NA
Fluoranthene	206-44-0	202.3	0.206	6.600E-04	131825.67	48977.88	8.130E-06	0.0302	6.35E-06	NA
Fluorene	86-73-7	166.2	1.98	2.610E-03	16218.10	7300.00	3.240E-03	0.0363	7.88E-06	NA
Fluoride (as Sodium Fluoride)	7681-49-4	42.0	40000	NA	0.17	NA	0.000E+00	NA	6.15E-06	NA
Glyphosate	1071-83-6	169.1	12000	3.200E-07	0.32	3500.00	2.500E+01	0.0437	5.92E-06	NA
Heptachlor	76-44-8	373.3	0.18	4.470E-01	1819700.00	11749.00	3.260E-04	0.0112	5.96E-06	NA
Heptachlor Epoxide	1024-57-3	389.3	0.2	3.900E-04	100000.00	7244.00	4.340E-06	0.0132	4.23E-06	NA
Hexachlorobenzene	118-74-1	284.8	6.2	5.410E-02	776247.11	28183.83	1.230E-05	0.0542	5.91E-06	NA
Hexachlorobutadiene	87-68-3	260.8	3.23	3.340E-01	64565.00	6918.30	1.770E-01	0.0561	6.16E-06	NA
Hexachloroethane	67-72-1	236.7	50	1.590E-01	10000.00	1819.70	4.720E-01	0.0177	6.80E-06	NA
Hexachlorocyclopentadiene	77-47-4	273.8	1.8	1.110E+00	245470.89	9549.92	7.320E-02	0.0161	7.21E-06	NA

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Hexazinone	51235-04-2	251.0	29800	4.440E-11	14.80	41.00	6.400E-05	0.0540	6.00E-06	NA
Hydrogen Sulfide	7883-4-6	34.1	4130	9.560E-01	48.97	NA	1.520E+04	0.1760	1.61E-05	NA
Indeno(1,2,3-cd)pyrene	193-39-5	276.3	0.000022	6.560E-05	4466835.92	3467368.50	1.400E-10	0.0190	5.66E-06	NA
Iron (as Iron Oxide)	1309-37-1	159.7	3.4E-09	NA	NA	NA	0.000E+00	NA	1.20E-05	NA
Isophorone	78-59-1	138.2	12000	2.720E-04	416.87	30.19	4.100E-01	0.0623	6.76E-06	NA
Isopropylbenzene (Cumene)	98-82-8	120.2	50	6.070E-01	2818.38	1.64	4.600E+00	0.0650	7.10E-06	NA
Lead	7439-92-1	207.0	NA	NA	5.40	NA	0.000E+00	NA	NA	2.27
Manganese	7439-96-5	54.9	NA	NA	NA	NA	0.000E+00	NA	NA	1.7
Mercury	7439-97-6	200.6	0.03	NA	0.34	NA	0.000E+00	NA	NA	-1.4
Methoxychlor	72-43-5	345.7	0.045	6.480E-04	467735.00	77625.00	1.230E-06	0.0156	4.46E-06	NA
Methylene Chloride	75-09-2	84.9	13000	8.980E-02	17.78	11.75	4.550E+02	0.1010	1.17E-05	NA
2-Methylnaphthalene	91-57-6	142.2	25.4	1.850E-02	5248.07	4365.00	6.750E-02	0.0629	7.20E-06	NA
4-Methyl-2-pentanone	108-10-1	100.0	19000	5.810E-03	15.50	6.20	1.570E+01	0.0750	7.80E-06	NA
2-Methylphenol	95-48-7	108.1	26000	4.920E-05	97.72	91.20	1.000E+00	0.0740	8.30E-06	NA
4-Methylphenol	106-44-5	108.1	22000	3.250E-05	87.10	49.00	4.000E-02	0.0800	8.00E-06	NA
Metolachlor	51218-45-2	283.5	500	9.800E-07	1096.00	200.00	3.150E-05	0.0480	6.00E-06	NA
Metribuzin	21087-64-9	214.3	1000	1.430E-09	50.10	52.00	1.300E-07	0.0610	7.10E-06	NA
MTBE[f]	1634-04-4	88.2	48000	2.440E-02	26.90	14.10	2.490E+02	0.0792	9.41E-05	NA
Naphthalene	91-20-3	128.0	31	1.980E-02	2290.86	1288.00	8.890E-02	0.0590	7.50E-06	NA
Nickel	7440-02-0	58.7	NA	NA	0.30	NA	0.000E+00	NA	NA	1.2
Nitrate (as Sodium Nitrate)	7631-99-4	85.0	9090000	NA	NA	NA	0.000E+00	NA	8.75E-06	NA
Nitrite (as Sodium Nitrite)	7632-00-0	69.0	666000000	NA	NA	NA	0.000E+00	NA	7.88E-06	NA
2-Nitroaniline	88-74-4	138.1	1260	2.080E-05	104.71	26.92	4.750E-03	0.0599	7.18E-06	NA
3-Nitroaniline	99-09-2	138.1	1200	2.310E-07	23.44	40.00	1.390E-05	0.0698	1.12E-05	NA
4-Nitroaniline	100-01-6	138.1	800	3.330E-08	24.55	11.00	2.860E-06	0.0698	1.12E-05	NA
Nitrobenzene	98-95-3	123.1	1900	9.840E-04	69.18	131.83	2.440E-01	0.0760	8.60E-06	NA
4-Nitrophenol	100-02-7	139.1	16000	2.000E-08	81.30	49.00	4.000E-05	0.0430	9.61E-06	NA
N-Nitrosodimethylamine	62-75-9	74.1	1000000	2.160E-05	0.23	3.63	5.370E+00	0.1340	9.72E-06	NA
N-Nitrosodi-n-propylamine	621-64-7	130.2	9890	9.230E-05	25.12	24.00	4.000E-01	0.0545	8.17E-06	NA
N-Nitrosodiphenylamine	86-30-6	198.2	35.1	2.050E-04	1445.44	331.13	9.880E-02	0.0312	6.35E-06	NA
Oxamyl (Vydate)	23135-22-0	219.3	280000	1.600E-11	0.06	5.00	3.830E-07	0.0557	5.75E-06	NA
Pentachlorophenol	87-86-5	266.3	1950	1.000E-06	54954.10	407.38	1.700E-05	0.0560	6.10E-06	NA
Phenanthrene	85-01-8	178.2	0.994	5.400E-03	22387.21	14125.37	6.800E-04	0.0333	7.47E-06	NA
Phenol	108-95-2	94.1	82800	1.630E-05	30.20	28.80	4.630E-01	0.0820	9.10E-06	NA
Picloram	1918-02-1	241.5	430	4.550E-10	251.18	228.80	6.160E-07	0.0923	1.47E-05	NA
Prometon	1610-18-0	225.3	620	1.300E-07	490.00	150.00	6.000E-07	0.0580	7.00E-06	NA
Pyrene	129-00-0	202.3	0.135	4.510E-04	128824.90	64565.00	4.250E-06	0.0272	7.24E-06	NA
sec-Butylbenzene	135-98-8	134.2	18.1	5.070E-01	12589.25	2830.00	1.250E+00	0.0576	6.75E-06	NA
Selenium	7782-49-2	79.0	NA	NA	1.74	NA	0.000E+00	NA	NA	0.34
Silver	7440-22-4	107.9	NA	NA	NA	NA	0.000E+00	NA	NA	-1
Simazine	122-34-9	201.7	3.5	4.000E-08	32.00	48.00	2.200E-08	0.0844	1.35E-05	NA

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Styrene	100-42-5	104.0	310	1.130E-01	870.96	912.00	6.240E+00	0.0710	8.00E-06	NA
2,3,7,8-TCDD[g]	1746-01-6	322.0	1.93E-08	1.620E-05	4370000.00	481000.00	6.400E-10	0.0145	4.14E-06	NA
Terbutryn	886-50-0	241.4	25	1.300E-06	5495.00	1628.00	2.100E-06	0.0560	6.00E-06	NA
tert-Butylbenzene	98-06-6	134.2	15.1	8.560E-01	12589.25	3410.00	1.760E+00	0.0584	6.76E-06	NA
1,1,1,2-Tetrachloroethane	630-20-6	167.9	1100	9.980E-02	851.13	954.99	1.220E+01	0.0710	7.90E-06	NA
1,1,2,2-Tetrachloroethane	79-34-5	167.9	2970	1.410E-02	245.47	79.00	5.170E+00	0.0710	7.90E-06	NA
Tetrachloroethene	127-18-4	165.8	200	7.540E-01	467.74	154.00	1.840E+01	0.0720	8.20E-06	NA
Thallium	7791-12-0	240.0	NA	NA	NA	NA	0.000E+00	NA	NA	1.64
Toluene	108-88-3	92.1	526	2.720E-01	562.34	135.00	2.820E+01	0.0870	8.60E-06	NA
Total Xylenes	1330-20-7	106.2	198	2.930E-01	1548.82	692.00	8.060E+00	0.0740	8.50E-06	NA
Toxaphene	8001-35-2	413.8	0.74	2.460E-04	316227.00	95500.00	4.190E-06	0.0116	4.34E-06	NA
2,4,5 TP[h] (Silvex)	93-72-1	269.5	140	5.450E-07	4786.00	2570.00	5.200E-06	0.0194	5.80E-06	NA
1,2,4-Trichlorobenzene	120-82-1	181.5	300	5.820E-02	10232.93	1659.58	3.360E-01	0.0300	8.23E-06	NA
1,1,1-Trichloroethane	71-55-6	133.4	1330	7.050E-01	302.00	135.00	1.240E+02	0.0780	8.80E-06	NA
1,1,2-Trichloroethane	79-00-5	133.4	4420	3.740E-02	112.20	50.10	2.520E+01	0.0780	8.80E-06	NA
Trichloroethene	79-01-6	131.4	1100	4.220E-01	512.86	93.30	7.200E+01	0.0790	9.10E-06	NA
Trichlorofluoromethane	75-69-4	137.4	1100	4.030E+00	134.90	159.00	6.870E+02	0.0870	9.70E-06	NA
2,4,5-Trichlorophenol	95-95-4	197.5	1200	1.780E-04	2818.38	295.12	1.630E-02	0.0291	7.03E-06	NA
2,4,6-Trichlorophenol	88-06-2	197.5	800	3.190E-04	2818.38	131.80	1.180E-02	0.0318	6.25E-06	NA
1,2,3-Trichloropropane	96-18-4	147.4	1900	1.580E-02	316.23	389.05	3.700E+00	0.0710	7.90E-06	NA
1,2,4-Trimethylbenzene (Pseudocumene)	95-63-6	120.2	56.8	1.840E-01	4466.80	933.25	1.590E+00	0.0622	7.28E-06	NA
1,3,5-Trimethylbenzene	108-67-8	120.2	51.5	2.720E-01	5011.87	1023.29	2.130E+00	0.0621	7.23E-06	NA
2,4,6-Trinitrotoluene	118-96-7	227.0	130	1.900E-05	977.00	302.00	1.240E-04	0.0541	6.57E-06	NA
Vinyl Chloride	75-01-4	62.5	2760	1.110E+00	31.62	18.60	2.800E+03	0.1060	1.23E-06	NA
Zinc	7440-66-6	65.4	NA	NA	3.00	NA	0.000E+00	NA	NA	1.2

[a] Chemical Abstract Service

[b] Benzene hexachloride

[c] Dichloro diphenyl dichloroethylene

[d] 1,1-Dichloro-2,2-bis(p-chlorophenyl) ethane

[e] Dichloro diphenyl trichloroethane

[f] Methyl tert-butyl ether

[g] Tetrachloro di benzo-p-dioxin

[h] 4,5,-Trichlorophenoxy propionic acid

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APPENDIX H

MODELS AND EQUATIONS FOR DEVELOPING IDTLs AND RATLs

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H.1 TARGET LEVELS FOR RESIDENTIAL, NON-RESIDENTIAL, AND CONSTRUCTION EXPOSURES

H.1.1 INDOOR INHALATION OF VAPOR EMISSIONS

Carcinogenic effects

$$RBTL_{ai} = \frac{TR \times BW \times AT_c \times 365}{IR_{ai} \times ED \times EF \times ET_i \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ai} \times ED \times EF \times ET_i}$$

Source: Modified from U.S. Environmental Protection Agency, 1989, Vol. I, p. 6-44

Where:

$RBTL_{ai}$=	Risk-based target level for indoor air inhalation [mg/m^3]
TR =	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ =	Target hazard quotient for individual constituents [-]
AT_c =	Averaging time for carcinogens [years]
AT_{nc}=	Averaging time for non-carcinogens [years]
ED =	Exposure duration [years]
EF =	Exposure frequency [days/year]
ET_i =	Exposure time for indoor inhalation [hours/day]
RfD_i =	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i =	Chemical-specific inhalation slope factor [(mg/kg-day)$^{-1}$]
IR_{ai} =	Indoor inhalation rate [m^3/hr]
365 =	Conversion factor [days/year]

H.1.2 OUTDOOR INHALATION OF VAPORS AND PARTICULATES FROM SURFICIAL SOIL

Carcinogenic effects

$$RBTL_{SS} = \frac{TR \times BW \times AT_c \times 365}{IR_{ao} \times ED \times EF_d \times ET \times SF_i \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

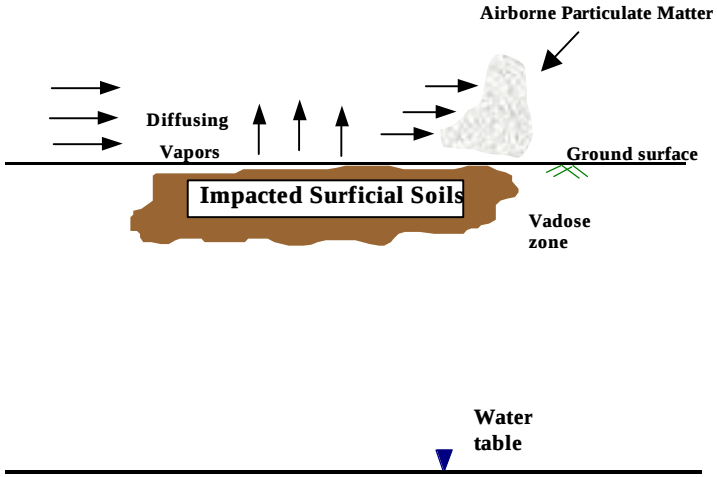
Non-carcinogenic effects

$$RBTL_{SS} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ao} \times ED \times EF_d \times ET \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Where:

$RBTL_{ss}$	=	Risk-based target level for outdoor inhalation of vapors and particulates from surficial soil [mg/kg dry weight]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
VF	=	Surficial soil to ambient air volatilization factor [(m^3-air)/(kg-soil)]
PEF	=	Particulate Emission Factor [(m^3-air)/(kg-soil)]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
ED	=	Exposure duration [years]
EF_d	=	Exposure frequency for direct contact pathway [days/year]
ET	=	Exposure time [hours/day]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation slope factor [$(mg/kg\text{-}day)^{-1}$]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
365	=	Conversion factor [days/year]

Source: U.S. Environmental Protection Agency, 1996



H.1.3 DIRECT INGESTION OF SURFICIAL SOIL

Carcinogenic effects

$$RBTL_S = \frac{TR \times BW \times AT_c \times 365}{SF_o \times EF_d \times ED \times IR_s \times RAF_o \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_S = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{EF_d \times ED \times IR_s \times RAF_o \times 10^{-6}}$$

Source: U.S. Environmental Protection Agency, 1996, p. 19.

Where:

$RBTLs$	=	Risk-based target level for the ingestion of soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
ED	=	Exposure duration [years]
EF_d	=	Exposure frequency [days/year]
IR_s	=	Soil ingestion rate [mg/day]
RAF_o	=	Oral relative absorption factor [-]
RfD_o	=	Chemical-specific oral reference dose [mg/(kg-day)]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
365	=	Conversion factor [days/year]
10^{-6}	=	Conversion factor [kg/mg]

H.1.4 DERMAL CONTACT WITH SURFICIAL SOIL

Carcinogenic effects

$$RBTL_{DC} = \frac{TR \times BW \times AT_C \times 365}{SF_o \times SA \times M \times RAF_d \times ED \times EF_d \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{DC} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{SA \times M \times RAF_d \times ED \times EF_d \times 10^{-6}}$$

Source: Modified from U.S. Environmental Protection Agency,1989, Vol. I, p. 6-35

Where:

$RBTL_{DC}$	=	Risk-based target level for dermal contact with soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
ED	=	Exposure duration [years]
EF_d	=	Exposure frequency for direct contact pathway [days/year]
RAF_d	=	Dermal relative absorption factor [-]
SA	=	Skin surface area [cm^2/day]
M	=	Soil to skin adherence factor [mg/cm^2]
RfD_o	=	Chemical-specific oral reference dose [mg/(kg-day)]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
365	=	Conversion factor [days/year]
10^{-6}	=	Conversion factor [kg/mg]

H.1.5 COMBINED SURFICIAL SOIL PATHWAY: INGESTION, INHALATION OF VAPORS AND PARTICULATES, AND DERMAL CONTACT

Carcinogenic effects

$$RBTL_{ss-combined} = \frac{TR \times BW \times AT_c \times 365}{ED \times EF_d \times SF_o \times 10^{-6}\left(IR_{soil} \times RAF_o + SA \times M \times RAF_d\right) + ED \times EF_d \times ET \times IR_{ao} \times SF_i\left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Non-carcinogenic effects

$$RBTL_{ss-combined} = \frac{THQ \times BW \times AT_{nc} \times 365}{ED \times EF_d \times 10^{-6} \times \frac{1}{RfD_o}\left(IR_{soil} \times RAF_o + SA \times M \times RAF_d\right) + ED \times EF_d \times ET \times IR_{ao} \times \frac{1}{RfD_i}\left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Note: All parameters are defined under the individual pathway equations.

H.1.6 SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{si} = \frac{RBTL_{ai}}{a} * EF$$

Where:

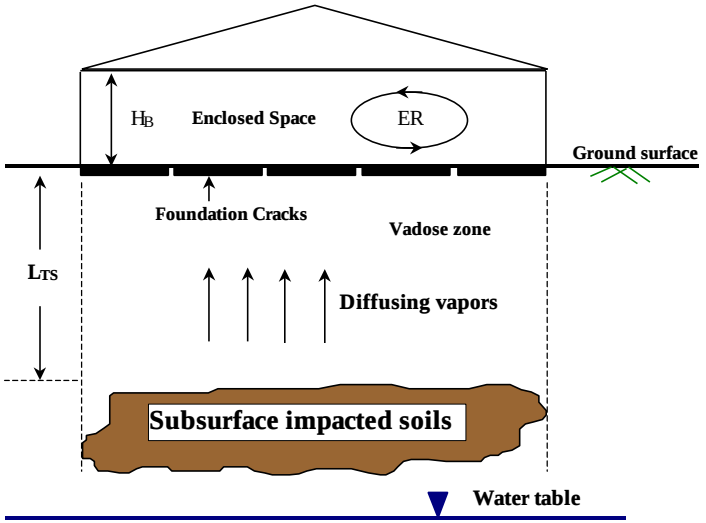
$RBTL_{si}$ = Risk-based target level for indoor inhalation of vapors from subsurface soils [mg/kg of dry soil]

$RBTL_{ai}$ = Risk-based target level for indoor inhalation of air [mg/m^3 of air]

a = Attenuation factor from subsurface soil to indoor (enclosed space) air derived from the Johnson-Ettinger model [dimensionless]

EF = Equilibrium factor to convert vapor target level to total soil target level

$$= \frac{\Theta_{ws} + (K_D\ r_s) + (H\ \Theta_{as})}{(H\ r_s)} * 0.001$$



H.1.7 GROUND WATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ai}}{a} * EF$$

Where:

$RBTL_{wi}$ = Risk-based target level for indoor inhalation of vapors from groundwater [mg/l of H_2O]

$RBTL_{ai}$ = Risk-based target level for indoor inhalation of air (mg/m^3 of air)

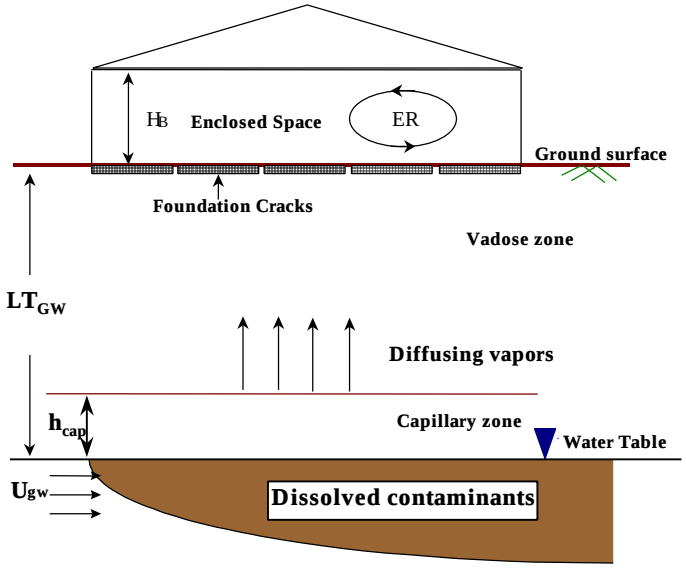
a = Attenuation factor from groundwater to indoor (enclosed space) air derived from the Johnson-Ettinger model [dimensionless]

EF = Equilibrium factor to convert vapor target level to water target level

= $(1/H)*0.001 m^3/L$

Where:

H = Henry's Constant [dimensionless]



H.1.8 DIRECT INGESTION OF GROUND WATER

Carcinogenic effects

$$RBTL_w = \frac{TR \times BW \times AT_C \times 365}{IR_w \times ED \times EF \times SF_o}$$

Non-carcinogenic effects

$$RBTL_w = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{IR_w \times ED \times EF}$$

Source: Modified from U.S. Environmental Protection Agency, 1989, Vol. I, p. 6-35.

Where:

$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
IR_w	=	Water ingestion rate [L/day]
ED	=	Exposure duration [years]
EF	=	Exposure frequency [days/year]
RfD_o	=	Chemical-specific oral reference dose [mg/(kg-day)]
SF_o	=	Chemical-specific oral cancer slope or potency factor [mg/(kg-day)]$^{-1}$
365	=	Conversion factor [days/year]

H.1.9 JOHNSON AND ETTINGER INFINITE SOURCE MODEL

The model predicts the vapor concentration inside a building from the measured soil-vapor, soil, or groundwater concentration.

$$C_{building} = \alpha \times C_{source}$$

Where:

$$C_{source} = \frac{H \times C_{soil} \times \rho_s}{\theta_{ws} + K_d \times \rho_s + H \times \theta_{as}}$$

OR

$$C_{source} = H \times C_w$$

OR

C_{source} = *Measured soil-vapor concentration [mg/L]*

$C_{building}$ = Steady-state vapor-phase concentration in the building [mg/L]
a = Attenuation coefficient in the vapor phase [-]
C_{source} = Vapor-phase concentration at the source [mg/L]
C_{soil} = Concentration in soil [mg/kg]
C_w = Concentration in groundwater [mg/L]
H = Chemical-specific Henry's Law constant [(L of H_2O)/(L of air)]
r_s = Dry soil bulk density [g of soil/cm^3 of soil]
q_{ws} = Volumetric water content in vadose zone soils [cm^3 of H_2O/cm^3 of soil]
K_d = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient [cm^3 of H_2O/g of soil]
q_{as} = Volumetric air content in vadose zone soils [cm^3 of air/cm^3 of soil]

$$\alpha = \frac{\frac{D_T^{eff} A_B}{Q_{building} L_T} \times EXP\left(\frac{Q_{soil} L_{crack}}{D_{crack}^{eff} A_{crack}}\right)}{EXP\left(\frac{Q_{soil} L_{crack}}{D_{crack}^{eff} A_{crack}}\right) + \frac{D_T^{eff} A_B}{Q_{building} L_T} + \frac{D_T^{eff} A_B}{Q_{soil} L_T} \times \left[EXP\left(\frac{Q_{soil} L_{crack}}{D_{crack}^{eff} A_{crack}}\right) - 1\right]}$$

Source: User's guide for evaluating subsurface vapor intrusion into buildings USEPA(2003).

D_T^{eff} = Total overall effective diffusion coefficient [cm^2/s]
D_{crack}^{eff} = Effective diffusion coefficient through cracks [cm^2/s]
A_B = Area of the enclosed space below grade [cm^2]
$Q_{building}$ = Building ventilation rate [cm^3/s]
L_T = Source-building separation [cm]
Q_{soil} = Volumetric flow rate of soil gas into the enclosed space [cm^3/s]
L_{crack} = Enclosed space foundation or slab thickness [cm]
A_{crack} = Total area of cracks [cm^2]

H.1.9 JOHNSON AND ETTINGER INFINITE SOURCE MODEL *(CONTINUED)*

Where:

$$Q_{building} = L_B W_B H_B ER$$

$$Q_{soil} = \frac{2\pi \Delta P k_v X_{crack}}{\mu \ln\left(\frac{2Z_{crack}}{r_{crack}}\right)}$$

For vapor release from soil:

$$D_T^{eff} = \frac{L_T}{\sum_{i=0}^{n} \frac{L_i}{D_i^{eff}}}$$

For vapor release from ground water:

$$D_T^{eff} = D_s^{eff} \qquad D_{crack}^{eff} = D_s^{eff}$$

$$D_T^{eff} = D_{ws}^{eff} = \frac{L_T}{\frac{h_{cap}}{D_{cap}^{eff}} + \frac{\left(L_T - h_{cap}\right)}{D_s^{eff}}} \qquad h_{cap} = \frac{0.75}{D}$$

$Q_{building}$	=	Building ventilation rate [cm^3/s]
L_B	=	Length of building [cm]
W_B	=	Width of building [cm]
H_B	=	Height of building [cm]
ER	=	Air exchange rate [1/s]
Q_{soil}	=	Volumetric flow rate of soil gas into the enclosed space [cm3/s]
p	=	3.14159
DP	=	Pressure differential between the soil surface and the enclosed space [$g/cm\text{-}s^2$]
k_v	=	Soil vapor permeability [cm^2]
X_{crack}	=	Floor-wall seam perimeter [cm]
m	=	Viscosity of air [g/cm-s]
Z_{crack}	=	Crack depth below grade [cm]
r_{crack}	=	Equivalent crack radius [cm]
D_T^{eff}	=	Total overall effective diffusion coefficient [cm^2/s]
L_T	=	Source-building separation [cm]
L_i	=	Thickness of soil layer i [cm]
D_i^{eff}	=	Effective diffusion coefficient in soil layer i [cm^2/s]
N	=	Number of soil layers [-]
D_s^{eff}	=	Effective diffusion coefficient in soil [cm^2/s]
D_{ws}^{eff}	=	Effective diffusion coefficient in capillary fringe [cm^2/s]
h_{cap}	=	Thickness of capillary fringe zone [cm]
D_{cap}^{eff}	=	Effective diffusion coefficient in the capillary fringe soil [cm^2/s]
D_{crack}^{eff}	=	Effective diffusion coefficient in the foundation/wall cracks [cm^2/s]
D	=	Mean particle diameter [cm]

H.1.10 JOHNSON AND ETTINGER FINITE SOURCE MODEL

The model predicts the vapor concentration inside a building from the measured soil concentration when the thickness of soil contamination is known.

$$C_{building} = \alpha \times C_{source}$$

Where:

$$C_{source} = \frac{H \times C_{soil} \times \rho_s}{\theta_{ws} + K_d \times \rho_s + H \times \theta_{as}}$$

$$a = \frac{r_s \; C_{soil} \; \Delta H_c \; A_B}{Q_{building} \, C_{source} \, t} \left(\frac{L_T^0}{\Delta H_c} \right) \left[\left(b^2 + 2 \, y \; t \right)^{1/2} - b \right]$$

$$b = \left(\frac{D_T^{eff} \; A_B}{L_T^0 \; Q_{soil}} \right) \left[1 - \exp\left(- \frac{Q_{soil} \; L_{crack}}{D_{crack}^{eff} \; A_{crack}} \right) \right] + 1$$

$$y = \frac{D_T^{eff} \; C_{source}}{\left(L_T^0 \right)^2 \; r_s \; C_{soil}}$$

$$t_D = \frac{\left[\Delta H_c / L_T^0 + b \right]^2 - b^2}{2y}$$

Source: User's guide for evaluating subsurface vapor intrusion into buildings USEPA(2003).

$C_{building}$	=	Steady-state vapor-phase concentration in the building [mg/L]
a	=	Attenuation coefficient in the vapor phase [-]
C_{source}	=	Vapor-phase concentration at the source [mg/L]
C_{soil}	=	Original Concentration in soil [mg/kg]
C_w	=	Concentration in groundwater [mg/L]
H	=	Chemical-specific Henry's Law constant [(L of H_2O)/(L of air)]
$?_s$	=	Dry soil bulk density [g of soil/cm^3 of soil]
T_{ws}	=	Volumetric water content in vadose zone soils [cm^3 of H_2O/cm^3 of soil]
K_d	=	f_{oc} ? K_{oc}
	=	Chemical-specific soil-water sorption coefficient [cm^3 of H_2O/g of soil]
T_{as}	=	Volumetric air content in vadose zone soils [cm^3 of air/cm^3 of soil]
$?H_c$	=	Initial thickness of contamination [cm]
t_D	=	Time for source depletion [seconds]
t	=	Exposure interval [seconds]
D_T^{eff}	=	Total overall effective diffusion coefficient [cm^2/s]
D_{crack}^{eff}	=	Effective diffusion coefficient through cracks [cm^2/s]
A_B	=	Area of the enclosed space below grade [cm^2]
$Q_{building}$	=	Building ventilation rate [cm^3/s]
L_T^0	=	Source-building separation at time = 0 [cm]
Q_{soil}	=	Volumetric flow rate of soil gas into the enclosed space [cm^3/s]
A_{crack}	=	Total area of cracks [cm^2]
L_{crack}	=	Enclosed space foundation or slab thickness [cm]

H.2 TARGET LEVELS FOR AGE-ADJUSTED RESIDENTIAL EXPOSURES

H.2.1 INDOOR INHALATION OF VAPOR EMISSIONS

Carcinogenic effects

$$RBTL_{ai\text{-}adj} = \frac{TR \times AT_c \times 365}{IR_{ai-aa} \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ai-aa}}$$

Where

$$IR_{ai-aa} = \frac{IR_{ai-c} \times ED_c \times EF_c \times ET_{i-c}}{BW_c} + \frac{IR_{ai-as} \times ED_{as} \times EF_{as} \times ET_{i-as}}{BW_{as}} + \frac{IR_{ai-a} \times ED_a \times EF_a \times ET_{i-a}}{BW_a}$$

Source: Modified from U.S. Environmental Protection Agency, 1989, Vol. I,

Where:

$RBTL_{ai\text{-}adj}$	=	Age-adjusted risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
$IR_{ai\text{-}aa}$	=	Age-adjusted indoor inhalation rate [m^3/ kg]
$IR_{ai\text{-}c}$	=	Resident Child indoor inhalation rate [m^3/hr]
$IR_{ai\text{-}as}$	=	Resident Adolescent indoor inhalation rate [m^3/hr]
$IR_{ai\text{-}a}$	=	Resident Adult indoor inhalation rate [m^3/hr]
ED_c	=	Exposure duration for child [years]
ED_{as}	=	Exposure duration for an adolescent [years]
ED_a	=	Exposure duration for an adult [years]
EF_c	=	Exposure frequency for a child [days/year]
EF_{as}	=	Exposure frequency for an adolescent [days/year]
EF_a	=	Exposure frequency for an adult [days/year]
$ET_{i\text{-}c}$	=	Indoor exposure time for a child [hours/day]
$ET_{i\text{-}as}$	=	Indoor exposure time for an adolescent [hours/day]
$ET_{i\text{-}a}$	=	Indoor exposure time for an adult [hours/day]
BW_c	=	Resident Child body weight [kg]
BW_{as}	=	Resident Adolescent body weight [kg]
BW_a	=	Resident Adult body weight [kg]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [mg/kg-day]$^{-1}$
365	=	Conversion factor [days/year]

H.2.2 OUTDOOR INHALATION OF VAPORS AND PARTICULATES FROM SURFICIAL SOIL

Carcinogenic effects

$$RBTL_{SS-adj} = \frac{TR \times AT_c \times 365}{IR_{ao-aa} \times SF_i \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Non-carcinogenic effects

$$RBTL_{SS-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ao-aa} \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

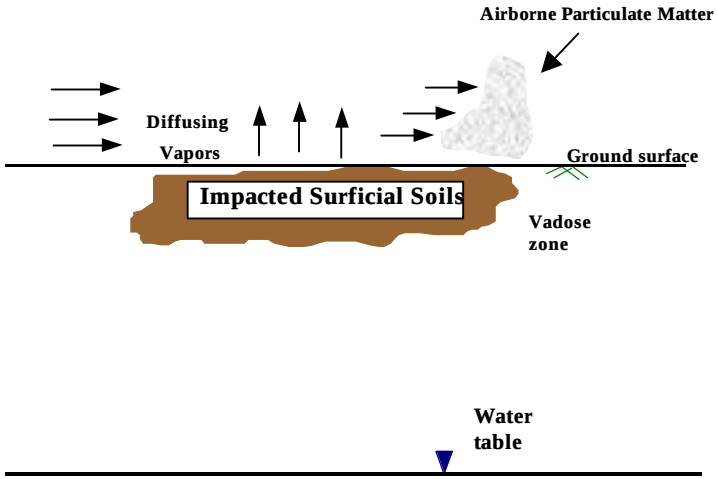
Where

$$IR_{ao-aa} = \frac{IR_{ao-c} \times ED_c \times EF_{dc} \times ET_{o-c}}{BW_c} + \frac{IR_{ao-as} \times ED_{das} \times EF_{as} \times ET_{o-as}}{BW_{as}} + \frac{IR_{ao-a} \times ED_a \times EF_{da} \times ET_{o-a}}{BW_a}$$

Source: U.S. Environmental Protection Agency, 1996

Where:

$RBTL_{ss\text{-}adj}$	=	Age-adjusted risk-based target level in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
VF	=	Surficial soil to ambient air volatilization factor [(m^3-air)/(kg-soil)]
PEF	=	Particulate Emission Factor [(m^3-air)/(kg-soil)]
$IR_{ao\text{-}aa}$	=	Age-adjusted outdoor inhalation rate [(m^3/kg)]
$IR_{ao\text{-}c}$	=	Resident Child outdoor inhalation rate [m^3/hr]
$IR_{ao\text{-}as}$	=	Resident Adolescent outdoor inhalation rate [m^3/hr]
$IR_{ao\text{-}a}$	=	Resident Adult outdoor inhalation rate [m^3/hr]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
ED_c	=	Exposure duration for child [years]
ED_{as}	=	Exposure duration for an adolescent [years]
ED_a	=	Exposure duration for an adult [years]
EF_{dc}	=	Exposure frequency for a child for direct contact pathway [days/year]
EF_{das}	=	Exposure frequency for an adolescent for direct contact pathway [days/year]
EF_{da}	=	Exposure frequency for an adult for direct contact pathway [days/year]
$ET_{o\text{-}c}$	=	Outdoor exposure time for a child [hours/day]
$ET_{o\text{-}as}$	=	Outdoor exposure time for an adolescent [hours/day]
$ET_{o\text{-}a}$	=	Outdoor exposure time for an adult [hours/day]
RfD_i	=	Chemical-specific inhalation reference dose [mg/(kg-day)]
SF_i	=	Chemical-specific inhalation cancer slope factor [mg/(kg- day)]$^{-1}$
365	=	Conversion factor [days/year]



H.2.3 DIRECT INGESTION OF SURFICIAL SOIL

Carcinogenic effects

$$RBTL_{S-adj} = \frac{TR \times AT_c \times 365}{SF_O \times IR_{s-aa} \times RAF_O \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{S-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_O}{IR_{s-aa} \times RAF_O \times 10^{-6}}$$

Where:

$$IR_{s-aa} = \frac{ED_c \times EF_{dc} \times IR_{s-c}}{BW_c} + \frac{ED_{das} \times EF_{as} \times IR_{s-as}}{BW_{as}} + \frac{ED_a \times EF_{da} \times IR_{s-a}}{BW_a}$$

Source: U.S. Environmental Protection Agency, 1996, p.20

Where:

$RBTLs\text{-}adj$	=	Risk-based target level for ingestion of soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
RAF_o	=	Oral relative absorption factor [-]
RfD_o	=	Chemical-specific oral reference dose [mg/(kg-day)]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
$IR_{s\text{-}aa}$	=	Age-adjusted soil ingestion rate [mg/kg]
$IR_{s\text{-}c}$	=	Resident Child soil ingestion rate [mg/day]
$IR_{s\text{-}as}$	=	Resident Adolescent soil ingestion rate[mg/day]
$IR_{s\text{-}a}$	=	Resident Adult soil ingestion rate [mg/day]
BW_c	=	Resident Child body weight [kg]
BW_{as}	=	Resident Adolescent body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ED_{as}	=	Resident adolescent exposure duration [year]
ED_a	=	Resident Adult exposure duration [year]
EF_{dc}	=	Exposure frequency for a child for direct contact pathway [days/year]
EF_{das}	=	Exposure frequency for an adolescent for direct contact pathway [days/year]
EF_{da}	=	Exposure frequency for an adult for direct contact pathway [days/year]
365	=	Conversion factor [days/year]
10^{-6}	=	Conversion factor [kg/mg]

H.2.4 DERMAL CONTACT WITH SURFICIAL SOIL

Carcinogenic effects

$$RBTL_{DC\text{-}adj} = \frac{TR \times AT_c \times 365}{SF_o \times SA_{aa} \times RAF_d \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{DC\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_o}{SA_{aa} \times RAF_d \times 10^{-6}}$$

Where:

$$SA_{aa} = \frac{ED_c \times EF_{dc} \times M_c \times SA_c}{BW_c} + \frac{ED_{as} \times EF_{das} \times M_{as} \times SA_{as}}{BW_{as}} + \frac{ED_a \times EF_{da} \times M_a \times SA_a}{BW_a}$$

Source: Modified from U.S. Environmental Protection Agency, 1989, Vol. I

Where:

$RBTL_{DC\text{-}adj}$	=	Age-adjusted risk-based target level for dermal contact with soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
EF_{dc}	=	Exposure frequency for a child for direct contact pathway [days/year]
EF_{das}	=	Exposure frequency for an adolescent for direct contact pathway [days/year]
EF_{da}	=	Exposure frequency for an adult for direct contact pathway [days/year]
RAF_d	=	Dermal relative absorption factor [-]
M_c	=	Resident Child soil to skin adherence factor [mg/cm^2]
M_{as}	=	Resident Adolescent soil to skin adherence factor [mg/cm^2]
M_a	=	Resident Adult soil to skin adherence factor [mg/cm^2]
RfD_o	=	Chemical-specific oral reference dose [mg/(kg-day)]
SF_o	=	Chemical-specific oral cancer slope or potency factor [mg/(kg-day)]$^{-1}$
SA_{aa}	=	Age-adjusted skin surface area [(mg/ kg]
BW_c	=	Resident Child body weight [kg]
BW_{as}	=	Resident Adolescent body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ED_{as}	=	Resident Adolescent exposure duration [year]
ED_a	=	Resident Adult exposure duration [year]
SA_c	=	Resident Child skin surface area [cm^2/day]
SA_{as}	=	Resident Adolescent skin surface area [cm^2/day]
SA_a	=	Resident Adult skin surface area [cm^2/day]
365	=	Conversion factor [days/year]
10^{-6}	=	Conversion factor [kg/mg]

H.2.5 COMBINED SURFICIAL SOIL PATHWAY:

INGESTION, INHALATION OF VAPORS AND PARTICULATES, AND DERMAL CONTACT

Carcinogenic effects

$$RBTL_{ss-combined} = \frac{TR \times AT_c \times 365}{SF_o \times 10^{-6} \times \left(IR_{s-aa} \times RAF_o + SA_{aa} \times RAF_d\right) + SF_i \times IR_{ao-aa} \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Non-carcinogenic effects

$$RBTL_{ss-combined} = \frac{THQ \times AT_{nc} \times 365}{\frac{1}{RfD_o} \times 10^{-6} \times \left(IR_{s-aa} \times RAF_o + SA_{aa} \times RAF_d\right) + \frac{1}{RfD_i} \times IR_{ao-aa} \times \left(\frac{1}{VF} + \frac{1}{PEF}\right)}$$

Note: All parameters are defined under the individual pathway equations.

H.2.6 SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{si\text{-}adj} = \frac{RBTL_{ai\text{-}adj}}{a} * EF$$

Where:

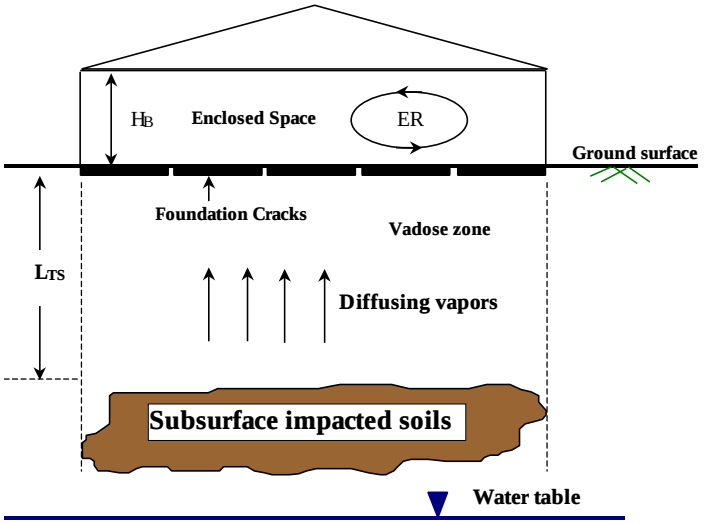
$RBTL_{si\text{-}adj}$ = Age-adjusted risk-based target level for indoor inhalation of vapors from subsurface soils [mg/kg of dry soil]

$RBTL_{ai\text{-}adj}$ = Age-adjusted risk-based target level for indoor inhalation of air [mg/m^3 of air]

a = Attenuation factor from subsurface soil to indoor (enclosed space) air derived from the Johnson-Ettinger model [dimensionless]

EF = Equilibrium factor to convert vapor target level to total soil target level

$$= \frac{\Theta_{ws} + (K_D\ r_s) + (H\ \Theta_{as})}{(H\ r_s)} * 0.001$$



Source: Modified from U.S. Environmental Protection Agency, 2000

H.2.7 GROUND WATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{wi-adj} = \frac{RBTL_{ai-adj}}{a} * EF$$

Where:

$RBTL_{wi-adj}$ = Age-adjusted risk-based target level for indoor inhalation of vapors from groundwater [mg/L of H_2O]

$RBTL_{ai-adj}$ = Age-adjusted risk-based target level for indoor inhalation of air (mg/m^3 of air)

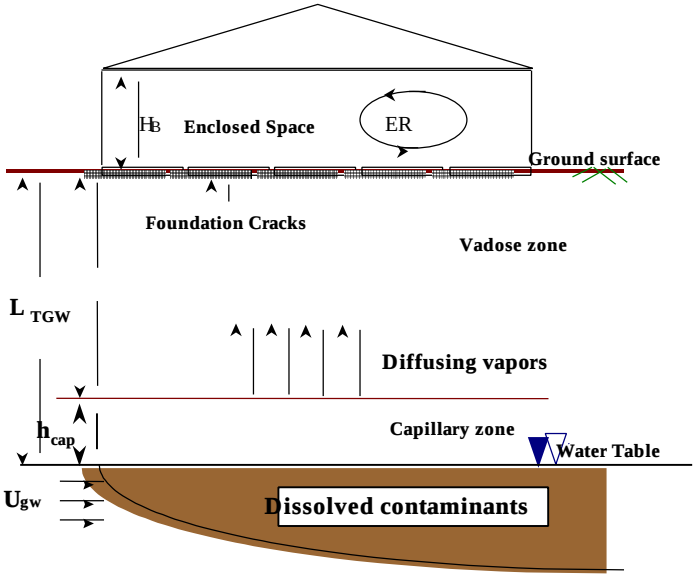
a = Attenuation factor from groundwater to indoor (enclosed space) air derived from the Johnson-Ettinger model [dimensionless]

EF = Equilibrium factor to convert vapor target level to water target level

= $(1/H)*0.001 m^3/L$

Where:

H = Henry's Constant [dimensionless]



Source: Modified from U.S. Environmental Protection Agency, 2000

H.2.8 DIRECT INGESTION OF GROUND WATER

Carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{TR \times AT_c \times 365}{IR_{w\text{-}aa} \times SF_o}$$

Non-carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_o}{IR_{w\text{-}aa}}$$

Where:

$$IR_{w\text{-}aa} = \frac{ED_c \times EF_c \times IR_{w\text{-}c}}{BW_c} + \frac{ED_{as} \times EF_{as} \times IR_{w\text{-}as}}{BW_{as}} + \frac{ED_a \times EF_a \times IR_{w\text{-}a}}{BW_a}$$

Source: Modified from U.S. Environmental Protection Agency, 1989, Vol. I, p. 6-35

Where:

$RBTL_{w\text{-}adj}$	=	Age-adjusted risk-based target level for ingestion of groundwater [mg/L of H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [years]
AT_{nc}	=	Averaging time for non-carcinogens [years]
RfD_o	=	Chemical-specific oral reference dose [mg/(kg-day)]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
$IR_{w\text{-}aa}$	=	Age-adjusted groundwater ingestion rate [L/kg]
$IR_{w\text{-}c}$	=	Resident Child groundwater ingestion rate [L/day]
$IR_{w\text{-}as}$	=	Resident Adolescent groundwater ingestion rate [L/day]
$IR_{w\text{-}a}$	=	Resident Adult groundwater ingestion rate [L/day]
BW_c	=	Resident Child body weight [kg]
BW_{as}	=	Resident Adolescent body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ED_{as}	=	Resident Adolescent exposure duration [year]
ED_a	=	Resident Adult exposure duration [year]
EF_c	=	Exposure frequency for a child [days/year]
EF_{as}	=	Exposure frequency for an adolescent [days/year]
EF_a	=	Exposure frequency for an adult [days/year]
365	=	Conversion factor [days/year]

H.3 TARGET LEVELS FOR GROUND WATER RESOURCE PROTECTION

H.3.1 DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and infinite source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\,a_x}\left[1-\sqrt{1+\frac{4\,k\,a_x}{v}}\right]\right]\times erfc\left[\frac{\left[(x-vt)\sqrt{1+\frac{4\,k\,a_x}{v}}\right]}{2\sqrt{a_x\times v\times t}}\right]\times$$

$$\left[erf\left[\frac{\left(y+\frac{W_{gw}}{2}\right)}{2\sqrt{a_y\,x}}\right]-erf\left[\frac{\left(y-\frac{W_{gw}}{2}\right)}{2\sqrt{a_y\,x}}\right]\right]\times\left[erf\left[\frac{(z+d_{gw})}{2\sqrt{a_z\,x}}\right]-erf\left[\frac{(z-d_{gw})}{2\sqrt{a_z\,x}}\right]\right]$$

Where:

C	=	dissolved-phase concentration [mg/L]
C_o	=	dissolved-phase concentration at the source (at x = y = z = 0) [mg/L]
v	=	retarded seepage velocity [m/sec]
k	=	overall first order bio-decay rate [1/day]
a_x	=	longitudinal dispersivity [m] (a_x = x/10)
a_y	=	lateral dispersivity [m] (a_y = x/30)
a_z	=	vertical dispersivity [m] (a_z = x/200)
x, y, z	=	spatial coordinates [m]
t	=	time [day]
x	=	distance along the centerline to POE from the downgradient edge of dissolved-plume, source zone, or source well [m]
W_{gw}	=	groundwater mixing zone width [m]
d_{gw}	=	groundwater mixing zone thickness [m]
DAF	=	Co/C

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)

At the centerline, for steady-state (after a long time) the concentration can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\,a_x}\left[1-\sqrt{1+\frac{4\,k\,a_x}{v}}\right]\right]\times erf\left[\frac{W_{gw}}{4\sqrt{a_y\,x}}\right]\times erf\left[\frac{d_{gw}}{2\sqrt{a_z\,x}}\right]$$

At the centerline, for steady-state the concentration without decay can be obtained by setting y = 0, z = 0, x << vt, and ? = 0 as:

$$\frac{C(x)}{C_o} = erf\left[\frac{W_{gw}}{4\sqrt{a_y\,x}}\right]\times erf\left[\frac{d_{gw}}{2\sqrt{a_z\,x}}\right]$$

Retarded seepage velocity v is given by the equation:

$$v = \frac{U_{gw}}{R\times q_T}$$

Where:

U_{gw}	=	groundwater darcy velocity [m/s]
R	=	retardation factor in the saturated zone [--]
q_T	=	Total soil porosity in the saturated zone
i	=	hydraulic gradient [--]

H.3.2 SOIL TO GROUND WATER LEACHING FACTOR

$$LF_{SW} = \frac{1}{DAF_{Summers} \times K_{Water-soil}}$$

[(mg/L-H_2O)/(mg/kg-soil)]

$$DAF_{Summers} = 1 + \frac{U_{gw} \times \delta_{gw}}{I \times W_{gw}} \quad \text{(The Summers Model)}$$

$$K_{Water-soil} = \frac{\theta_{ws} + K_d \rho_s + H \times \theta_{as}}{\rho_s}$$

Where:

$DAF_{Summers}$ = Dilution attenuation factor in the mixing zone [--]
$K_{Water-soil}$ = Water-soil partitioning coefficient [(mg/kg-soil)/(mg/L-H_2O)]
r_s = Dry soil bulk density [g-soil/cm^3-soil]
q_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_d = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient [cm^3-H_2O/g-soil]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
q_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
U_{gw} = Groundwater Darcy Velocity [cm/yr]
d_{gw} = Groundwater mixing zone thickness [cm]
I = Infiltration rate of water through soil [cm/year]
W_{gw} = Groundwater mixing zone length [cm]

Source: U.S. Environmental Protection Agency, 1996

H.3.3 SOIL SATURATION LIMIT

C_s^{SAT}: Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]

$$C_s^{sat} = \frac{S}{r_s} \times [H \times q_{as} + q_{ws} + K_d r_s]$$

Where:

S = Pure component solubility in water [mg/L-H_2O]
r_s = Dry soil bulk density [g-soil/cm^3-soil]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
q_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
q_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_d = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient [cm^3-H_2O/g-soil]

Source: ASTM E1739-95

H.3.4 RISK-BASED SOIL AND GROUND WATER CONCENTRATION FOR GROUND WATER RESOURCE PROTECTION

$$\textit{Allowable soil concentration at the source} = \textit{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{LF_{SW}} \times DAF_{unsat}$$

$$\textit{Allowable groundwater concentration at the source} = \textit{Target groundwater concentration at the POE} \times DAF_{POE}$$

$$\textit{Allowable groundwater concentration at the POC} = \textit{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{DAF_{POC}}$$

Where:

POE	=	Point of exposure
POC	=	Point of compliance
DAF_{POE}	=	Dilution Attenuation Factor (in the saturated zone) between the point of exposure and the source
DAF_{POC}	=	Dilution Attenuation Factor (in the saturated zone) between the point of compliance and the source
DAF_{unsat}	=	Dilution Attenuation Factor (in the vadose zone) between water table and soil source
LF_{SW}	=	Dry soil leaching factor

Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

$$\textit{First order decay rate} = \frac{0.693}{Half - Life}$$

$$\text{Retardation Factor for Organics in saturated zone} = 1 + \left(\frac{r_{ss} \times K_{ds}}{q_{TS}} \right)$$

$$\text{Retardation Factor for Metals in saturated zone} = 1 + \left(\frac{r_{ss} \times K_{ds}}{q_{TS}} \right)$$

Where:

r_{ss}	=	Dry soil bulk density of the saturated zone soil [g-soil/cm^3-soil]
K_{ds}	=	Chemical-specific soil-water distribution coefficient in the saturated zone[mL/g]
	=	K_{oc} x foc_s
f_{ocs}	=	fractional organic carbon content in the saturated zone [--]
q_{TS}	=	Total soil porosity in the saturated zone[cm^3/cm^3-soil]

H.4 VOLATILIZATION FACTORS AND EFFECTIVE DIFFUSION COEFFICIENTS

H.4.1 VOLATILIZATION FACTORS

H.4.1.1 ***VF***: Volatilization Factor from Surface Soil to Outdoor (ambient) Air [(m^3-air)/(kg-soil)]

$$VF = Q/C \times \frac{\left(3.14 \times D_A \times t\right)^{1/2}}{\left(2 \times r_s \times D_A\right)} \times 10^{-4}$$

Where:

$$D_A = \frac{\left(q_{as}^{10/3} \times D^a \times H + q_{ws}^{10/3} \times D^w\right) / q_T^2}{r_s \times K_d + q_{ws} + q_{as} \times H}$$

Where:

Q/C	=	Inverse of the mean concentration at the center of square source [cm^2/s]
D_A	=	Apparent diffusivity [cm^2/s]
t	=	Averaging time for vapor flux [s]
r_s	=	Dry soil bulk density [g of soil/cm^3 of soil]
K_d	=	Chemical-specific solid-water sorption coefficient [cm^3 of H_2O/g of soil]
D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
q_T	=	Total soil porosity in the impacted zone [cm^3/cm^3 of soil]
q_{as}	=	Volumetric air content in the vadose zone soils [cm^3 of air/cm^3 of soil]
q_{ws}	=	Volumetric water content in the capillary fringe soils [cm^3 of H_2O/cm^3 of soil]
H	=	Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
W	=	Width of source area parallel to wind, or groundwater flow direction [cm]
10^{-4}	=	Conversion factor [m^2/cm^2]

Source: U.S. Environmental Protection Agency, 1996

H.4.1.2 ***PEF*** : Particulate Emission Factor [(m^3-air)/(kg-soil)]

$$PEF = Q/C \times \frac{3600}{0.036 \times (1 - V) \times \left(U_m / U_t\right)^3 \times F(x)}$$

Where:

Q/C	=	Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)]
V	=	Fraction of vegetative cover [-]
U_m	=	Mean annual windspeed [m/s]
U_t	=	Equivalent threshold value of windspeed at 7 m [m/s]
F(x)	=	Function dependent on U_m/U_t derived using Cowherd *et al.* 1985 [-]
0.036	=	Empirical constant [m^2-hr/g]

Source: U.S. Environmental Protection Agency, 1996

H.4.2 EFFECTIVE DIFFUSION COEFFICIENTS

H.4.2.1 Effective Diffusion Coefficient In Soil

D_s^{eff} : effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]

$$D_s^{eff} = D^a \times \frac{q_{as}^{3.33}}{q_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{q_{ws}^{3.33}}{q_T^{2.0}}$$

Where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
q_{as}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
q_{ws}	=	Volumetric water content in capillary fringe soils [cm^3-H_2O/cm^3-soil]
q_T	=	Total soil porosity in the impacted zone [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]

H.4.2.2 Effective Diffusion Coefficient In Capillary Fringe Soil

D_{cap}^{eff} : effective diffusion coefficient for the capillary fringe [cm^2/s]

$$D_{cap}^{eff} = D^a \times \frac{q_{acap}^{3.33}}{q_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{q_{wcap}^{3.33}}{q_T^{2.0}}$$

Where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
q_{acap}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
q_{wcap}	=	Volumetric water content in capillary fringe soils [cm^3-H_2O/cm^3-soil]
q_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]

Source: ASTM E1739-95

H.4.2.3 Effective Diffusion Coefficient Between Ground Water And Soil

D_{ws}^{eff} : effective diffusion coefficient between ground water and surface soil [cm^2/s]

$$D_{ws}^{eff} = L_{TGW} \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{\left(L_{TGW} - h_{cap}\right)}{D_s^{eff}} \right]^{-1}$$

Where:

h_{cap}	=	Thickness of capillary fringe [cm]
D_{cap}^{eff}	=	Effective diffusion coefficient through capillary fringe [cm^2/s]
D_s^{eff}	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
L_{TGW}	=	Source-building separation [cm]

H.4.2.4 Effective Diffusion Coefficient In Foundation/Wall Cracks

D_{crack}^{eff} : effective diffusion coefficient through foundation cracks [cm^2/s]

$$D_{crack}^{eff} = D^a \times \frac{q_{acrack}^{3.33}}{q_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{q_{wcrack}^{3.33}}{q_T^{2.0}}$$

Where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
q_{acrack}	=	Volumetric air content in foundation/wall cracks [cm^3-air/cm^3-total volume]
q_{wcrack}	=	Volumetric water content in foundation/wall cracks [cm^3-H_2O/cm^3-total volume]
q_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]

H.4.2.5 WATER CONTENT IN SOIL IN THE CAPILLARY FRINGE

$$\theta_{wcap} = \theta_r + \frac{\theta_T - \theta_r}{\left[1 + (\alpha h)^N\right]^M}$$

θ_{wcap}	=	Water content in the capillary fringe zone soil [cm^3 water/cm^3 soil]
θ_r	=	Residual soil water content [cm^3 water/cm^3 soil]
θ_{Tcap}	=	Total porosity of soil in the capillary fringe zone [cm^3 voids/cm^3 soil]
a	=	Point of inflection in the water retention curve where $d\theta_w/dh$ is maximal [1/cm]
h	=	Air-entry pressure head [cm]
	=	$1/\alpha$ and assumed to be positive
N	=	van Genuchten curve shape parameter [-]
M	=	1-(1/N)

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APPENDIX I

SAMPLE TABLE OF CONTENTS FOR A RISK-BASED DECISION-MAKING DOCUMENT (RISK EVALUATION-1 AND RISK EVALUATION-2)

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APPENDIX J

NOTIFICATION OF MIGRATION OF CONTAMINATION FORM

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DEPARTMENT OF ENVIRONMENTAL QUALITY

NOTICE OF MIGRATION OF CONTAMINATION FORM
(April 2004)

An owner or operator of property that is a facility, who has knowledge that a hazardous substance is emanating from, has emanated from, or is likely to be emanating from the property and migrating beyond the boundaries of the property that he or she owns or operates shall notify all impacted property owners using this form. The form report should be submitted to the DEQ for approval and provided to property owners within 7 days after the owner or operator has knowledge that hazardous substances have migrated, or are likely to have migrated, to or beyond the boundary of his or her property in reportable concentrations.

This notice should be sent to the DEQ Regional Office that serves the county in which the property is located. Upon DEQ approval the sender is responsible for sending the notice using a method that provides proof of delivery if such proof is desired.

Please answer the following questions as completely as possible.

1. Name and address of owner or operator making the report.
   _____
   _____
   _____
   _____

2. Status relative to the property.
   (Check one or both, as applicable.)
   Owner ☐
   Operator ☐

3. Name and telephone number of contact person for owner or operator.

4. Address/location of the property that is the subject of this notice (i.e., owned or operated by the person identified in item #1).

   County

5. Complete the Table on Page 3 of this Form for each chemical of concern that has migrated, or is likely to have migrated, up to or beyond the property boundary. Complete additional copies of Page 3, if necessary, to list all chemicals of concern that must be reported. Include a scaled map or drawing that shows the location of sampling points identified on the Table on Page 3.

6. If a map, report, or other additional information is available which depicts or describes the conditions reported on this form, and the basis for your conclusion that this report is required, that information may be (but is not required to be) submitted with this form. You may also identify by title and date any reports previously submitted to the DEQ that contain relevant information. Include the name of the site or facility that the report addresses. This additional information may assist the DEQ in determining whether response activity is required to address conditions described in this notice.

With my signature below, I certify that I am legally authorized to execute this notice on behalf of the owner or operator named on this form, and that to the best of my knowledge and belief the above representations are complete and accurate

Signature _____ Date _____
(Person legally authorized to bind the person making this report)

Name (Typed or Printed)

Title (Typed or Printed)

NOTICE OF MIGRATION OF CONTAMINATION FORM

See Item 5 on Page 1 of this Form for instructions to be used in completing this Table. The information to be included in each column of the Table is:

Column A Name of chemical of concern.
Column B Chemical Abstract Service (CAS) Number for the hazardous substance.
Column C Sample location for Column D (relate to label on map).
Column D Maximum chemical of concern concentration measured on the property, including units (e.g., 100 ug/l or 20 mg/kg). Report maximum concentration separately for each environmental medium.
Column E Environmental medium in which concentration reported in Column D was measured (e.g., soil or groundwater).
Column F Distance from point of maximum measured concentration (Column C) to property boundary, in direction of contaminant migration, if direction is known or can reasonably be inferred. If direction is unknown, list distance to nearest property boundary.
Column G Direction of contaminant migration, if known.
Column H Sample location for Column I (relate to label on map).
Column I Concentration closest to property boundary, if known. If a concentration lower than the maximum concentration reported in Column D has been measured at a point closer to the property boundary in the direction of contaminant migration, use Column I to list the concentration that was measured closest to the property boundary in the direction of contaminant migration.
Column J Environmental medium for measurement reported in Column I, if applicable.

A Hazardous Substance	B CAS Number	C Sample Location for "D"	D Maximum Concentration	E Environmental Medium for "D"	F Distance to Property Boundary	G Direction of Migration	H Sample Location for "I"	I Boundary Concentration	J Environmental Medium for "I"

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APPENDIX K

APPLICATION OF NATURAL ATTENUATION WITHIN THE RISK EVALUATION PROCESS

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INTRODUCTION

This appendix presents general guidance on the applicability and implementation of remediation by natural attenuation (RNA) at contaminated sites in Idaho. It is divided into three parts:

Part I presents a brief overview of the science of natural attenuation (NA);

Part II presents the regulatory requirements for implementing NA as a remedial option;

Part III discusses the techniques available to support, quantify, and implement NA as a remedial option.

This document should be used in conjunction with the Idaho Risk Evaluation Manual (REM) and publicly available literature when implementing RNA. Additional information is available in the references provided at the end of this document.

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PART I: THE SCIENCE OF NATURAL ATTENUATION

Part I presents an overview of the science of natural attenuation. This includes general concepts, how these concepts apply to attenuation of petroleum hydrocarbon and chlorinated solvent contamination, and the methods used to evaluate the activity of natural attenuation at a release site.

K.I.1 THE CONCEPT OF NATURAL ATTENUATION

The term natural attenuation refers to the reduction in concentration or mass of chemicals in a media due to the effects of various environmental fate and transport processes. Natural attenuation occurs without human intervention. Although the term NA is applicable to a reduction in concentration in any medium (air, surface water, ground water), in this document it refers to the reduction in concentration of a dissolved ground water contaminant plume. For a ground water plume, environmental fate and transport processes include physical processes (advection, dispersion, dilution, sorption, and volatilization), chemical processes (hydrolysis, oxidation, and reduction), and biodegradation processes (aerobic and anaerobic). Physical processes are non-destructive in that they redistribute the chemicals in the environment without affecting the total mass of the individual chemical. Biodegradation and chemical transformation processes result in the destruction of the chemical, or, more accurately, the transformation of the parent chemical into other chemicals referred to as daughter products.

Since the publication of the American Society for Testing and Materials' (ASTM) *Standard Guide for Remediation of Groundwater by Natural Attenuation at Petroleum Release Sites* (1998), the U.S. Environmental Protection Agency's (EPA) guide to *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (1999), and other protocols related to NA (e.g., *Technical Protocol for Evaluation of Natural Attenuation of Chlorinated Solvents in Ground Water* [EPA, 1998]) the application of RNA as a tool to cost-effectively clean up contaminated sites has increased. The only human action involved in RNA is monitoring to demonstrate that concentration reduction is occurring at a reasonable rate. Depending on site-specific conditions, RNA may be used as a stand-alone corrective action strategy or in combination with other engineered remediation alternatives.

This guidance focuses on using NA on sites contaminated with petroleum products and chlorinated solvents. Natural attenuation has also been used at sites with other classes of contaminants, such as metals, explosives, and pesticides (USACE, 1999; SNL, 1997). The same concepts for evaluation, requirements for site characterization, and demonstrations as to effectiveness are required regardless of the class of contaminant. A general approach to the evaluation of the bioremediation aspects of natural attenuation for a range of biotreatable compounds is described in ITRC, 2002.

Part I of this guidance includes

- A brief overview of the processes that constitute NA (K.I.2),
- A description of how these processes operate in attenuating petroleum hydrocarbons and chlorinated solvent contamination (K.I.3 and K.I.4), and
- A description of ways to estimate the site-specific NA rate (K.I.5).

K.I.2 OVERVIEW OF NATURAL ATTENUATION PROCESSES

Although each contaminated site is unique, for this discussion it is useful to consider a generic site where a spill has occurred. The soil immediately below and around the point of release becomes contaminated and the contaminant front moves downward. The downward movement of the contaminant front continues until one of the following three conditions occurs:

- The soil pores are saturated and no more contaminant is available,
- An impermeable barrier is encountered and the contaminant spreads horizontally, or
- The contaminant reaches the water table and, if it is a light non-aqueous phase liquid (LNAPL), spreads horizontally.

If a dense non-aqueous phase liquid (DNAPL) reaches the water table, it will continue to migrate downwards through the aquifer.

Note the terms DNAPL and LNAPL relate to the density of the contaminant that was/is released. The DNAPLs are chemicals that are liquid at ambient temperature and heavier than water (e.g., chlorinated solvents). For example, the density of perchloroethylene (PCE) is 1.624 g/cc, compared to a density of 1g/cc for water. The LNAPLs are chemicals that are liquid at ambient temperature but lighter than water. For example, the density of toluene is 0.866 g/cc compared to a density of 1 g/cc for water.

After the contaminant movement has stopped, the soil through which it traveled would be contaminated with residual chemicals that act as a contaminant source for the ground water plume. Figure K.1 shows a schematic of a LNAPL moving through the soil to the ground water.

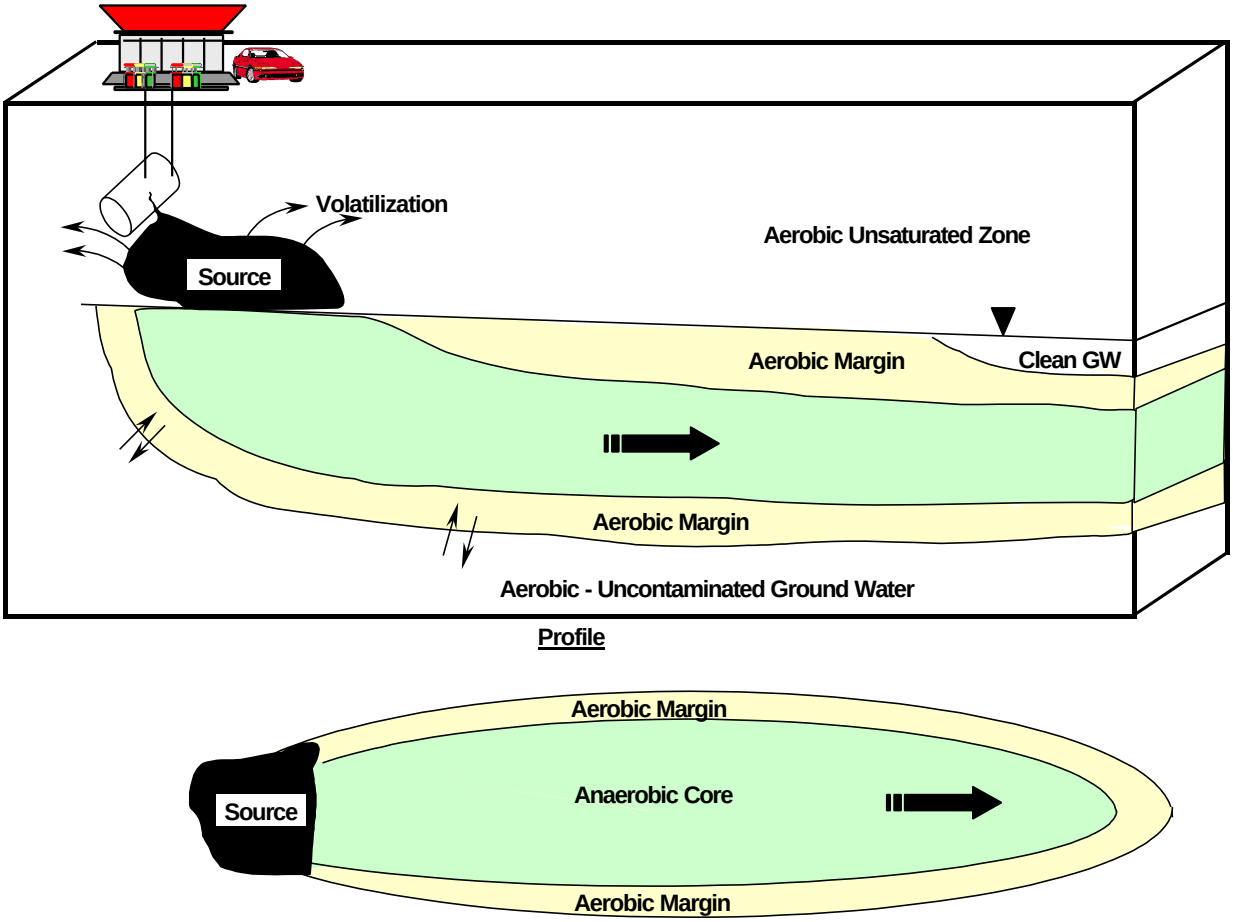


Figure K-1. Schematic of a Hydrocarbon Release

When rainwater infiltrates through the residual contaminated soils, it dissolves and leaches out the soluble components. For petroleum hydrocarbons, the toxic soluble chemicals include, but are not limited to, benzene, toluene, ethylbenzene, and xylene (BTEX); the soluble additives methyl tertiary butyl ether (MTBE) and ethylene dibromide; and smaller fractions of other less soluble constituents. These dissolved chemicals reach the water table, after undergoing NA processes in the unsaturated zone, mix with ground water, and move with the ground water to form a dissolved plume. At sites where the spill is of a sufficient quantity to reach the water table and form a LNAPL layer on the water table, soluble constituents from the LNAPL gradually dissolve in ground water and form a dissolved ground water plume.

A typical DNAPL spill might involve chlorinated solvents such as trichloroethylene (TCE) and PCE. The downward movement of these chemicals would leave residual chemicals in the unsaturated zone and below the water table that are potential future sources of dissolved plumes. Additionally, vapors of volatile hydrocarbons (chemicals with a Henry's constant of less than 1×10-5) will spread outwards from the contaminated soil and dissolve in soil moisture and ground water.

As the dissolved plume moves through the unsaturated and the saturated zones, its concentration decreases due to the combined influence of several NA processes. Each of these processes is briefly discussed below.

K.I.2.1 Advection

Advection refers to the bulk movement or flow of water caused by differences in density, temperature, or pressure. In most aquifers, flow occurs predominantly due to hydraulic gradients, which may be natural, resulting in regional ground water movement, or man-made caused by pumping or artificial recharge. In saturated zones, hydraulic gradients may exist in horizontal and vertical directions resulting in complex three-dimensional flow patterns. However, at most sites there exists a predominant flow direction that results in the migration of most mass.

As water moves in the saturated zone it carries with it the dissolved constituents. The process results in the migration of dissolved constituents in the saturated zone without change in concentration and is termed advection.

Parameters required to estimate the volume of water moving through a saturated zone include the Darcy velocity and the cross-sectional flow area. Darcy velocity is estimated using hydraulic conductivity and hydraulic gradient.

Hydraulic conductivity may be estimated using a variety of methods including slug tests, pump tests, grain size distribution, and literature values corresponding to the site stratigraphy. For most saturated zones, hydraulic conductivity varies in the horizontal and the vertical direction.

Site-specific values of hydraulic gradients are estimated based on water level measurements in monitoring wells, or piezometers. When estimating horizontal hydraulic gradients, it is important to compare data from wells screened in the same saturated zone. Wells screened in different zones or at different depths (e.g., cluster wells) can be used to estimate the vertical hydraulic gradient between the zones. Site-specific hydraulic gradients may exhibit seasonal and spatial variations (magnitude and direction) due to a variety of factors such as pumping, seasonal flow in surface water bodies, and seasonal variations in rainfall.

Another related parameter, used to estimate the travel time of a chemical due to advection, is the seepage velocity that requires an estimate of the porosity of the media. Typically literature values corresponding to the aquifer type (sand, silt, etc.) are used to estimate porosity.

K.I.2.2 Molecular Diffusion

Molecular diffusion refers to the transport of chemical mass from a zone of higher concentration to a zone of lower concentration due to the movement of molecules. The effect of diffusion is to spread the chemical mass over a large area and hence reduce the overall concentration. Thus, diffusion results in a reduction in concentration by dilution. In most ground water systems where there is advection, the attenuation in concentration or the chemical mass transport due to diffusion is small and often negligible. However, in no flow or low flow situations, diffusion can be an important attenuation mechanism.

Molecular diffusion is quantified using the Fick's Law and the parameter required to quantify diffusion is the effective diffusion coefficient of the chemical (Freeze and Cherry, 1979).

K.I.2.3 Mechanical Dispersion

Mechanical dispersion refers to the spreading of the contaminant plume that occurs due to variations in the flow velocity. In the saturated zone, velocity variations occur due to a variety of factors including inter-pore and intra-pore velocity variations and the tortuosity of the porous media. The net effect of mechanical dispersion is that the chemical spreads both horizontally and vertically, thus reducing the overall concentration in the plume. Thus, like diffusion, dispersion is a dilution process.

The transport of mass due to mechanical dispersion is quantified using Fick's Law. The key parameters are the dispersivity coefficients in the three cardinal (x, y, and z) directions. Dispersivity values have been measured using tracers at several research sites, based on which empirical dispersivity relationships (EPRI, 1985; Xu and Eckstein, 1995) have been developed. For most site-specific applications of fate and transport models, these empirical relationships are used. Higher dispersivity values result in larger plumes, which result in increased dilution and lower concentrations.

K.I.2.4 Hydrodynamic Dispersion

The term hydrodynamic dispersion refers to the sum of molecular diffusion and mechanical dispersion. In most ground water systems where there is advection, hydrodynamic dispersion is approximately equal to mechanical dispersion, since the effect of molecular diffusion is negligible.

K.I.2.5 Sorption

Sorption refers to the transfer or distribution of mass between the liquid and the solid phases. Sorption has the overall effect of reducing the mobility of the chemical, which increases its residence time in the subsurface and hence the amount of microbial degradation. This distribution is quantified by the soil water distribution or partition coefficient. For organic chemicals, the distribution coefficient depends on the chemical-specific normalized organic carbon partition coefficient and the organic carbon content in the soil. The distribution coefficient is used to estimate the retardation factor for the chemical, which is a measure of the "stickiness" of the chemical to the formation. Parameters required to estimate the retardation factor include porosity, organic carbon content of soil, bulk density of soil, and chemical-specific normalized organic partition coefficient.

K.I.2.6 Volatilization

Volatilization refers to the transfer of chemical from the NAPL or the dissolved phase to the vapor phase. Vapors can migrate by diffusion alone (in the absence of a pressure gradient) and by diffusion and advection if a pressure gradient exists in the formation. Chemicals volatilizing from the dissolved plume occupy the pores in the unsaturated zone and migrate outwards due to the combined influences of molecular diffusion and vapor-phase advection if pressure gradients exist. Thus, volatilization can result in a net loss of chemical from the dissolved phase or from the NAPL, especially from the LNAPL plume.

The chemical-specific factors controlling volatilization from a dilute solution and LNAPL are the Henry's Law constant and saturated vapor pressure, respectively. These factors are sensitive to the temperature of the media where volatilization occurs.

K.I.2.7 Biodegradation

Biodegradation refers to the destruction of chemicals by indigenous microorganisms present in the aquifer. For petroleum hydrocarbons, biodegradation is the primary destruction mechanism. Due to the significance of biodegradation within the overall process of NA, biodegradation is discussed at length in Sections K.I.3 and K.I.4. In certain situations, additional nutrients or microorganisms may be added to the contaminant plume to enhance the rate of biodegradation.

K.I.2.8 Overall Effect of Natural Attenuation Processes

As explained above, the process of NA refers to a combination of advection, molecular diffusion, dispersion, sorption, volatilization, chemical reactions, and biodegradation. The combined effect of these processes is to spread or reduce the chemical mass in the dissolved plume. Thus, the concentration of the chemical decreases at increasing distances from the source. Figure K.2 shows the concentration profiles in monitoring wells down-gradient of a source under ideal conditions. Although such patterns have been observed at several sites, fluctuations in water levels, flow direction, and climatic conditions often result in non-ideal behavior. Additional complications occur due to errors in data collection, analytical measurements, and the existence of multiple sources (in space and time) at a site.

Depending on the overall rate of NA and the on-going contribution of chemicals to the ground water plume from the residual soil source, ground water plumes may be classified as expanding, stable, or shrinking. These concepts are discussed below.

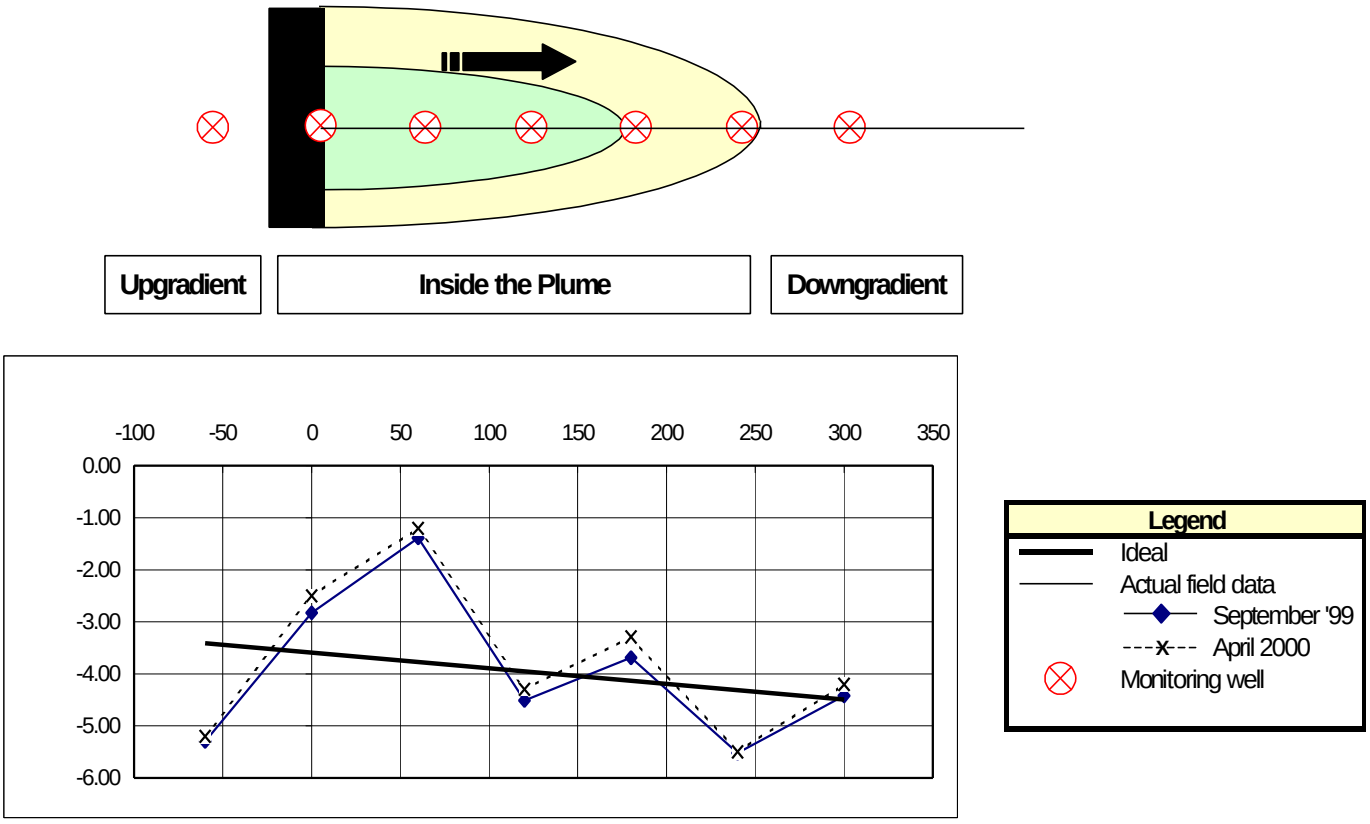


Figure K-2. Concentration Profile as a Function of Distance (Ideal Behavior and Data from an Actual Site)

K.I.2.8.1 Expanding Plume

An expanding plume is characterized by increasing concentrations within the plume and/or an outward movement of the plume that increases the size of the plume. An expanding plume occurs when the chemical mass loading to the plume from leaching, or dissolution of residual NAPL or DNAPL exceeds the mass loss due to NA processes. In an expanding plume, NA processes continue to occur but at a rate too slow to prevent the increase in concentrations or the size of the plume.

K.I.2.8.2 Stable Plume

A stable plume is characterized by stable concentrations within the plume and at the periphery of the plume (i.e., the concentrations do not show a decreasing or an increasing trend). For a plume to be stable, the rate of chemical mass addition to the plume from the source is equal to the rate of chemical mass loss by NA processes. The source may be the chemicals leaching from adsorbed and residual concentrations in the capillary/water table fluctuation zone or in the vadose zone, or the dissolution of chemicals from the NAPL source.

K.I.2.8.3 Shrinking Plume

A shrinking plume is characterized by decreasing ground water concentrations within the plume, decreasing concentrations at the periphery of the plume, or a decrease in the area of the plume. For a shrinking plume, the addition of chemical mass from the source is less than the mass lost due to NA processes. Thus, unless site-specific conditions change that result in

an increase in chemical mass addition to the plume or a decrease in the rate of NA, the plume will eventually disappear.

K.I.2.8.4 Lifecycle of a Plume

Initially, when a chemical reaches the ground water and a plume forms, it is an expanding plume. The plume continues to expand until the addition of chemical mass from the source exceeds mass loss by NA processes. As the plume expands and occupies an ever-increasing portion of the aquifer, the loss of mass by NA processes increases. Thus a point is reached when the mass addition equals mass lost, and the plume becomes stable. Because of the phenomenon of NA, most, but not all, BTEX plumes resulting from service station spills become stable at lengths less than 500 feet, as demonstrated by numerous plume studies (Buscheck et al., 1996; Rice et al., 1995). Since chlorinated solvent plumes emanate from sources that vary widely and chlorinated constituents tend to be more persistent in the groundwater environment (unlike gas station plumes) a similar generalization is not possible.

At most sites the chemical source is finite; hence, in time the mass loading from the source to the dissolved plume decreases. Meanwhile, the rate of mass loss due to NA processes increases or stays the same, so eventually the plume begins to shrink.

Under ideal conditions, all dissolved chemical plumes would follow the above lifecycle; however, real plumes may not follow this pattern due to a number of confounding factors. These factors include, but are not limited to:

- Variations in ground water velocities that affect the rate of NA,
- Fluctuations in the water table that affect the source mass loading due to the release of chemicals trapped in the capillary fringe,
- Variations in climatic conditions that affect the rate of NA,
- Variations in rainfall and infiltration that affect mass loading to ground water, and
- Additions to the plume from new releases and spills from operating facilities.

Because of the above complications, it is important to collect and evaluate all the site data and look at multiple lines of evidence to understand the plume behavior and predict its future behavior. This aspect is discussed in Section K.I.3.5.

K.I.3 BIODEGRADATION OF PETROLEUM HYDROCARBONS

This section discusses the biodegradation of dissolved petroleum hydrocarbons and identifies the various indicators that should be measured to confirm the occurrence of biodegradation.

The biodegradation of hydrocarbons is the process by which naturally occurring subsurface organisms biodegrade contaminants. The process of biodegradation, as facilitated by microorganisms can be represented by the general reaction:

Hydrocarbon + Electron Acceptors + Nutrients **YIELDS** *Carbon Dioxide + Water + Microorganisms + Waste Products*

The above biologically mediated reaction produces energy for cell growth and reproduction of the microbial population. The process of electron transfer results in the oxidation of the donor (hydrocarbon), reduction of the electron acceptor, and the production of usable energy for the organisms. Based on the principles of thermodynamics, biologically mediated reactions that yield the most energy take are favored over reactions that yield less usable energy for the organisms. For hydrocarbons, biologically mediated reactions ideally occur in the following order:

1. Dissolved oxygen in the ground water is used as the electron acceptor.

2. After all oxygen has been depleted, and anaerobic conditions exist within the dissolved plume, dissolved nitrate is used as the electron acceptor.

3. After the depletion of dissolved oxygen and nitrate, ferric iron is used as an electron acceptor and is reduced to ferrous iron.

4. After the depletion of oxygen, nitrate, and iron, sulfate is used by sulfate-reducing bacteria to degrade the hydrocarbons.

5. Finally, methanogenesis degrades the hydrocarbons.

While all petroleum hydrocarbons are biodegradable, the rate of biodegradation can differ significantly from site to site depending on the composition and amount of hydrocarbons; type and amount of available electron acceptors; type, number, and characteristics of the microorganisms; and quantity and quality of nutrients.

Thus, site-specific measurements of these factors, comparison of these factors within and outside the plume, and temporal variations in these factors can be used to demonstrate the occurrence of biodegradation. Each of these factors is discussed below.

K.I.3.1 Composition and Amount of Hydrocarbons

Almost all petroleum hydrocarbons are degradable under aerobic conditions. The ease of biodegradation depends on the type of hydrocarbon. Low molecular weight hydrocarbons (e.g., C10 to C24 alkenes) and single ring aromatics are most easily biodegradable. As the molecular weight increases, the resistance to biodegradation increases. Individual compounds degrade at different rates under aerobic and anaerobic conditions.

For most hydrocarbon-impacted sites, the primary chemicals of concern (from a risk perspective) are BTEX, MTBE, and naphthalene. Naphthalene and BTEX are readily degradable under aerobic conditions. Benzene typically degrades slower than other BTEX hydrocarbons under anaerobic conditions. The biodegradation of MTBE is a topic of significant current research. The conditions under which MTBE degrades and the rate of degradation have not yet been established.

K.I.3.2 Available Electron Acceptors

As indicated above, the biodegradation of hydrocarbons is essentially an oxidation- reduction reaction. In this reaction the hydrocarbon donates the electron (i.e., the hydrocarbon is oxidized) and a second compound (the electron acceptor) is reduced. Of the several electron acceptors available in the subsurface environment, oxygen, because of it's high energy yield, is typically utilized first by microorganisms. Anaerobic bacteria can use other electron acceptors including:

- Nitrate (NO3-) that is reduced to nitrogen (N2)
- Manganese (Mn4+) that is reduced to a water soluble (Mn2+)
- Ferric iron (Fe3+) that is reduced to water soluble (Fe2+)
- Sulfate (SO4--) that is reduced to sulfide (S-)
- Carbon dioxide (CO2) that may be used by methanogens to yield methane (CH4)

As the biodegradation of hydrocarbons occurs, the concentration of the electron acceptors decreases and the concentration of the products formed increases. This concept can be used to demonstrate the occurrence of biodegradation (secondary line of evidence, see Section K.I.3.5.2). Figure K.3 shows the expected relationship between the BTEX concentration and the electron acceptors and the products of the oxidation reduction reaction.

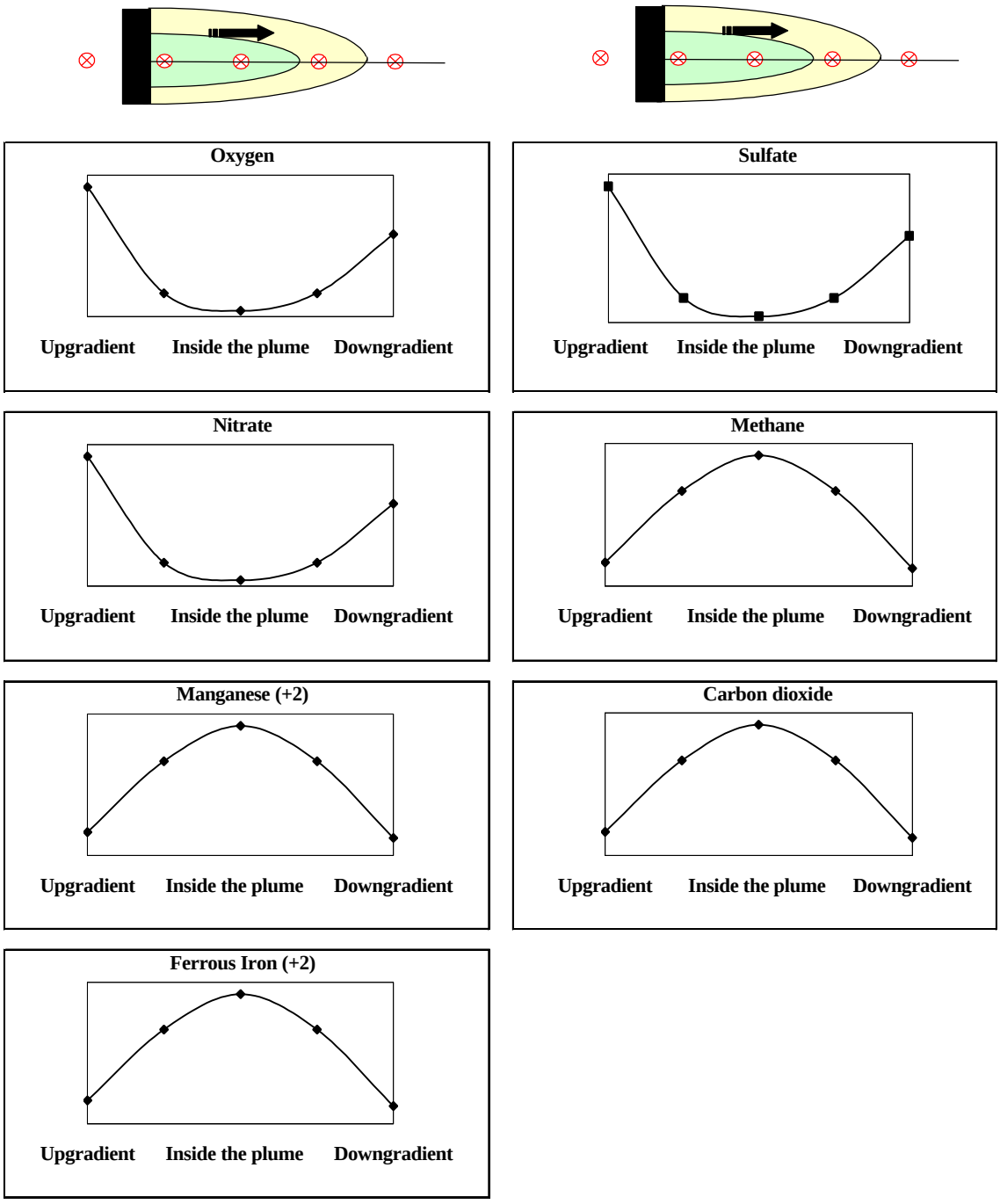


Figure K.3. Expected Pattern of Natural Attenuation Indicators (Secondary Line of Evidence)

K.I.3.3 Quantity and Quality of Nutrients

In addition to the electron acceptors, microorganisms also require nutrients. These nutrients get incorporated into the biomass and are necessary to form cells. The nutrients, nitrogen, and phosphorous are required in relatively large amounts. Small amounts of micro-nutrients, such as sulfur, manganese, and magnesium, are also required. Certain compounds, such as nitrates and sulfates, can serve either as nutrients or electron acceptors. Nutrients are rarely a

limiting factor in the subsurface biodegradation of petroleum hydrocarbons. A decrease in nutrient levels within the zone of degradation can be used as an indicator of biodegradation.

K.I.3.4 Characteristics of Microorganisms

The ability of microorganisms to degrade a wide variety of petroleum hydrocarbons is well documented. Hydrocarbon-degrading microorganisms are widespread in the environment, as they occur in fresh water, salt water, soil, and ground water. The number of cells per milliliter of water can also be used as an indicator of biodegradation. As the hydrocarbons degrade, the cell count for the hydrocarbon degrading bacteria increases. McKee et al. (1972) found 50,000 or more hydrocarbon-degrading bacteria per milliliter in samples from wells containing traces of gasoline, while a non-contaminated well had only 200 microorganisms per milliliter.

K.I.3.5 Indicators of Natural Attenuation of Hydrocarbon Plumes

Based on the information presented above, concentrations of several parameters (hydrocarbons, electron acceptors, microorganisms, nutrients, and carbon dioxide) can be measured to demonstrate the occurrence of NA.

These measurements are typically divided into three tiers, or "lines of evidence" (primary, secondary, and tertiary lines of evidence) to demonstrate NA. Data collected under each line of evidence can be evaluated qualitatively or quantitatively as discussed in the following sections.

K.I.3.5.1 Primary Line of Evidence

The purpose of the primary line of evidence of NA is to demonstrate the loss of chemical mass by evaluating measured petroleum hydrocarbon concentrations. Of all the methods available to demonstrate the occurrence of NA, this is perhaps the simplest and most useful to demonstrate site-specific reductions in risk. Site-specific application of the primary line of evidence requires an adequate number of correctly installed sampling points (monitoring wells), an adequate amount of chemical data from these points, and a thorough evaluation of this data. These issues are discussed in Parts II and III of this document.

Although the primary line of evidence can show whether the concentration of a plume is attenuating, it does not show whether the decrease is due to destructive mechanisms or merely dilution. Secondary lines of evidence are necessary to determine whether the decrease is due to biodegradation.

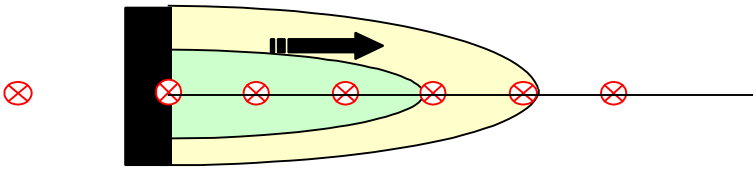
K.I.3.5.2 Secondary Line of Evidence

Secondary evidence of NA refers to the measurement of electron acceptors and products of metabolism within the plume and their comparison with concentrations in the unimpacted area of the aquifer, where no biodegradation activity would be expected to occur. Parameters that are typically measured in the field include dissolved oxygen, dissolved nitrates, manganese, ferrous iron, sulfate, and methane. These parameters should be measured at up-gradient locations, inside the plume near the source, and at down gradient locations. The expected pattern, indicative of biodegradation, is shown in Table K.1. and Figure K.3.

As microorganisms consume chemicals, there is a corresponding consumption of the compounds that serve as electron acceptors. Thus the concentration of these compounds would decrease in the portion of the plume where biodegradation is occurring. For example, under aerobic biodegradation, the concentration of oxygen would decrease assuming oxygen is not being added to the plume. Similarly under anaerobic conditions, a depletion of nitrate, ferric (III) iron, sulfate, and carbon dioxide can be expected.

Biodegradation also results in an increase in the concentration of metabolic by-products. For example, increased concentrations of nitrite and ferrous (II) iron within the plume would be indicative of biodegradation.

Table K.1: Expected Pattern Of Natural Attenuation Indicators (Secondary Line of Evidence)



	Upgradient	Inside the plume		Downgradient
BTEX	ND	High	Low	ND

Type of Reaction	**Geochemical Indicator**	**Geochemical Indicator Concentration**		
Aerobic	Oxygen	High	Low	High
Anaerobic	Nitrate	High	Low	High
	Manganese	Low	High	Low
	Ferrous Iron	Low	High	Low
	Sulfate	High	Low	High
	Methane	Low	High	Low
	Carbon dioxide	Low	High	Low

The secondary line of evidence demonstrates the occurrence of biodegradation only. It does not provide any data on the occurrence of other NA processes.

K.I.3.5.3 Tertiary (Optional) Line of Evidence

The tertiary (optional) line of evidence involves performing microbiological studies, such as identifying the microorganisms present in the formation and counting their cells, in an effort to demonstrate the occurrence of NA. Thus, the objectives of secondary and tertiary lines of evidence are similar. Although petroleum-degrading microbes are ubiquitous in soil and ground water, microbes at a site may not be able to degrade certain compounds such as

MTBE. In the portion of the plume where NA is occurring, the ratio of petroleum degraders to the total number of bacteria should be higher than in the uncontaminated portion of the plume due to the readily available petroleum energy source. Tertiary lines of evidence are seldom required at petroleum hydrocarbon impacted sites; hence, they are not discussed further here.

K.I.4 BIODEGRADATION OF CHLORINATED HYDROCARBON PLUMES

This section discusses the biodegradation of chlorinated hydrocarbons and identifies the various indicators that should be measured to confirm the occurrence of biodegradation. Most organic substances undergo transformation to smaller molecules via oxidation and reduction mechanisms induced by the metabolic activity of native microorganisms. This process is known as biodegradation. The biodegradation pathways for petroleum hydrocarbons have been extensively studied and are reasonably well understood. Unlike the biodegradation of petroleum hydrocarbons, there are numerous pathways and products that result from the biodegradation of chlorinated hydrocarbons, and this area has not been as well studied as the biodegradation of petroleum hydrocarbons.

During the process of reductive dehalogenation, the primary degradation mechanism for chlorinated solvents, electrons are transferred to the halogenated hydrocarbon (electron acceptor) from another source of carbon (electron donor), which can be used as an energy source by microorganisms. There are a number of thermodynamically favorable oxidants that could act as electron acceptors for biologically mediated processes in the subsurface environment. These other electron acceptors compete with the halogenated hydrocarbons for use by microbes. However, those oxidants that yield the most energy take precedence over reactions that yield less usable energy for the organisms. For this reason, in order for reductive dehalogenation to occur, the conditions that energetically favor halogenated hydrocarbons need to be limited as much as possible. A typical example of reductive dehalogenation, using PCE with benzene as an oxidant, would be:

PCE + Benzene + Reducing Conditions + Nutrients **YIELDS** *TCE + Carbon Dioxide + Chlorine + Microorganisms + Waste Products*

For subsurface environments, the most energetically favorable electron acceptors for biologically mediated reactions occur in the following order:

1. Dissolved oxygen in the ground water is used as the electron acceptor.

2. Once dissolved oxygen is depleted, dissolved nitrate in the ground water is used as the electron acceptor.

3. After the depletion of dissolved oxygen and nitrate, ferric iron oxyhydroxide is used as the electron acceptor.

4. If ferric iron oxyhydroxide is not available, dissolved sulfate is used as the electron acceptor.

5. Finally, if dissolved sulfate is not available, carbon dioxide is used as the electron acceptor.

Reductive dechlorination is favored by redox conditions more reducing in magnitude than those associated with sulfate reduction. While all chlorinated hydrocarbons are biodegradable, the rate of biodegradation can differ significantly from site to site depending on the composition and amount of hydrocarbons; type and quantity of available electron acceptors; type, number, and characteristics of the microorganisms; and quantity and quality of nutrients. Thus site-specific measurement of these factors, comparison of these factors within and outside the plume, and temporal variations in these factors can be used to demonstrate the occurrence of biodegradation. Each of these factors is discussed below.

K.I.4.1 Composition and Amount of Hydrocarbons

For chlorinated hydrocarbons, the degree of halogenation determines the rate and applicability of biodegradation, with more highly chlorinated solvents undergoing reductive dehalogenation at a greater rate. For example, the rate of reduction for tetrachloroethylene, which has four chlorine atoms per molecule and is the most oxidized of the chlorinated solvents, is faster than that of vinyl chloride, the least chlorinated solvent.

K.I.4.2 Available Electron Acceptors and Electron Donors

As indicated above, the biodegradation of chlorinated hydrocarbons is essentially an oxidation-reduction reaction. In this reaction, the chlorinated hydrocarbon is reduced by accepting an electron from a second compound (the electron donor) that in turn becomes oxidized. During the process of reductive dehalogenation, the concentration of the electron donor, usually in the form of organic carbon occurring at the site naturally or from an associated fuel spill, is critical. This means the biodegradation process may be limited at sites with low concentrations of the electron donor.

Anaerobic bacteria can use electron acceptors other than oxygen, including:

- Nitrate (NO3-) that is reduced to nitrogen (N2)

- Ferric iron (Fe3+) that is reduced to water soluble ferrous iron (Fe2+)

- Sulfate (SO4--) that is reduced to sulfide (S-)

- Carbon dioxide (CO2) that may be used by methanogens to yield methane (CH4)

As biodegradation of the chlorinated hydrocarbons occurs, the concentration of the electron acceptor decreases and the concentration of the products formed increases. This process can be used to demonstrate the occurrence of biodegradation (secondary line of evidence, see Section K.I.4.3.2).

K.I.4.3 Indicators of Natural Attenuation of Chlorinated Hydrocarbon Plumes

Based on the information presented above, several parameters (microorganism populations and concentrations of chlorinated hydrocarbons, electron acceptors, electron donors, carbon dioxide, and various ground water parameters) can be measured temporally to demonstrate the occurrence of NA. Unlike the biodegradation of petroleum hydrocarbons, the biodegradation of chlorinated hydrocarbons produces daughter products that can also be analyzed as evidence of NA. This analysis is important, as some of the daughter products produced are more toxic than the original chlorinated hydrocarbon, as is the case with vinyl chloride, a daughter product of TCE and PCE.

As with petroleum hydrocarbons, the measurements mentioned above are typically divided into three lines of evidence to demonstrate NA: primary, secondary, and tertiary. Data collected under each line of evidence can be evaluated qualitatively or quantitatively as discussed in the following sections. Of the three lines of evidence discussed below the data collected to support the primary and secondary lines of evidence typically provide the most cost-effective evaluation of biodegradation processes and plume behavior for evaluation of natural attenuation.

K.I.4.3.1 Primary Line of Evidence

The purpose of the primary line of evidence of NA is to demonstrate the loss of chemical mass of the target contaminant by evaluating measured chlorinated hydrocarbon concentrations over time. Of all the methods available to demonstrate the occurrence of NA, this is perhaps the simplest and most useful for demonstrating a site-specific reduction in risk. Site-specific application of the primary line of evidence requires an adequate number of correctly installed sampling points (monitoring wells), an adequate amount of chemical data from these points, and a thorough evaluation of this data. These issues are discussed in Parts II and III of this document.

Although the primary line of evidence can show whether the concentration of a plume is attenuating, it does not demonstrate whether the decrease is due to destructive mechanisms or merely dilution. A secondary line of evidence is necessary to determine whether the decrease is due to biodegradation.

K.I.4.3.2 Secondary Line of Evidence

Secondary evidence of NA documents the loss of contaminant mass due to NA processes. In the case of the degradation of chlorinated hydrocarbons, secondary evidence refers either to:

- The measurement of electron donors and acceptors and products of metabolism within the impacted area and comparison of these measurements with those taken outside the zone of impact, or

- The use of a conservative tracer within the plume. This tracer provides a rigorous estimate of residence time along the plume, and can be used to calculate biological decay rates.

Parameters that are typically measured in the field include: dissolved oxygen, dissolved nitrates, hydrogen, ferrous iron, sulfate, methane, alkalinity, redox potential, and daughter products such as 1, 2, dichloroethene and vinyl chloride. These parameters should be measured at up-gradient locations, inside the plume near the source, and in down gradient locations.

As chemicals are consumed by microorganisms, there is a corresponding consumption of the compounds that serve as electron acceptors. Thus, the concentration of these compounds would decrease in the portion of the plume where biodegradation is occurring. For example, under anaerobic conditions, a depletion of nitrate, ferric (III) iron, sulfate, and carbon dioxide can be expected.

A conservative tracer that is commonly used in chlorinated hydrocarbon plumes is chloride. During biodegradation, chloride is released into the ground water, resulting in chloride concentrations within the plume that are much higher than those found outside the plume boundary.

The secondary line of evidence demonstrates the occurrence of biodegradation only. It does not provide any data on the occurrence of other NA processes.

K.I.4.3.3 Tertiary (Optional) Line of Evidence

The tertiary (optional) line of evidence involves performing microbiological studies, such as identifying the microorganisms present in the formation and counting their cells, in an effort to demonstrate the occurrence of NA. Thus the objectives of secondary and tertiary lines of evidence are similar in that both attempt to demonstrate the occurrence of NA. The tertiary line of evidence is an useful, but costly tool to prove the existence of NA processes. For this reason, secondary lines of evidence may be more advantageous to employ when attempting to demonstrate NA.

K.I.5 ESTIMATION OF A SITE-SPECIFIC NATURAL ATTENUATION RATE

The data collected to demonstrate the primary line of evidence of NA can be used to estimate site-specific NA rates and biodegradation rates. Since NA includes biodegradation, the NA rate would be higher than the biodegradation rate. The latter can be used as an input into a ground water fate and transport model, such as Domenico's model (Domenico, 1987), to estimate the future migration of the plume and to estimate a site-specific dilution attenuation factor. The methods available to estimate the NA rate include mass balance analysis for expanding, stable, or shrinking plumes; plume concentration vs. time plots; and plume concentration vs. distance plots. Descriptions of each of these methods are presented below. An excellent discussion of the calculation and use of rate constants for use in natural attenuation evaluations is presented in Newell, et al, (2002).

K.I.5.1 Mass Balance Analysis

This method of estimating the NA rate is based on the concept of mass balance. For a stable plume, the mass entering the ground water plume must equal the mass lost by NA. Thus, if the mass entering the plume can be estimated, it should be possible to estimate the NA rate. A detailed description of the application of mass balance analysis to estimate the NA rate of a

petroleum release is described in Section X6.1 of the Standard Guide for Remediation of Groundwater by Natural Attenuation at Petroleum Release Sites (ASTM, 1998).

K.I.5.2 Well Concentration vs. Time Plot

The estimate of the overall attenuation rate for a shrinking plume can be calculated assuming a first order decay rate, mathematically represented as:

$$\frac{dC}{dt} = exp^{(-kt)} \tag{K.1}$$

Where:

k = NA rate [1/yr]

The solution to the above differential equation results in the familiar exponential decay:

$$C(t) = C(t=0)\, exp^{(-kt)} \tag{K.2}$$

Where:

C(t) = Concentration at any time t (mg/L)

By taking the natural logarithms of both sides of Equation K.2,

$$ln\,C(t) - ln\,C(t=0) = -kt \tag{K.3}$$

Thus a plot of natural log of concentration vs. time would plot as a straight line with a slope equal to “k”: the NA rate.

K.I.5.3 Well Concentration vs. Distance Plot

Recognizing that advective travel time can be expressed as:

$$t = \frac{x}{v} \tag{K.4}$$

Where:

x = Advective travel distance (cm)

v = Seepage velocity (cm/yr)

By substituting equation K.4 in equation K.2, equation K.2 becomes:

$$C(t) = C(t=0)\, exp^{(-k\frac{x}{v})} \tag{K.5}$$

Taking natural log of both sides of the equation,

$$ln[C(t=0)] - ln[C(t)] = -k\,\frac{x}{v} \tag{K.6}$$

For a shrinking plume that follows the first order attenuation rate presented above, a plot of log concentration vs. distance would plot on a straight line with a slope of k/v. By multiplying the slope with the seepage velocity, the NA rate, k, can be estimated.

Buscheck and Alcantar (1995) used the solution of the one-dimensional transport equation with biodecay to estimate the biodegradation rate based on the slope of the log concentration vs. distance plot. Specifically, they derived the following expression for the biodecay rate:

$$l = \frac{v}{4a_x}\left\{\left[1+2a_x\left(\frac{k}{v}\right)\right]^2 - 1\right\} \tag{K.7}$$

Where:

λ = Biodecay rate, assumed to occur at equal rates in the dissolved and sorbed phases

α_x = Longitudinal dispersivity (0.1 x)

The site-specific application of this method to estimate NA (k) and the biodecay rate (λ) is discussed in Part II.

Zhang and Heathcote (2003) modified this method to account for situations with finite source size and lateral dispersion to improve the estimates of the biodegradation rate.

PART II: REGULATORY REQUIREMENTS FOR THE IMPLEMENTATION OF REMEDIATION BY NATURAL ATTENUATION

Remediation by natural attenuation refers to the achievement of site-specific cleanup goals using NA. As discussed in Part I, NA consists of several processes that occur at all contaminated sites at varying rates. As with any other remedial option, the site-specific applicability of RNA must be carefully evaluated before it is selected as the remedial alternative of choice. Remediation by natural attenuation should not be considered a presumptive remedy; rather, it is one of several available strategies that should be evaluated to ensure its applicability based on site-specific conditions. The first step in any evaluation of NA is the collection of appropriate site characterization data. In general, the data collected need to confirm the occurrence of NA, the effectiveness of RNA, and that the receptors are not exposed to unacceptable risk throughout the period when the site is being remediated by NA. The data collected should be able to answer the following questions and support the activities described in the questions.

- Has the full horizontal and vertical extent of the source and the plume been delineated?
- Is the plume at steady state and is it stable or shrinking in size?
- Can contaminant degradation be demonstrated and quantified?
- Can the long-term behavior of the source and the plume be modeled?
- Can the time frame to achieve remedial cleanup goals be estimated?
- What is the impact of source removal/reduction on the remedial time frame?

Once the site has been characterized to document the feasibility of NA, an evaluation as to the site-specific appropriateness of NA as the preferred remedy should be performed. Remediation by natural attenuation is applicable only at the following types of sites:

- Sites where immediate threats to human health, safety, and the environment do not exist or have been mitigated
- Sites where "active" sources such as leaking tanks, drums, etc. have been removed
- Sites where the projected time frame to achieve remedial objectives is "reasonable," as defined in section K.II.4
- Sites where the plume is stable or shrinking and is not likely to impact current receptors or sensitive habitat
- Sites where active remediation has removed the bulk of the contaminants and the role of RNA is to perform the "final touchup"

- Sites where any necessary institutional controls can be reliably implemented.

Upon selection of RNA as part or all of the preferred remedy, a risk management plan will be developed to document the selection process and provide details about implementation of the remedy for Department of Environmental Quality (DEQ) approval. At all sites, RNA will be accompanied by long term monitoring to demonstrate that RNA is occurring at the rate anticipated when RNA was selected as the remedial option. Monitoring will continue until the specified cleanup goals have been achieved. If the monitoring data indicate that RNA is not occurring at an acceptable rate, the remedial plan will need to be modified and the contingency remedy will need to be implemented. This is further discussed in the following sections.

K.II.1 RISK MANAGEMENT PLAN FOR REMEDIATION BY NATURAL ATTENUATION

At sites where RNA is part of the preferred remedial option, the responsible party must include in a discussion in the risk management plan that includes the following elements:

- A summary of site characterization activities that demonstrates a thorough understanding of nature and extent of the source and the nature and extent of the impacts, provides data supporting the likely effectiveness of RNA, and discusses any source removal/control activities performed at the site.

- A discussion of remedial endpoints and points of compliance, and the manner in which these were determined.

- A discussion of the time frame over which the endpoints are expected to be achieved.

- A demonstration that during this time frame, risks to human health and the environment are acceptable.

- A discussion of monitoring locations, the rationale for monitoring location selection, and the type and frequency of data that will be collected to monitor the performance of RNA and the achievement of remedial goals.

- A description of the tools to be used to evaluate/analyze the monitoring data.

- A description of the institutional controls that will be required and documentation of their implementation.

- A description of a contingency plan that will be implemented if the monitoring results indicate that RNA is not sufficiently effective or is not proceeding at the expected rate.

- A description of the frequency and form of the reports to be submitted to DEQ during the course of implementing RNA.

Approval of the plan will ensure that the data being collected and analyzed will meet the needs of DEQ. A brief discussion of critical components of the RNA portion of the risk management plan is presented below.

K.II.2 SOURCE CHARACTERIZATION AND CONTROL

Characterizing and controlling the source are important aspects of RNA. Sufficient data should be collected during the site investigation phase to delineate the nature and extent of the source and enable the estimation of source lifetime. The term "nature" refers to an evaluation of the chemicals of concern and a determination that the chemicals are amenable to NA. The extent refers to the physical dimensions of the source as well as a determination of the mass of residual chemicals present in the source. An estimate of the lifetime of the source can be made by calculating the mass flux out of the source area (using ground water flow characteristics and contaminant concentrations in the source area) and comparing this to the total contaminant mass in the source area (including free phase product, soils, and ground water).

DEQ requires that all active sources (leaking pipes, tanks, spills, etc.) be stopped and any free phase product in ground water be removed, to the maximum extent practicable. It is best to reduce the source and remediate soils containing residual product that are significant sources of contamination to ground water. Such control measures will reduce the time required to achieve remedial objectives. At a minimum, sufficient source material should be removed to ensure a declining plume. The amount of active remedial activity necessary should be determined on a case-by-cases basis and clearly presented in the risk management plan.

K.II.3 PLUME CHARACTERIZATION

The goals of collecting data to characterize the plume are to demonstrate the magnitude and direction of contaminant transport and the stability status of the plume, to confirm degradation is occurring, and to estimate the contaminant degradation rate or the ability of the aquifer to assimilate the contamination.

To achieve these goals, the responsible party must construct wells to account for aquifer heterogeneity and dominant zones of contaminant transport, select appropriate monitoring locations, collect samples at an adequate frequency, and collect and evaluate the appropriate analytical data. How to determine the appropriate monitoring locations, sampling frequency, and data is discussed below.

The location and number of ground water samples collected and analyzed must be determined based on site-specific conditions. At a minimum, sampling points should be located so as to:

- Locate the distribution of contaminants within the plume,
- Locate the plume boundaries, and
- Track plume movement and migration.

While they do define the extent of the plume, sampling points at non-detect locations provide little useful information for documenting plume characteristics for an NA evaluation. Most sampling points need to be located within the plume boundaries for NA evaluation purposes.

Monitoring wells should be located up-gradient of the source, within or immediately down-gradient of the source area, and within the plume aligned along the plume axis. Data should be collected from a clean downgradient well as well. A downgradient clean well can be used to help characterize the extent of the plume and may be used to protect downgradient receptors by providing early detection of plume movement. This function is described in Section KII.4. Wells delineating the sides of the plume assist in determining if there are significant seasonal changes in ground water flow direction.

As discussed in Sections K.I.4.1 and K.I.4.2, data related to the primary and secondary lines of evidence should be collected. In rare cases, it may be necessary to collect data to demonstrate tertiary lines of evidence as well. Based on the data collected, a determination should be made whether the plume is expanding, stable, or decreasing. The specific analytical tools that may be used to conduct this characterization are discussed in Part III of this document.

Expanding plumes require continued frequent monitoring. Depending on site conditions, such as the risk to current or potential future receptors and the rate at which the plume is expanding, additional assessment of the plume and/or source removal and reduction may be necessary. An expanding plume typically requires active remediation.

Plumes documented to be stable or shrinking are candidates for the use of NA. These plumes will also require continued monitoring, though perhaps at a lower frequency than expanding plumes. Depending on site conditions and the time frame of remediation, a stable plume may require residual source characterization or removal.

The frequency and the duration of monitoring during the plume characterization phase should be determined on a site-specific basis and in consultation with DEQ. However, in most cases, one to two years of quarterly monitoring data are necessary to evaluate the degree of seasonal variations in water levels and flow directions present at a site. This information is necessary to characterize a plume as expanding, stable, or shrinking and to estimate degradation rates. As clear trends emerge in the data, the monitoring frequency may be modified. The actual duration of sampling will depend on the time it takes to demonstrate a clear trend in the concentrations.

K.II.4 REASONABLE TIME FRAME DETERMINATION

The determination as to what constitutes a reasonable time frame for RNA is a complex, site-specific determination not amenable to simple rules of thumb or quantification. In making this determination DEQ will take into account factors that include, but are not limited to:

- The time frame for RNA compared to that for other remedies being evaluated.

- The time frame in which affected portions of the aquifer might be needed for various uses.

- The classification of the ground water resources that are impacted.

- The degree of uncertainty in site characterization and NA estimates.

- The reliability of institutional controls over the time frames for which they may be required to function.

- The ability of the responsible party to maintain the required monitoring and plume evaluation required when NA is used as a remedy.

K.II.5 MONITORING TO DEMONSTRATE THE EFFECTIVENESS OF REMEDIATION BY NATURAL ATTENUATION

Due to the uncertainties associated with the site-specific implementation of RNA, long-term monitoring is necessary to demonstrate its effectiveness. Long-term monitoring is used to ensure that the behavior of the plume does not change (EPA, 1999) and that predictions of plume behavior are accurate. The objectives of long-term monitoring are to demonstrate NA is continuing to occur, human health and the environment are being protected, and the plume is not expanding.

The specifics of the monitoring plan (e.g., the location, frequency, and type of samples to be collected and the analytical procedures to be used) should be determined on a site-specific basis. The primary factors that should be considered when designing a long-term monitoring program include:

- Distance to potential receptor exposure points

- Ground water seepage velocity and direction

- Types of contaminants

- Aquifer heterogeneity

- Three-dimensional distribution of chemicals of concern

- Areas of unique geochemical conditions

- Surface water impacts

- Effects of active remediation systems (Wiedemeier et al., 2000)

The secondary factors that should be considered include:

- Access issues
- Property lines
- Contaminant contributions from offsite sources (Wiedemeier et al., 2000)

Two types of wells will be required for any long-term monitoring program: performance monitoring wells and contingency monitoring wells. Performance monitoring wells are used to demonstrate that NA is proceeding according to expectations; document that geochemical conditions continue to be adequate to support NA processes; identify any toxic products resulting from NA processes; determine if plume conditions remain stable or shrinking; identify changes in ground water conditions, such as change in flow direction, recharge, etc.; and document that cleanup criteria have been met.

Contingency monitoring wells are placed beyond the predicted downgradient boundary of the plume and up-gradient from known or potential receptor exposure points. Their purpose is to provide an "early-warning" if unexpected plume expansion occurs and allow implementation of a contingent remedy if needed. Multiple contingency wells may be needed, particularly if seasonal variations in ground water flow direction are known to occur.

Sampling frequency decisions should be based on:

- The natural variability observed in contaminant concentrations,
- The distance and travel time from the source to the point of compliance, and
- The reduction in concentrations needed to meet target levels (EPA, 1998).

K.II.6 CONTINGENCY MEASURES

The RNA risk management plan must include a contingency plan to be implemented if the site data indicate that RNA is not occurring at the expected rate or the exposure conditions at the site have changed, resulting in an unacceptable risk to human health or environment. Specific triggers should be established and included in the work plan that would cause the responsible party to implement alternative active strategies such as soil vapor extraction, air sparging, and pump and treat, or other activities to enhance RNA.

Examples of triggers that would cause the responsible party to implement alternative strategies include, but are not limited to, a consistent increase in concentrations in one or

more wells, a failure of any of the institutional conditions necessary to protect human health and the environment during the period of RNA, a change in the exposure conditions (e.g., the removal of a pavement), continued expansion of the plume, or unacceptably low rates of RNA. To minimize the effort spent on negotiations, the established triggers should be as objective and quantitative as possible.

Establishing contingency measures in the risk management plan will prevent delays in site remediation by avoiding negotiations as situations arise and will provide a clear roadmap for site remediation.

PART III: TECHNIQUES AVAILABLE TO DEMONSTRATE NATURAL ATTENUATION

Several techniques are available to evaluate the data collected to demonstrate NA or to design and implement an RNA program. These techniques can be divided into three categories: techniques to demonstrate the occurrence of NA, techniques to estimate the site-specific rate of NA, and techniques to quantify the future behavior of the plume. The available techniques for each of these evaluations are presented below:

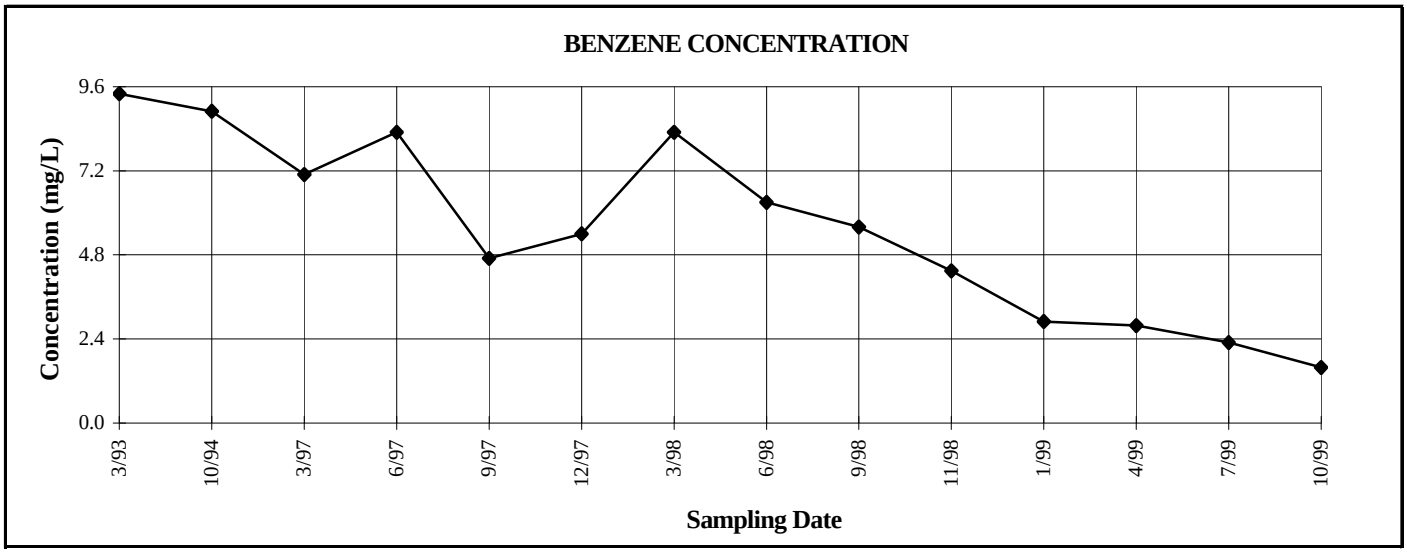
K.III.1 TECHNIQUES TO DEMONSTRATE THE OCCURRENCE OF NATURAL ATTENUATION

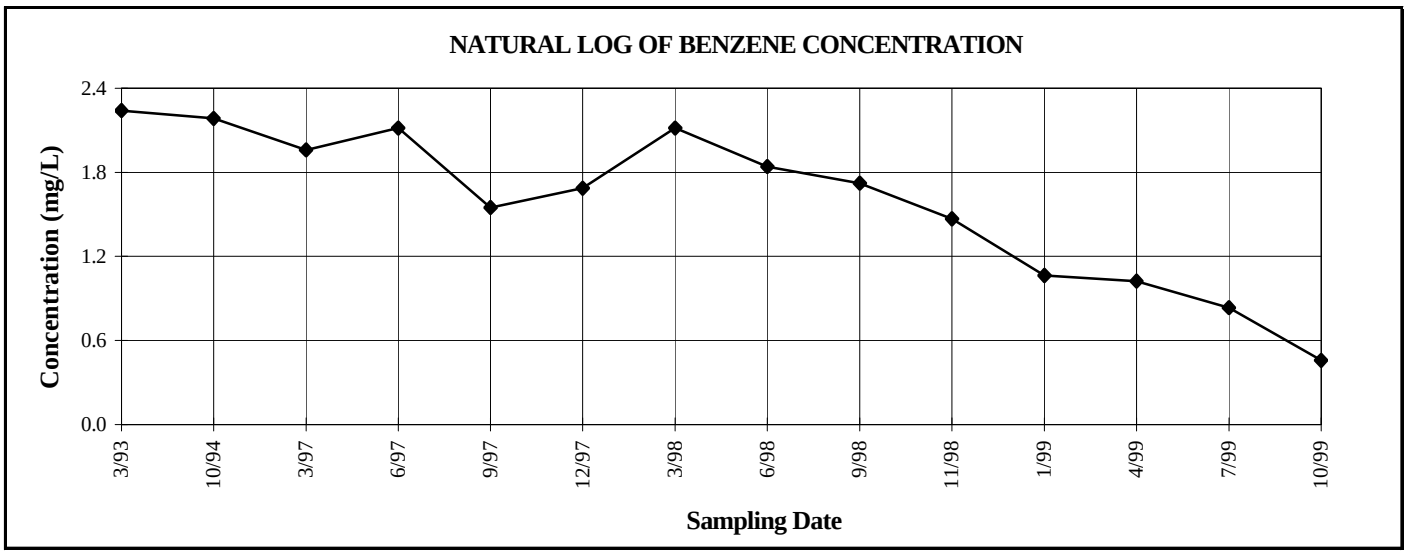
The occurrence of NA may be demonstrated by using one or a combination of graphical and statistical techniques. The specific techniques used will vary depending on site conditions and the specifics of the data. To the extent possible, multiple techniques should be used to provide added insight into the NA process.

K.III.1.1 Graphical Techniques

Chemicals of concern data collected from strategically located monitoring wells should be used to draw site-wide contour maps of individual constituent concentrations for each monitoring event, create concentration vs. time plots for each well with detectable constituent levels and at least four rounds of data, and create concentration vs. distance plots along the flow direction for several monitoring events. Depending on the variability in the concentrations, it may be better to plot the natural logarithm of concentration vs. time and distance. An example plot is shown in Figure K.4. When creating these plots, care should be taken to ensure that the selected scale clearly demonstrates the trend. Since the concentrations are affected by water level fluctuations, it is important to also plot water levels as a function of time.

These plots can indicate whether the concentration trend is decreasing, stable (no significant trend), increasing, or mixed. The latter refers to a situation where different wells (source wells vs. periphery wells) exhibit different trends. Increasing concentrations in the source well and decreasing concentrations in the downgradient wells may occur due to a variety of reasons. For example, the mass loading to the source may cause an increase in the source wells due to an increase in the infiltration rate, or the rate of biodegradation near the source may be reduced due to a depletion of oxygen.





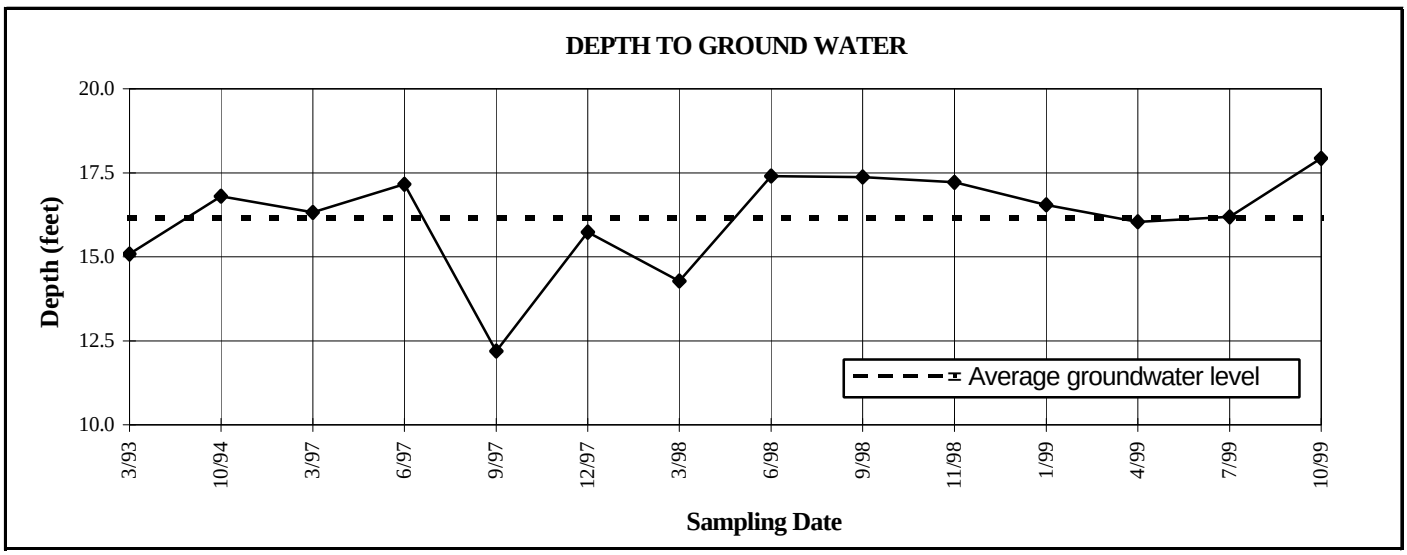


Figure K.4. Concentration vs. Time Plot of Benzene

Conversely, increasing concentrations in downgradient wells and decreasing concentrations near the source may indicate that the plume is moving but the source has depleted. Conclusions related to concentration trends based on visual observations of the data must be supported by statistical analysis.

In addition to the chemical of concern concentrations, indicator chemical concentrations should be plotted along the plume axis (concentration vs. distance plots) along with the hydrocarbon concentrations. The observed pattern of concentrations can be used to demonstrate NA. For example, low dissolved oxygen concentrations within the plume and higher concentrations up-gradient and down-gradient of the source are indicative of biodegradation within the plume.

K.III.1.2 Statistical Evaluations

Statistical tools may be used to determine and quantify the concentration trend. These tests can be used to test a null hypothesis and an alternative hypothesis. A null hypothesis might be that there is no time trend in the concentrations vs. distance or time and the alternative hypothesis might be that there is a downward trend. Application of the statistical test would then result in the acceptance or rejection of the null hypothesis at a specified level of significance.

A non-parametric test, called the Mann-Kendall test, is often used to determine whether a trend exists in the data. This test is particularly useful for environmental data for several reasons:

- The test is non-parametric, which implies that the test is applicable irrespective of the underlying distribution of the data.
- The test is simple to implement.
- Concentration values below the detection limit can be used.
- The results are not affected by missing data.

The Mann-Kendall test is applicable only when there is no seasonality in the data. This is the case if the data do not show any seasonal variations or the data were collected from one season. When data indicate seasonality, the seasonal Kendall test may be used. For details on both of these tests, refer to Gilbert (1987), Gibbons (1994), or other books on statistical analysis.

DEQ strongly recommends the use of the Mann Kendall test to determine the trend in non-seasonal data except in situations where a visual plot of data indicates without **ANY** ambiguity that a trend exists in the data.

If the concentration vs. time or concentration vs. distance data indicate a decreasing trend, a regression analysis may be used to estimate the slope of the best-fit line. As explained in Section K.I.5.3, the slope of the line can be used to estimate the NA or the biodegradation rate. For additional information on regression analysis, refer to any statistics textbook.

K.III.1.3 Evaluation of Plume Behavior with a Recalcitrant Tracer

Physical, chemical, and biological processes act together to decrease contaminant concentrations away from a source. However, monitored NA requires that accurate biodegradation rates for a site be known. To estimate accurate biodegradation rates, conservative tracers can be employed. The concentrations of these tracers are not affected by biodegradation processes and so can be used to delineate between the affects of biodegradation and other NA processes such as dilution, dispersion, and sorption. Generally, tracers are biologically recalcitrant, and have chemical properties similar to the contaminant of concern. Examples of common tracers include MTBE for petroleum hydrocarbon plumes and chloride ions for chlorinated hydrocarbon plumes.

K.III.2 TECHNIQUES TO ESTIMATE THE SITE-SPECIFIC RATE OF NATURAL ATTENUATION

The theoretical basis for estimating NA rates was presented in Section K.I.5. The following step-by-step description of the process can be implemented on a site-specific basis.

Step 1: Determine the ground water flow direction based on the water level measurements for each monitoring event.

Step 2: For each monitoring event, identify the wells located along the direction of flow (i.e., along the plume center line). Note since the flow direction may vary seasonally, different wells may be used for different monitoring events.

Step 3: Tabulate the concentrations of the chemicals of concern and calculate the natural log concentrations.

Step 4: Plot the natural log concentrations on the Y-axis and the distance along the X-axis.

Step 5: Calculate the slope of the best-fit line and the confidence in this estimate by examining the 95% confidence limits of the slope.

Step 6: Estimate the ground water seepage velocity

Step 7: Multiply the slope of the best-fit line calculated in Step 5 with the seepage velocity.

The result will represent the overall NA rate. This NA rate represents the reduction in concentration due to the combined influence of the various NA processes mentioned in Section K.I.2. This decay rate should not be confused with the biodegradation rate (?) that is an input to ground water models (Section K.III.3).

Step 8: Estimate the biodecay rate from Equation K.7.

The above steps 1 to 8 should be completed for each time period for which data are available and the results presented as a range of NA and biodecay rates. The latter can be used as an input to the Domenico model (Domenico, 1987) to estimate the dilution attenuation factor. Due to confounding factors such as seasonal variations in ground water velocity, fluctuations in water levels, and errors in sampling and analysis methods, the NA and biodecay rates may vary significantly (by as much as a factor of 10). Therefore, it is best to present the range as well as the average rates.

K.III.3 TECHNIQUES TO QUANTIFY THE FUTURE BEHAVIOR OF THE PLUME

The future behavior of the plume can be estimated by using fate and transport models. A number of analytical and numerical models are available.

A few commonly used analytical models include the Domenico model (Domenico, 1987), BIOSCREEN, and BIOCHLOR. The latter two can be downloaded from the www.epa.gov/ada/csmos/models/bioscrn.html and www.epa.gov/csmos/models/biochlor.html websites. These models can be used to estimate plume length, concentrations at downgradient receptor locations, and dilution attenuation factors. The correct application of fate and transport models requires experience and specialized knowledge that is beyond the scope of this document.

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APPENDIX L

ESTIMATION OF REPRESENTATIVE SOIL AND GROUND WATER CONCENTRATIONS

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L.1 BACKGROUND

Representative concentrations are the **average** chemical concentrations to which receptors are exposed over a specified duration within a specified geographical area. The geographical area about which a receptor moves and contacts contaminated media during the specified exposure duration is termed an exposure unit (EU). In the field of risk assessment representative concentrations are typically referred to as exposure point concentrations (EPA, 2001).

In the site-specific application of the risk evaluation process, representative concentrations are used to estimate the risk to a specified receptor for each complete route of exposure identified in the site conceptual exposure model (SCEM) and each chemical of concern (COC). Risk management decisions are then made based on a comparison of the estimated risk with the regulatory specified target risk. This is termed a forward mode calculation. Representative concentrations can also be used in what are termed backward mode calculations when they are compared with calculated target levels for each complete route of exposure and each COC. In either mode the calculation of representative concentrations is critical in the outcome of the risk evaluation.

Complications in the calculation of the representative concentrations may arise because the concept of representative concentration is often mistakenly associated with a site as opposed to an exposure pathway or the source. Since there may be several complete pathways at a site, several representative concentrations, one for each complete pathway, have to be estimated. The following sections describe the concept and the methodology that should be used to estimate the representative concentrations.

The accurate estimation of representative concentrations is complicated by several factors, including (i) spatial variability in the concentrations; (ii) temporal variability in the concentrations; (iii) lack of sufficient, appropriately located, site-specific concentration data; and (iv) poor definition or uncertainty in the location, size, or other characteristics of the EU.

The uncertainty in the representative concentration introduced by some of these factors can be reduced through giving them adequate consideration during the development of the SCEM and the sampling and analysis plan.

After samples have been collected and analyzed, the results need to be appropriately evaluated to produce sound estimates of representative concentrations. This evaluation includes an assessment of data quantity, data quality (which data are acceptable for use),

statistical methods (which to use), and a determination as to which data (of that which is useable) apply to a specific EU. This guidance focuses primarily on the latter two issues.

This guidance is an attempt to provide general recommendations on procedures to accurately determine representative concentrations. It is not expected that these recommendations will apply to all sites, particularly large, complex sites. Site-specific circumstances will often require consultation with the Department of Environmental Quality (DEQ), the application of professional judgment, and reference to the more detailed literature cited herein.

L.2 STATISTICAL CONSIDERATIONS FOR ESTIMATING REPRESENTATIVE CONCENTRATIONS

Numerous methods can be employed to develop estimates of the representative (average) chemical concentration to which a receptor will be exposed. These methods include examining the maximum detected concentration, 95 percent upper confidence limit of the mean (95% UCL), arithmetic average, area-weighted average, depth-weighted average, geometric average, and volumetric average concentration (very rarely used). Associated with each of these methods are certain advantages, disadvantages, and constraints on their appropriate use. There is no uniformly accepted statistical methodology to estimate the representative concentration. Implicit in the decision to use any particular method is the need to acknowledge and account for the representativeness of the samples collected, the homogeneity of the EU that is defined, the statistical distribution of the data, the minimum data requirements of the statistical method used, and the uncertainty in the resultant data used to derive the estimated concentration.

L.2.1 Maximum

The use of the maximum detected chemical concentration is required for comparison to Initial Default Target Levels (IDTLs) during the screening level evaluation. Depending on the quality of the site characterization data available, the maximum can be used as representative concentrations in risk evaluation-1 (RE-1) and risk evaluation-2 (RE-2) evaluations and will typically represent a conservative estimate of the average concentrations. This will particularly be the case when sample numbers are low (i.e., less than 8-10).

The effort necessary to calculate representative concentrations for certain complete pathways can be avoided by using the maximum media-specific concentrations when they do not exceed the target levels or when the cumulative risk, calculated using maximum concentrations, does not exceed the target risk.

L.2.2 95% Upper Confidence Limit

For the calculation of exposure point concentrations, the Environmental Protection Agency (EPA) has recommended, in most cases, using the 95% UCL (EPA, 1992). The calculation using this method is discussed in more detail in section L.5. Ideally, a minimum of eight to ten samples is desirable to generate a 95% UCL. With lower sample numbers the 95% UCL estimate tends to be larger than the arithmetic average and will sometimes exceed the maximum measured concentration. In these instances the maximum measured concentration can be substituted for the 95% UCL. For lognormal distributions the methods presented in EPA (1992) to generate the 95% UCL can be used but with caution. For more robust estimates of the 95% UCL for lognormal distributions, see Chapter 13 in *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987) or *The Lognormal Distribution in Environmental Applications* (EPA, 1997).

L.2.3 Arithmetic Average

The use of the arithmetic average is similar to the 95% UCL with the disadvantage that no estimate of the uncertainty or variability of the average is incorporated into the value generated. As the number of samples approaches 20 to 30, the estimates generated using the 95% UCL versus the straight arithmetic average tend to converge.

L.2.4 Geometric Average

The geometric average is sometimes used as an estimator of the mean of lognormally distributed variables. It represents the value in the original scale of the mean of the transformed variable. It is, however, a biased estimate of the mean, and statistical texts such as *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987) caution against its use in environmental applications. As with the UCL discussion above, *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987) or *The Lognormal Distribution in Environmental Applications* (EPA, 1997) should be consulted when attempting to develop an unbiased estimate of the mean of a lognormally distributed variable. As with the arithmetic average, no estimate of the uncertainty or variability is incorporated into the value generated by the geometric average and may not be conservative.

L.2.5 Area-Weighted Average

Where sampling locations are unevenly spaced, area-weighted averaging methods can be employed to generate an estimate of the average concentration across an area. This is done by generating an area (or Theissen polygon) associated with each sampling location, assigning a "weight" to each data point based on the area of the polygon associated with that point, and summing the weighted data point values. One advantage of the method is that it is useful in characterizing areas when the number of sample points is low. There are also several disadvantages. First, the shape, and consequently, the contribution of an area associated with a sample location to the "average" is totally dependant on the spatial distribution of all data points and may not be reflective of the true distribution of contaminants at a site. Second, since each polygon is associated with one sample point, no estimate of the accuracy or error in the average value is possible. Finally, the method, unlike several other interpolation schemes, does not assume that points that are closer together are more similar than points that are farther apart. The method for calculating an area-weighted average using Theissen polygons is discussed in section L.6.

L.2.6 Depth-Weighted Average

Depth-weighted averaging methods are used to develop an average or representative concentration for a specific borehole where multiple samples at varying depth intervals have been obtained. In characterizing a source area with multiple boreholes, the depth-weighted averages from each borehole can be used in a 95% UCL calculation. The

methodology for depth-weighted averaging is described in EPA's *Soil Screening Guidance: User's Guide* (EPA, 1996).

L.2.7 Volume-Weighted Average

Volume-weighted averaging methods are a combination of area and depth weighted averaging techniques. They are rarely used in risk assessment evaluations.

L.3 GENERAL CONSIDERATIONS FOR ESTIMATING REPRESENTATIVE CONCENTRATIONS

Estimating representative concentrations requires the consideration of several issues. Prior to performing the computations, identified in Section L.4, consider the information in the following sections.

L.3.1 Surface and Subsurface Soil Concentrations

Keep the following in mind when evaluating representative soil concentrations:

- The spatial resolution of the data must be sufficient. While the exact number of necessary samples cannot be specified, data should be available from areas of known or likely sources and the EU should be defined for a given receptor.
- If the data are "old" (> 4 years old) and the concentrations exceed the IDTLs, or a new spill is suspected, it may be useful to collect recent data. This particularly applies if the COC are susceptible to biodegradation or other attenuation mechanisms. If sufficient new data are collected, they may be used for risk evaluation and the old data may be disregarded. A new release will always require the collection of additional data.
- If there is a "high" density of soil samples (> 30) for a homogeneous EU and sample locations are approximately equally spaced, the arithmetic average may be used instead of the 95% UCL or the area-weighted average. This is acceptable because the area-weighted average, the arithmetic average, and the UCL concentrations will tend to converge (EPA, 1992). The > 30 value mentioned above should also be considered in relation to the size of the EU and may not be appropriate for very large EU.
- Non-detect soil samples located at the periphery of the EU (e.g., the footprint of a building) should not be used.
- Non-detect samples located within the EU may be replaced by half the detection limit.

- If multiple surficial soil samples and/or multiple subsurface soil samples are available from the same borehole within the EU, the depth-average or arithmetic average concentration of these samples may be used. If the samples are equally spaced, the depth-averaged concentration will be the same as the arithmetic average concentration.

L.3.2 Ground Water Concentrations

Follow the guidelines listed below to account for the temporal variation in ground water concentrations.

(a) For wells with a clear increasing or a decreasing trend, data from the most recent 12 months or the four most recent measurements should be averaged (use whichever covers the longer duration). Note that for wells with increasing trends, continued monitoring will be required until the trend stabilizes or decreases.

(b) For wells with stable or fluctuating concentrations with no apparent trend, data from either the most recent 24 months or the eight most recent measurements should be averaged.

(c) While performing the average for (a) and (b), any concentration below detection limits should be replaced by half the detection limit. If the percentage of non-detects is a significant percentage of the total number of data points (> 25 percent) the representativeness of the data set for the exposure unit in question should be evaluated.

(d) Wells with concentrations consistently below detection limits in the periphery of the EU should not be used.

(e) For wells that contain free product, in lieu of actual data, the effective solubility of COC should be used as a surrogate for their chemical concentration in estimating representative concentrations.

L.4 CALCULATION OF REPRESENTATIVE CONCENTRATIONS

As mentioned above, a representative concentration is necessary for each complete exposure pathway at a site. Based on the pathways typically considered in the risk evaluation process, the representative concentrations listed below are necessary for each media.

L.4.1 Surficial Soil (0-1 foot below ground surface)

The risk evaluation process requires consideration of two pathways of exposure associated with the surficial soil: (i) the ingestion of chemicals in ground water due to leaching of residual chemicals present in the surficial soil, and (ii) the accidental ingestion of soil, outdoor inhalation of vapors and particulates from surficial soil emissions, and dermal contact with surficial soil. These are referred to as the ground water protection and direct soil contact pathways, respectively. Thus at most, two different surficial soil representative concentrations are required.

L.4.1.1 Representative surficial soil concentration for the protection of ground water

Figure L-1 shows a schematic of the soil leaching to ground water. The evaluation of this pathway for surficial soil assumes that the contamination does not extend greater than one foot below ground surface. If this is not the case then samples taken in the surficial soil zone should be included with those from greater depth and evaluated together.

The risk evaluation process also assumes that the leachate from the surficial soil source travels vertically downwards to the water table without any lateral or transverse spreading. Thus the horizontal dimensions of the surficial soil source and the ground water source are identical. Estimating the source dimensions requires considerable professional judgement. Factors that should be considered include:

Site history: Historic information may be used to locate the area where the spill occurred or where the source (sump, tanks, process area, etc.) was located.

Field readings: For certain volatile chemicals, the source may be defined as the area with high photo-ionization detector readings.

Laboratory data: Laboratory data may be used to delineate the source. Samples with results below the method detection limit should not be included in the calculation of the source area representative concentration.

Irrespective of the manner in which the source area is identified, it is important to indicate the dimensions of the source on a map. The representative surficial soil source concentration should be estimated using only the surficial soil data collected within the

delineated source zone. The statistical method used to derive the representative concentration should be appropriate to the quantity and characteristics of the data available, typically the 95% UCL of the mean.

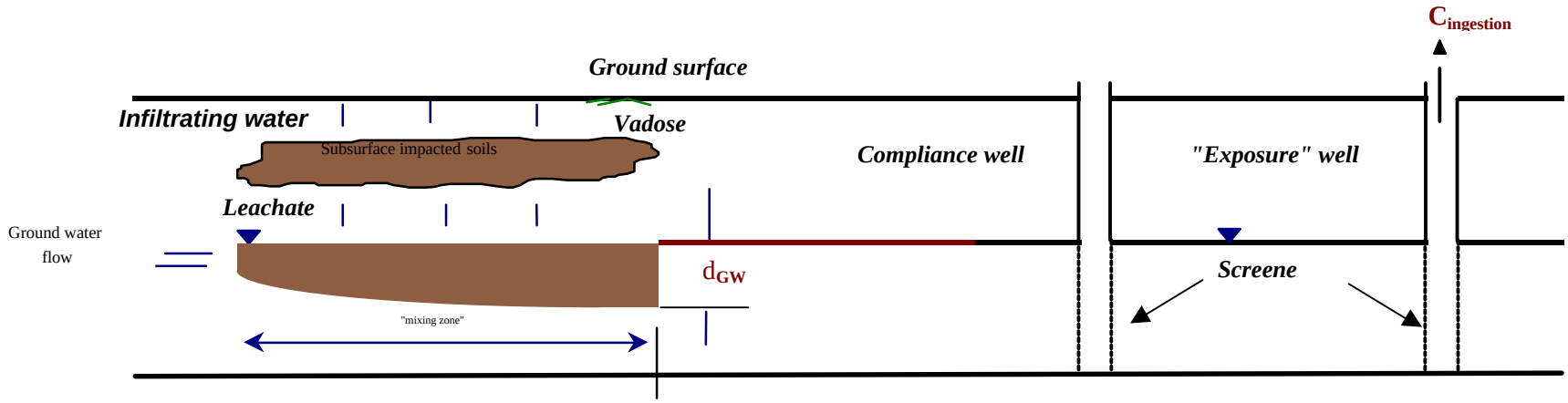


Figure L-1. Schematic Of Soil Leaching To Ground Water

L.4.1.2 Representative concentrations for the direct contact pathway

For this pathway, the representative surficial soil concentration has to be based on the receptor's EU (i.e., the area over which the receptor may be exposed to the surficial soil). The exact location of this area is often very difficult to estimate since it must be representative of a period of time equal to the receptor's exposure duration (for example, up to 30 years for residential land use and about 7 years for non-residential land use). In most cases it is reasonable to assume that the receptor will access all portions of the EU in a random manner. Under current conditions, in the absence of specific information about the receptor's activities, the unpaved portion of the site may be approximately considered as the receptor's EU. Where volatile organic compounds (VOCs) are included in the list of potential COC and/or the paved portion is in poor condition or consists of a material that does not limit VOC migration, this guide would not apply. For potential future exposures, if the current condition cannot be assumed to occur, the assumption should be made that the pavement is removed, exposure to surficial soil is possible, and the entire site should be considered as the EU.

To estimate the representative concentration for this pathway, it would be necessary to estimate the receptor's area of exposure and determine the number of soil samples available within this EU. This information should be used to estimate the 95% UCL or an area-weighted average concentration using the procedures discussed in Sections L.5 and L.6, respectively.

L.4.2 Subsurface Soil (greater than 1 foot below ground surface)

The risk evaluation process includes two pathways of exposure associated with the subsurface soil: (i) the ingestion of chemicals in ground water or exposure to surface water impacted by discharge of contaminated ground water resulting from leaching of residual concentrations in the subsurface soil, and (ii) indoor inhalation of vapor emissions. Thus, two different subsurface soil representative concentrations are required (one for each complete pathway). Additionally, representative concentrations may be required if the receptor's EU for current and future conditions is different.

L.4.2.1 Representative subsurface soil concentration for protection of ground water

The leachate from the subsurface soil source is assumed to travel vertically downwards without any lateral or horizontal spreading (Figure L-1). Thus, the representative concentration for this pathway should be based on the subsurface soil concentrations measured within the source area.

As in the case of the surficial soil concentration protective of ground water, discussed in Section L.2.1.1, the representative subsurface soil source concentration would be the average concentration calculated using the data within the soil source area. If the source size is small (several tens of feet across) typically few (1-5) soil samples are available within the soil source. In this case, the maximum or the 95% UCL of the available data within the subsurface soil source should be used as an approximation for the average concentration.

L.4.2.2 Representative subsurface soil concentration for protection of indoor inhalation

Risks resulting from the inhalation of vapors emanating from a contaminated soil source and subsurface soil chemical concentrations protective of indoor inhalation are estimated using the Johnson and Ettinger model (Johnson and Ettinger, 1991). This model assumes that the chemicals volatilize from a subsurface soil source, travel vertically upwards via diffusion without any lateral or transverse spreading, and enter the building via advection through cracks in the foundation. To be completely consistent with the model, the representative concentration for this pathway should be based on the soil or soil vapor concentrations measured in the soil directly below the enclosed space. In many cases this is not possible and, depending on site conditions (such as the location of pavement, preferential pathways, and site lithology), vapors from source areas adjacent to but not under an existing structure may contribute to indoor inhalation exposures. The goal should be to characterize the average concentration in the source area that may potentially contribute vapors to any existing or potential future structures. If the pathway is considered complete for current conditions, appropriate samples for representative concentration estimates should be selected to achieve this goal. If current and reasonably anticipated future land uses are the same, the representative concentration calculation is unchanged.

To evaluate representative concentrations for potential future indoor inhalation (e.g., in the event that an enclosed structure is constructed on top of contaminated soil), it is

necessary to determine the nature of any future structure and estimate the size (footprint) of the structure and its location.

If the location and characteristics of future structures are known, the representative concentration should be conservatively estimated using samples from that vicinity. If the nature of future structures is not known the assumption should be made that a structure could be placed anywhere on the property in question and potentially located directly over the source. The size of the structure would be assumed to be similar to that of the likely future land use, in most cases either residential or non-residential. The default size of a residential structure for developing IDTLs and using in RE-1/RE-2 is approximately 40 feet by 40 feet. For sites where the footprint of the current and likely future enclosed spaces are different, different representative subsurface soil concentrations (one for current conditions and one for future conditions) may be necessary. The 95% UCL or area-weighted average methods should be used, as appropriate. Where multiple boreholes with several depth interval samples are available, a depth-weighted average from individual boreholes can be developed.

L.4.3 Representative Concentration for Protection of a Construction Worker

The risk evaluation process requires the evaluation of one pathway of exposure for construction workers: accidental ingestion, dermal contact, and outdoor inhalation of vapors and particulates from soil.

For the construction worker, no distinction is made between the surficial and subsurface soil because during construction subsurface soils may be exposed. To estimate the representative concentration for the construction worker, it is necessary to identify the depth, areal extent, and number of samples taken within the zone of construction. The potential future depth of construction can be estimated by contacting local construction firms and identifying the typical depth of utilities on and adjacent to the site. If the areal extent of the construction area is not known, conservatively it may be estimated as the source area. If sample results are available for several depth intervals these should be averaged using depth-weighting. The depth-averaged values from multiple boreholes could then be combined to calculate a 95% UCL or area-weighted average, as appropriate. The representative concentration would be the depth-averaged concentration within this zone of construction.

L.4.4 Ground Water

The risk evaluation process requires the evaluation of two routes of exposure associated with shallow ground water: (i) ingestion of water and (ii) indoor inhalation of vapor emissions from ground water. Where multiple aquifers are present, the shallowest aquifer is typically the aquifer first considered for both pathways. Site-specific circumstances, such as disappearance of the shallow aquifer or transport of contamination to the deeper aquifer may require evaluation of both aquifers. Characterization of chemical concentrations in both aquifers should still be performed. Thus, at a minimum two different ground water representative concentrations, one for each complete pathway, are required.

L.4.4.1 Representative compliance well concentration for protection of ground water

For the ingestion of ground water pathway, maximum contaminant levels or equivalent concentrations have to be met at the point of exposure location. Often the point of exposure well location is hypothetical and data may not be available. In this case, ground water transport models are used to calculate the predicted concentrations at the point of exposure, the allowable concentrations in the source area, or an alternate point of compliance location that will result in acceptable concentration at the point of exposure. In any case, representative concentrations will need to be estimated for the source area or for the alternate point of compliance location. In addition, one or more compliance wells have to be identified and target compliance well concentrations (typically higher than the exposure well concentration) have to be calculated at these wells.

To evaluate this pathway, the representative concentrations in the source area, point of compliance, or point of exposure locations should be calculated based on the measured concentrations as discussed below. In all cases, measurements taken more frequently than monthly will not be accepted to meet the specified number of measurements.

- For wells with fluctuating concentrations, such that no clear trend is present, the representative concentration is estimated as the 95% UCL of the most recent two years or most recent eight measurements, whichever represents the longer time duration.

- For compliance wells with stable, clearly decreasing, or clearly increasing trends, the representative concentration is estimated as the 95% UCL of the most recent one year of data or most recent four measurements, whichever represents the longer

time duration. For wells with an increasing concentration trend, continued monitoring will be required until the trend stabilizes. Quarterly data for at least one year is recommended. The data should be pooled for source area characterization where multiple wells are available. Wells clearly not part of the source area of contamination should not be included in the calculations.

L.4.4.2 Representative ground water concentration for protection of indoor inhalation

Ground water concentrations protective of indoor inhalation are estimated using the Johnson and Ettinger model (Johnson and Ettinger, 1991). This model assumes no lateral or transverse spreading of the vapors as they migrate upward from the water table through the capillary fringe, the unsaturated zone, and into the enclosed space. Thus, the representative concentrations for this pathway should be based on the ground water concentration measured within and adjacent to the footprint of the building. Also refer to Section L.4.2.2 for discussion related to the future land use footprints and their relationship to the impacted area.

For the indoor inhalation of vapor emissions from ground water, multiple representative concentrations may be required if the plume has migrated below several current or potential future buildings. For example, if a plume has migrated or is likely to migrate below two different buildings (for example on-site and off-site building), separate on-site and off-site representative concentrations should be estimated.

If the plume has migrated below several buildings with similar receptors (residential or commercial) it may be sufficient to evaluate this pathway only for the building below which the concentrations are the highest and/or the depth to ground water is the lowest. If this building is protective of indoor inhalation exposures, it may not be necessary to evaluate other buildings.

While the target ground water concentrations are based on the assumption of no lateral or transverse spreading of the vapors as they diffuse upwards to the building, site characteristics such as site lithology and preferential pathways may result in lateral migration towards a structure. For this reason the representative concentrations should be conservatively based on data gathered adjacent to the structure. After identifying the locations of the building footprints and the appropriate ground water monitoring data within and adjacent to each footprint, the 95% UCL or area-weighted average concentration within each footprint should be estimated, as discussed in Section L.5.

L.5 ESTIMATING THE AREA-WEIGHTED AVERAGE CONCENTRATION

The area-weighted average concentration can be estimated using the Thiessen Polygon Method (Fetters, 1993 and Linsley, 1975). If the available data are located on a uniform grid, the area-weighted average would be the same as the arithmetic average. If the dimensions of the source and the receptor's EU are relatively small (several tens of feet across), and very few (1 to 6) soil samples are available within the soil source, the arithmetic average concentration may be used as an approximation of the area-weighted average concentration.

STEP 1: IDENTIFY THE EXPOSURE UNIT

The first and most critical step is to identify the size and location of the EU over which the area-weighted average concentration has to be estimated. The location and size of this EU will often vary depending on the pathway being evaluated. Specific guidance on the location of the receptor's area of exposure has been discussed in Sections L.3 and L.4. Area weighted average concentrations can only be estimated if multiple samples have been collected within the unit. If several samples are available just outside the EU, it may be reasonable to extend the size of the unit to include this data. If the values of these samples are non-detect they should not be included. This step is technically justified since at most sites the location of the unit is at best approximate.

As part of this step the various EUs for which area-weighted average concentration is desired should be drawn on a site map and the location of data points (soil borings, monitoring wells, etc.) should be clearly located on the map.

If the borings or monitoring wells within the EU are located in a regular grid, the calculation of an area-weighted average is unnecessary and the user should proceed with a representative concentration calculation using a different method, such as the 95% UCL.

STEP 2: SUBDIVIDE THE EXPOSURE UNIT

The EU, identified in Step 1, is discretized into polygonal elements by connecting the sampling points within each EU identified in Step 1 and drawing perpendicular bisectors to these lines to form polygons. The area of each Theissen polygon is then estimated.

STEP 3: ESTIMATE REPRESENTATIVE CONCENTRATION FOR EACH THEISSEN POLYGON

The concentration measured at the sampling location within each polygon is considered representative of the area of each polygon. As discussed in Section L.3, if multiple data are available from a location (either multiple depths or dates), compute the arithmetic average concentration of each COC measured at that location. The arithmetic concentration is then considered representative of the polygon.

STEP 4: ESTIMATE AREA-WEIGHTED AVERAGE CONCENTRATION FOR THE EXPOSURE UNIT

The area-weighted average concentration for the EU is estimated using:

$$C_{area} = \frac{\sum_{i=1}^{i=n} (A_i * C_{avg,i})}{A_{Total}} \qquad \text{(L-1)}$$

where,

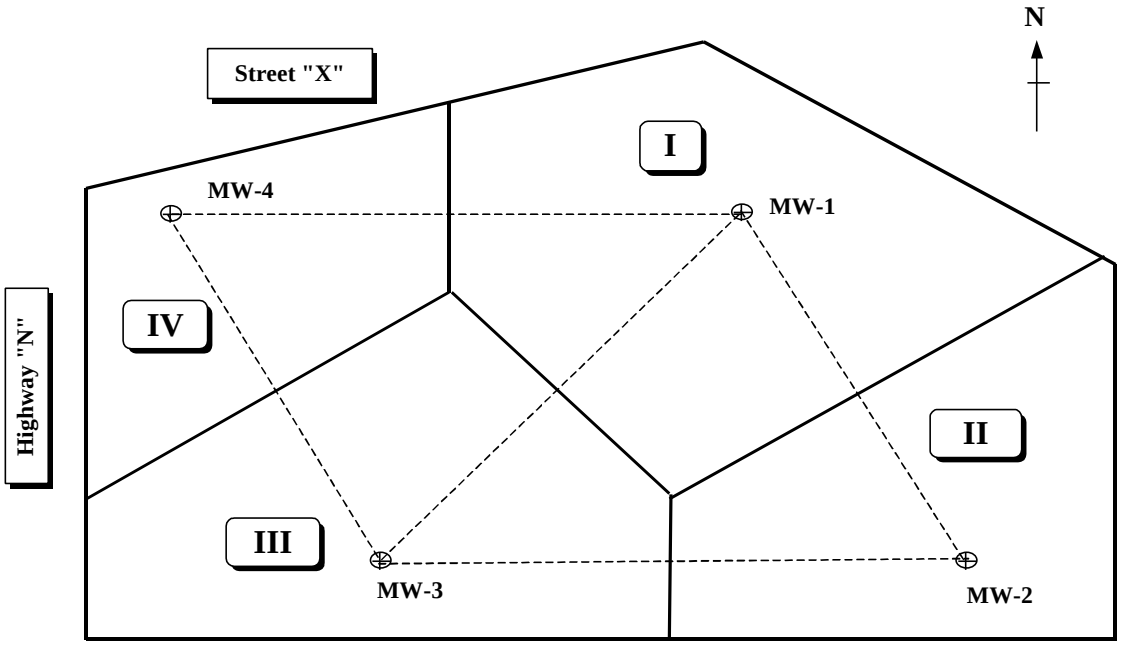
C_{area} = area-weighted average concentration over the EU [mg/kg]

A_i = area of each Theissen polygon [m^2]

A_{Total} = total area of the polygons (i.e., area of the EU) [m^2]

$C_{avg,i}$ = mean of soil or ground water concentrations measured within the polygonal element i [mg/kg]

An example application of the Thiessen polygon method is schematically shown in Figure L-2.



Polygonal Element	Mean Soil Concentration $C_{avg,i}$ mg/kg	Area of the Element A_i m^2	$A_i * C_{avg,i}$ m^2 - mg/kg	Area Weighted Average Concentration mg/kg
I	2	604	1208	
II	1.8	398	716.4	
III	1.2	578	693.6	
IV	1	234	234	
	TOTAL	**1814**	**2852**	
Area Weighted Average Concentration = $C_{area} = \frac{\sum_{i=1}^{i=n} (A_i * C_{avg,i})}{A_{Total}}$				**1.57**

Figure L-2. Thiessen Polygon Method

L.6 ESTIMATING THE UPPER CONFIDENCE INTERVAL OF THE MEAN

It is usually assumed when calculating representative concentrations that the receptor is an individual who randomly moves over the EU. Although the receptor may not actually exhibit a truly random pattern, the assumption of equal time spent in different parts of the area is reasonable. In these cases the most accurate representative concentration would be the true population mean concentration. Unfortunately, the true population mean concentration is impossible to obtain. The true population mean is a unique value that can be calculated only if the entire population has been sampled (i.e., the entire contaminated media analyzed). Since the entire population is almost never sampled, the true mean is never known. Thus, at best, only an estimate of the true population mean concentration is possible.

To account for the uncertainty associated with the estimated mean concentration, a confidence interval about the true but unknown mean is often constructed. The interval estimate includes a range and an associated degree of confidence that the true unknown mean lies within this range. Thus a two-sided 95% confidence interval about the true mean represents a range within which 95% of the estimates of the true mean are likely to exist. This also implies that there is a 5% chance that the true but unknown mean would lie outside these limits. If this interval is symmetrical then there is a 2.5% chance that the true mean exceeds the upper limit and a 2.5% chance that the true mean is less than the lower limit. Confidence intervals can be estimated for a variety of different confidence levels.

In risk assessment applications, instead of calculating the two-sided confidence interval, a one-sided confidence interval is most often estimated. The upper limit for a one-sided 95% confidence interval of the mean is defined as a value that, when calculated repeatedly for randomly drawn subsets of site data, equals or exceeds the true mean 95% of the time. Alternatively the true mean exceeds the UCL only 5% of the time.

Depending on the underlying distribution of the data the one-sided, 95% UCL can be calculated using a number of methodologies. Prior to the calculation of the 95% UCL the likely distribution of the data (normal, lognormal, indeterminate) should be investigated. This is typically done visually through the use of histograms and probability plots, and statistical means such as goodness of fit tests, like the Shapiro-Wilk test. In the case of lognormal distributions the degree of skewness present in the data should also be evaluated.

For data which appear to follow a normal distribution the 95% UCL is estimated as follows:

$$\overline{C}_u = \overline{C} + \frac{S}{\sqrt{n}} t_{0.05, n-1} \quad \text{(L-2)}$$

If the concentration distribution is lognormally distributed (i.e., the natural logarithm of the concentration is normally distributed) the Cox's method with Student's t is recommended (Remington, 2003).

$$\overline{C}_u = \exp\left[\overline{C}_l + \frac{s_l^2}{2} + t_{(0.05, n-1)}\sqrt{\frac{s_l^2}{n} + \frac{s_l^4}{2(n-1)}}\right] \quad \text{(L-3)}$$

Where, $\overline{C}_u$ = the upper 95 percentile confidence limit of the mean

$\overline{C}$ = the mean of the concentration

$\overline{C}_l$ = the mean of the natural logarithm of the concentration

S = the standard deviation of the concentration

S_l = the standard deviation of the natural logarithm of the concentration

n = the number of samples used to estimate the mean and standard deviation

$t_{(0.05,n-1)}$ = the 95th quantile of the statistic t distribution with n-1 degrees of freedom

The values of the t statistic for a 95 % UCL are tabulated in statistics textbooks and are provided in Table L-1 for easy reference. Figure L-3 illustrates how the value of t changes with sample size and how the value stabilizes significantly with sample sizes greater than about 10. The UCL for lognormally distributed parameters calculated using the methodology described above should be used with caution, particularly if sample sizes are low and there is a suspicion that the samples are derived from multiple populations.

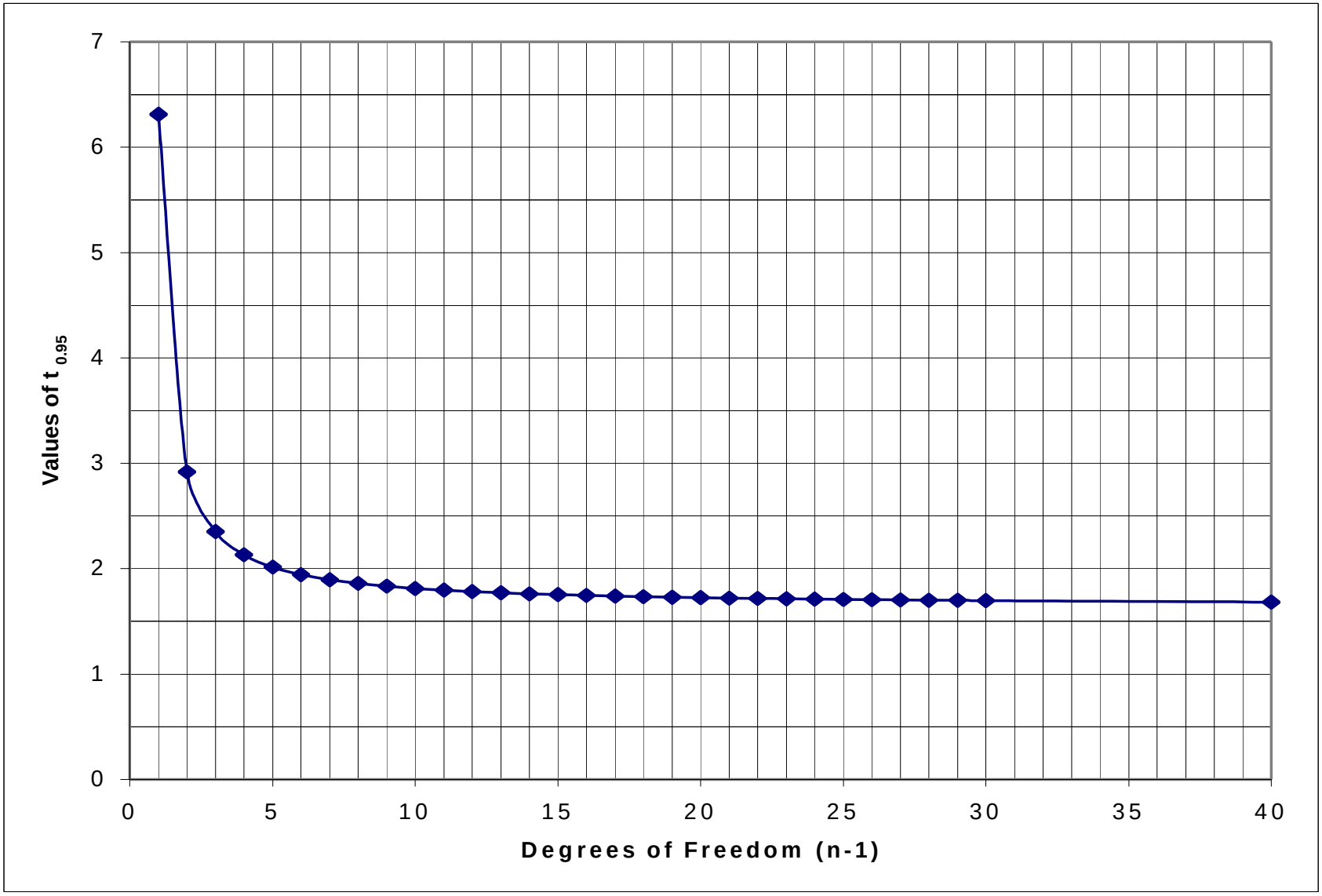


Figure L-3. Plot of Values of the t Distribution (at the 95% Confidence Level) vs. Degrees of Freedom (n-1).

In equations L-1 to L-3, the mean and standard deviation of normally distributed data can be calculated as follows:

$$\overline{C} = \frac{C_1 + C_2 - - - - - - - + C_n}{n} \qquad \text{(L-4)}$$

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (C_i - \overline{C})^2} \qquad \text{(L-5)}$$

Where: C_1-----C_n = the "n" sample values of chemical concentration
n = the number of measurements
$\overline{C}$ = the arithmetic mean

For lognormally distributed data:

$$C_{li} = \ln C_I \qquad \text{(L-6)}$$

$$\overline{C_l} = \frac{C_{l1} + C_{l2} - - - - - - - + C_{ln}}{n} \qquad \text{(L-7)}$$

$$S_l = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (C_{li} - \overline{C_l})^2} \qquad \text{(L-8)}$$

Note the above estimates of the UCLs assume that concentrations are randomly distributed and uncorrelated.

For those instances where the data do not fit either normal or lognormal distributions alternative methods to develop representative concentrations, such as bootstrapping, should be considered (EPA, 1997, 2002b).

Table L-1. Quantiles of the t Distribution

(Values of t such that 100p% of the distribution is less than t_p)

Degrees of Freedom (n-1)	$t_{0.95}$
1	6.314
2	2.92
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.86
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761
15	1.753
16	1.746
17	1.74
18	1.734
19	1.729
20	1.725
21	1.721
22	1.717
23	1.714
24	1.711
25	1.708
26	1.706
27	1.703
28	1.701
29	1.699
30	1.697
40	1.684

Taken from Table A2 of *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987).

L.7 RECOMMENDATIONS

- For most pathways, 95% UCL techniques are recommended for development of representative concentration estimates of average concentrations. For cases where the number of samples is low (<4) use of the maximum concentration may be most appropriate. The use of the maximum may also be appropriate when the calculated 95% UCL exceeds the maximum concentration measured at the site and the collected data are considered representative of site and exposure unit conditions.

- The use of area-weighted average methods is not recommended for most pathways. Their use in developing representative concentrations for the surficial soil pathway may be justified. The inclusion of methods that evaluate and incorporate spatial uncertainty into the area-weighted average calculation increases the validity of the estimate derived (Burmaster and Thompson, 1997).

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APPENDIX M is the user's guide for the Risk Evaluation software accompanying this manual. It is not included in this document of combined appendices, because of size. It is available for download separately.

APPENDIX N

SUPPLEMENTAL TOXICOLOGICAL INFORMATION FOR DIOXINS, PCBS, AND LEAD

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The Risk Evaluation Manual (REM) provides a straightforward process to assess and manage risk associated with most chemicals for which toxicological and physical/chemical information is available. However, some chemicals and classes of chemicals do not easily fit the risk evaluation methodology for assessing risk and determining appropriate risk-based target levels. This appendix will provide some supplemental information that will facilitate risk-based decision-making at sites contaminated with these chemicals.

Evaluation of the Health Risks of Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are a class of compounds characterized by a biphenyl structure to which one to ten chlorine atoms are attached. There are 209 possible PCB types, or congeners, based on the various combinations of numbers of chlorine substitutions and their positions on the biphenyl molecule.

The physical and chemical characteristics of PCBs are related to their chlorine content. PCBs are relatively insoluble in water, and congeners with high chlorine contents tend to be more insoluble than those with low chlorine contents. PCBs are fat-soluble, or lipophilic, and tend to accumulate in human tissue. The organic content (K_{oc}) values of PCBs indicate that that they adsorb readily to soils and sediments; adsorption increases with organic content of the media and also with the chlorine content of the congener or mixture. PCBs will volatilize into the atmosphere, although they have relatively low vapor pressures; congeners with lower chlorine content are the most volatile. Biodegradation and other breakdown processes are slow, leading to long persistence of PCBs in the environment.

The PCB nomenclature is based on the positions of the chlorine atoms on the biphenyl molecule. For example, 2,3,3′,4,4′-PeCB and 2,3,4,4′,5-PeCB are two examples of penta-chlorinated biphenyl congeners. The various PCB congeners are also known by the numbers assigned to them by the International Union of Pure and Applied Chemists (IUPAC). The two congeners above are IUPAC # 105 and IUPAC # 114, respectively.

Several PCB congener mixtures were produced in the United States between 1929 and 1977, primarily by the Monsanto Corporation. These PCB mixtures were marketed under the trade name Aroclor, and are collectively referred to as “Aroclors.” The primary Aroclors were given the commercial designations 1016, 1221, 1232, 1242, 1248, 1254, and 1260. The last two digits indicate the chlorine content, by percent, of the mixture. Aroclor 1242, for example, is a mixture of mono- through penta- chlorinated congeners with an average chlorine content of 42 percent. This Aroclor accounted for approximately 50% of the domestic production of PCB mixtures (EPA, 1996a).

One challenge in assessing the risk of commercial mixtures is that environmental mixtures may be more or less toxic than the original commercial mixture because the

congener composition of the mixture changes through partitioning, transformation, and bioaccumulation after its release into the environment. Physical and chemical data are available for the various Aroclors, but not for environmental mixtures; therefore, toxicity studies have only been conducted using Aroclors.

PCBs have the potential to cause cancer as well as a variety of noncancer health effects through all routes of exposure. It is necessary to assess the risk of both cancer and noncancer health effects if appropriate toxicity values are available. The U.S. Environmental Protection Agency (EPA) has derived a range of slope factors based on what is known regarding the toxicity of the different Aroclors and the environmental processes that act to change the congener composition of the original mixtures (EPA, 1996a). In the absence of a congener analysis, the recommendation is to use a slope factor of 2.0 $(mg/kg/day)^{-1}$ for soil ingestion, dust inhalation, and dermal absorption when an absorption factor has been applied. The recommended slope factor for water ingestion and vapor inhalation is 0.4 $(mg/kg/day)^{-1}$. A slope factor of 0.07 $(mg /kg/day)^{-1}$ is recommended only when it has been determined, based on congener analysis, that congeners with more than four chlorine atoms comprise less than 0.5% of the total mixture, and that dioxin-like congeners are not present. This might be the case if the predominant or only commercial PCB mixture originally used or disposed at the site was Aroclor 1016, which contains no congeners with more than four chlorine atoms.

DEQ is focusing on six Aroclors for which physical and chemical information is available: Aroclors 1016, 1221, 1242, 1248, 1254, and 1260. A slope factor of 0.07 $(mg/kg/day)^{-1}$ is used for Aroclor 1016, since this Aroclor contains no congeners with more than four chlorine atoms. A slope factor of 2.0 $(mg/kg/day)^{-1}$ is used for the other mixtures for all exposure routes. The major uncertainty associated with this approach is that the congener composition of the environmental mixture may not conform to any of the Aroclors. However, use of the upper-bound slope factor estimate for all exposure routes decreases the likelihood that actual risk will be underestimated. Reference doses are available for two commercial mixtures, Aroclors 1016 and 1254, and these should be used to assess noncancer risks.

U.S. Environmental Protection Agency Method 8082 should be used at sites with known or suspected PCB contamination to analyze individual Aroclors and total Aroclors.

Twelve PCB congeners are considered to be dioxin-like in terms of their toxicity. For these congeners, listed in Table 1, toxic equivalency factors (TEFs) have been developed, which relate the toxicity of the PCB congener to that of 2,3,7,8-tetrachloro-dibenzo-p-dioxin (TCDD), the most toxic of the polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans. If a congener analysis confirms the presence of dioxin-like PCB congeners at a site, it is necessary to follow the TEF procedure described in the following section in order to characterize risk. At the present time, DEQ does not require a congener analysis for all sites with PCB contamination; a decision on whether to

perform congener analysis will be made on a case-by-case basis upon consultation with DEQ.

TABLE 1
TOXIC EQUIVALENCY FACTORS (TEF) OF DIOXIN AND DIOXIN-LIKE COMPOUNDS

Congener	TEFa
Polychlorinated Dibenzo-p-Dioxins (PCDDs)	
2,3,7,8-TCDDb	1
1,2,3,7,8-PeCDDc	1
1,2,3,4,7,8-HxCDDd	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,4,6,7,8-HpCDDe	0.01
1,2,3,4,6,7,8,9-OCDDf	0.0001
Polychlorinated Dibenzofurans (PCDFs)	
2,3,7,8 TCDF	0.1
1,2,3,7,8-PeCDF	0.05
2,3,4,7,8-PeCDF	0.5
1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
1,2,3,4,6,7,8,9-OCDF	0.0001
Polychlorinated Biphenyls (PCBs)	
3,3',4,4'-TCB (IUPAC # 77)[g]	0.0001
3,4,4',5-TCB (IUPAC # 81)	0.0001
2,3,3',4,4'-PeCB (IUPAC # 105)	0.0001
2,3,4,4',5-PeCB (IUPAC # 114)	0.0005
2,3,4,4',5-PeCB (IUPAC # 118)	0.0001
2',3,4,4'5-PeCB (IUPAC # 123)	0.0001
3,3',4,4',5-PeCB (IUPAC # 126)	0.1
2,3,3',4,4',5-HxCB (IUPAC # 156)	0.0005
2,3,3',4,4',5'-HxCB (IUPAC # 157)	0.0005
2,3',4,4',5,5'-HxCB (IUPAC # 167)	0.00001
3,3',4,4',5,5'-HxCB (IUPAC # 169)	0.01
2,3,3',4,4',5,5'-HpCB (IUPAC # 189)	0.0001

[a]World Health Organization's recommended TEFs (van Leeuwen, 1997)
[b]T = tetrachlorodibenzo-p-dioxin
[c]Pe = pentachlorodibenzo-p-dioxin
[d]Hx = hexachlorodibenzo-p-dioxin
[e]Hp = heptachlorodibenzo-p-dioxin
[f]O = octachlorodibenzo-p-dioxin
[g]International Union of Pure and Applied Chemists (numbering system for PCBs)

The dioxin TEF approach should be applied to the dioxin-like congeners. The slope factor approach is then applied to the PCB total, minus the dioxin-like congeners. For the modified total PCB concentration in surficial soil, a slope factor of 2.0 $(mg/kg/day)^{-1}$ should be used. A slope factor of 0.07 $(mg/kg/day)^{-1}$ can be used to estimate risk only when the congener analysis indicates that congeners with more than four chlorine atoms comprise less than one-half percent of the total mixture, and that dioxin-like congeners are not present. In general, it is believed that weathering processes in soil are not likely to alter congener ratios in Aroclors to a significant extent, so that an Aroclor analysis will provide a reasonable estimate of PCB contamination.

If PCBs at a site have contaminated surface water, then state surface water quality standards apply. Surface water standards identify levels not to be exceeded for total PCBs to protect human health. Additionally, there is a criterion specific to aquatic life protection for all Aroclors, however, it is superceded by the more stringent human health criteria. If there is the potential for exposure to sediment through dermal contact and incidental ingestion, it is possible that DEQ will request a congener analysis. EPA Method 1668, Revision A should be used to determine the PCB congeners present in the media of concern, including water, sediment, and fish tissue. This method provides the concentrations of the 12 coplanar, dioxin-like congeners, as well as the total concentration of all congeners.

Evaluation of the Health Risks of Dioxin and Dioxin-like Compounds

In April 1991, the EPA announced that, because of significant advances in the scientific understanding of the mechanisms of dioxin toxicity, it would reexamine the health risks associated with dioxins and dioxin-like compounds. This reassessment led to the development of a draft report in 1994, 11 public meetings, extensive public comment, and a technical critique by the EPA's Science Advisory Board (SAB). Based on the comments received, EPA revised and issued a revised draft final dioxin reassessment document in September 2000 for public and SAB comment (EPA, 2000a,b,c). The reassessment report and guidance on this health issue have not yet been finalized. Until this occurs, DEQ recommends that the TEF approach as defined by the World Health Organization (van Leeuwen, 1997) be used to address the health risks associated with exposures to dioxin and dioxin-like compounds. The EPA's published methods for analyzing dioxins and related compounds (Method 1613B for polychlorinated dibenzo-p-dioxins [PCDDs] and polychlorinated dibenzofurans [PCDFs]; Method 8082 modified or Method 1668, when available, for dioxin-like PCBs) should be used at sites where contamination by these chemicals is known or reasonably anticipated.

The World Health Organization approach uses the TEFs of the major congeners of each dioxin or dioxin-like compound to convert the measured concentration of each congener

to an equivalent concentration of TCDD. The total toxic equivalency (TEQ) is calculated by summing the equivalent TCDD concentrations of all measured PCDD, PCDF, and PCB congeners, as shown in Equation 1 (see list of specific congeners in Table 1).

$$TotalToxicEquilavency(TEQ) = \sum_{n=1}^{k} C_n \times TEF_n \qquad \text{(Equation 1)}$$

The TEQ (i.e., the total equivalent concentration of TCDD) is then evaluated for health and environmental risks as any other chemical contaminant per DEQ guidance. At present, the compounds evaluated by this approach include PCDDs, PCDFs, and PCBs.

As discussed in the draft dioxin reassessment report (EPA, 2000b Chapter 2), the majority of scientific evidence supports the theory that binding to a cellular receptor called AhR plays an important role in the toxicity of dioxin-like compounds. Other chemicals are known to bind with AhR with different affinities including polycyclic aromatic hydrocarbons, polybrominated biphenyls, polychlorinated naphthalenes, polybrominated naphthalenes, chlorinated paraffins, hexachlorobenzene, polybrominated dioxins, and polybrominated furans. These chemicals should not be included in the TEQ calculation at this time.

Evaluation of the Health Risks of Lead

Lead has a number of toxic effects, but the main target for lead toxicity is the nervous system. Young children are especially vulnerable from the standpoints of both exposure and toxicity. Certain behaviors, such as crawling and playing on the floor or ground, lead to increased exposure, and the central nervous system of a young child is particularly susceptible because it is still developing. Chronic exposure to even low levels of lead that are not overtly toxic can result in impaired mental development.

The EPA has developed a model (the Integrated Exposure Uptake Biokinetic [IEUBK] Model) to predict the risk of elevated blood lead (PbB) in children under the age of seven that are exposed to environmental lead from various sources. The model predicts the probability that a child exposed to specified media lead concentrations will have a PbB level greater than 10 μg/dL, the level associated with adverse health effects (EPA, 1999).

Because of the greater vulnerability of children to exposure and toxicity, the primary concern in a residential setting is risk to children. In a nonresidential scenario, children are not directly exposed, but fetuses carried by female workers can be exposed. The EPA has developed an adult lead methodology (ALM) to assess risk in this scenario (EPA, 1996b). The methodology is limited in terms of exposure media (soil/dust). Specifically, the methodology estimates the PbB concentrations in fetuses carried by women exposed to lead contaminated soils.

EPA has evaluated a number of other adult lead models (EPA, 2001) in order to determine if recently developed models might be a significant improvement over the ALM. It was decided that, while components of several of the models could be integrated into a hybrid model, time would be better spent developing an all ages lead model capable of simulating multimedia exposures over the entire human lifetime. Until this model is developed, DEQ requires the use of the IEUBK model for residential scenarios (EPA, 1994a) and the ALM for nonresidential scenarios.

It is not necessary to use the IEUBK or ALM to assess lead risk and determine cleanup goals at all sites with lead contamination. The EPA has developed a screening level for lead in soil for residential land use of 400 mg/kg (EPA, 1994b). An appropriate screening level for nonresidential sites is 750 mg/kg (EPA, 1996b). However, these levels are based on exposure routes related to surface soil, and they do not address potential leaching to ground water. The soil IDTL for lead, 49.6 mg/kg, is based on ground water protection. In a situation in which the potential exists for leaching of lead to ground water, it is appropriate to use this IDTL. If the pathway from soil to ground water is not complete, the screening levels developed by EPA can be used.

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