Appendix A

2001 National Sewage Sludge Survey - Congener Concentration Data

Table A-1. Appendix A 2001 National Sewage Sludge Survey Sampling Data for Dioxins and Furans

Episode	Tier	2,3,7,8-TCDD 1746016 (ng/kg)	1,2,3,7,8,9-HXCDD 19408743 (ng/kg)	OCDD 3268879 (ng/kg)	1,2,3,4,6,7,8-HPCDD 35822469 (ng/kg)	OCDF 39001020 (ng/kg)	1,2,3,4,7,8-HXCDD 39227286 (ng/kg)	1,2,3,7,8-PECDD 40321764 (ng/kg)	2,3,7,8-TCDF 51207319 (ng/kg)	1,2,3,4,7,8,9-HPCDF 55673897 (ng/kg)	2,3,4,7,8-PECDF 57117314 (ng/kg)	1,2,3,7,8-PECDF 57117416 (ng/kg)	1,2,3,6,7,8-HXCDF 57117449 (ng/kg)	1,2,3,6,7,8-HXCDD 57653857 (ng/kg)	2,3,4,6,7,8-HXCDF 60851345 (ng/kg)	1,2,3,4,6,7,8-HPCDF 67562394 (ng/kg)	1,2,3,4,7,8-HXCDF 70648269 (ng/kg)	1,2,3,7,8,9-HXCDF 72918219 (ng/kg)
6338	2	0.8	3.9	934	90	178	1.3	4.1	2.5	2.4	2.4	1.3	3.1	5.9	4.1	48.6	4.3	0.5
6339	3	0.7	3.1	957	86.7	237	1.4	4	1.7	1.9	1.5	1.8	1.9	5.6	1.6	68.4	2.6	1.8
6340	2	1.7	25.6	10600	668	6020	9.1	7.7	5	12.5	3.7	2.3	10	33.7	16.5	357	9.5	0.5
6341	2	0.5	4	1010	95.9	169	1.5	1.7	0.8	2.3	1	0.7	1.8	4.4	1.7	35.2	2.1	0.5
6342	4	1.1	5.4	1800	237	296	1.2	2.7	1.4	1.7	1	0.5	1.6	12.3	1.9	72	1.7	0.5
6343	3	0.3	1.1	1510	80.2	77.8	0.4	0.5	0.4	1	0.3	0.3	0.5	2.5	0.6	16.7	0.6	0.5
6344	3	1.4	13.8	1970	338	147	2.2	2.8	1.7	2.5	1.2	1	2.2	40.8	1.9	47.5	3	0.5
6345	2	14	332	3040	1410	1510	124	92	79.7	418	463	189	618	230	974	2540	500	54.4
6346	1	47.2	49.7	5040	783	1070	9.8	11	6.3	9.1	6.6	5.7	9.7	92.8	12.6	227	24.1	0.6
6347	2	0.7	62.2	4200	639	64.9	3.2	19	4	2.2	4.3	2.2	6.2	264	14.8	98.6	12.8	0.5
6348	3	0.9	6.9	3040	209	554	2.2	5.2	4.9	3.4	1.9	1.1	2.6	10.1	2.8	117	3.1	0.5
6349	1	1.6	16.7	7140	672	462	6.1	7.1	3	8.1	4.8	2.6	7.9	24.9	7.5	146	9	0.2
6350	1	1.8	33.7	12600	1230	844	13.6	11.8	4.6	17.2	4.9	3	13.6	45	11.1	259	12.8	0.5
6351	4	3	21.6	3350	321	201	3.9	9.5	2.5	2.8	1.6	1	2.7	43.1	2.5	62	3.4	0.5
6370	2	0.7	5.8	3630	615	121	1.3	3.1	1.7	1.5	2.3	0.5	1.2	12.4	1.1	28.9	1.9	0.5
6371	1	0.5	2.1	1070	83.3	395	0.6	1.7	1.9	3	0.7	0.6	0.9	5	2.8	38.8	3.8	0.2
6352	1	1.5	22.1	10000	735	2460	8.9	8.6	4.8	43.7	4.9	3.7	11.9	27.1	12.7	227	19.4	1
6353	1	1.4	22.2	13200	1030	1680	7.9	7.6	5.6	30.3	4.8	4	9.6	33.9	7.4	199	17.2	0.9
6354	3	0.25	19.8	2170	184	2100	1	4.5	0.6	3.4	0.8	0.4	1.9	73.5	3.9	319	2.1	0.5
6355	4	2.4	22.8	7790	560	544	8.6	11.8	6.5	7	4	2.5	8.4	28.1	7	145	8.9	0.5
6356	3	0.9	13.3	3400	340	351	5.3	4.8	2.4	5.7	2.4	1.5	5.5	14.8	4.8	120	5.7	0.5
6357	1	0.2	24.5	3780	698	181	3.5	5.5	1.2	4.3	1.4	0.9	3.3	84.7	2.7	63.7	3.7	0.5
6358	4	1.1	12.5	2750	312	266	4.8	6.4	10.6	6.9	7.8	2.7	8.2	14.9	7.9	105	10.2	0.6
6359	3	0.7	2.7	1730	198	184	0.7	1.2	1	1.7	1.1	0.6	1.3	8.5	1.2	34.4	1.9	0.5
6360	3	0.7	5.9	2170	146	277	1.9	3.1	1.4	2.2	1.1	0.6	2.1	7.4	1.8	64.6	2.3	0.5
6361	1	1.1	19.4	11300	946	505	6.8	8.1	4.7	14.8	6	4.3	11.7	30.2	9.4	188	13.9	0.7
6363	4	1	7.5	3930	302	757	2.9	5	2.9	4.1	2.2	1.1	4	15.1	4.3	233	4.9	0.5
6364	4	0.9	6.7	2360	216	327	1.6	4.9	5.1	2	1.6	3.1	2.6	15.5	3.7	116	3.1	3.1
6365	2	1.8	8.7	4620	527	408	2.6	5.1	2.8	3.3	1.8	1	3.3	22	3	94.3	4	0.5
6366	4	0.5	1.9	683	64.7	80.2	0.7	1.8	0.5	0.8	0.4	0.3	0.8	3.3	1	28.3	1	0.5
6367	4	0.4	2.4	588	62.5	190	0.8	2	0.8	1.4	0.7	0.4	1.1	3.4	1.3	39.3	1.4	0.5
6368	3	1.2	14.8	5040	534	267	5.1	4	2.7	4.4	1.6	1.1	4.8	23.8	4.2	88.4	5	0.5
6369	3	2.3	19.6	7560	594	451	7.8	7.7	2.8	9.2	3.5	1.9	10.2	22.8	8	195	10.8	0.5
6372	3	0.9	2.8	1760	93.5	125	0.9	3.4	1.3	0.9	0.7	0.5	1.1	4.1	1.2	42.7	1.4	0.5
6373	2	0.5	3.1	1610	78.1	1660	0.9	4.5	4.3	11.9	1	1.7	1.9	5.1	1.3	62.8	9.1	0.9
6374	2	6.3	1.8	1050	49.1	176	0.7	3.3	9.6	0.7	3.6	2.4	1.1	3.2	1.5	32.4	1.7	0.5
6376	3	1.2	8.3	3180	225	213	2.3	8.2	2.1	2.8	1.4	1	2.7	15	2.7	76.6	2.8	0.5
6377	3	1.9	144	360000	22600	52700	45.1	16.7	2.5	772	4.4	8.6	106	367	29.6	7450	82.6	18.8
6378	3	5.3	6.3	2410	191	942	1.9	4.6	2.8	2.6	1.7	1.2	2.4	13.1	3.2	139	2.8	0.5
6379	3	0.7	3.9	1140	98.5	81.2	1.4	3.7	1.6	1.1	0.9	0.5	1.5	5.6	1.3	33.3	1.8	0.5
6380	4	1	7.4	1420	118	434	1.9	3.8	5.4	1.9	1.5	0.8	2	7.2	2.3	88	2.1	0.5
6381	2	3.2	6.8	2050	162	188	2	2.6	5.3	5.1	3.9	1.8	2.8	6.7	4.8	41.9	2.8	0.3
6382	2	0.35	30.6	1690	196	95	0.5	7.6	1.7	0.5	0.6	0.6	1	115	1.3	25.2	1.2	0.5
6383	4	0.6	2.7	917	77.8	131	1	2.9	0.7	1.4	0.6	0.3	1.1	3.8	1.3	39.7	1.2	0.5
6384	3	0.6	1.9	784	60.1	107	0.8	3.4	0.7	0.7	0.6	0.4	0.8	3.2	1.1	30	1	0.5

(continued)

Table A-1. (continued)

Episode	Tier	2,3,7,8-TCDD 1746016 (ng/kg)	1,2,3,7,8,9-HXCDD 19408743 (ng/kg)	OCDD 3268879 (ng/kg)	1,2,3,4,6,7,8-HPCDD 35822469 (ng/kg)	OCDF 39001020 (ng/kg)	1,2,3,4,7,8-HXCDD 39227286 (ng/kg)	1,2,3,7,8-PECDD 40321764 (ng/kg)	2,3,7,8-TCDF 51207319 (ng/kg)	1,2,3,4,7,8,9-HPCDF 55673897 (ng/kg)	2,3,4,7,8-PECDF 57117314 (ng/kg)	1,2,3,7,8-PECDF 57117416 (ng/kg)	1,2,3,6,7,8-HXCDF 57117449 (ng/kg)	1,2,3,6,7,8-HXCDD 57653857 (ng/kg)	2,3,4,6,7,8-HXCDF 60851345 (ng/kg)	1,2,3,4,6,7,8-HPCDF 67562394 (ng/kg)	1,2,3,4,7,8-HXCDF 70648269 (ng/kg)	1,2,3,7,8,9-HXCDF 72918219 (ng/kg)
6385	3	0.4	9.9	13800	183	25700	0.7	1.6	1.8	14.8	0.9	0.5	5.1	40.3	20.1	3860	4.2	0.5
6387	4	1.4	21.3	2520	225	135	3.6	12.3	1.5	1.7	1	0.6	2	29.8	2.3	54	1.8	0.5
6386	3	0.8	7.8	4570	445	290	2.7	5.3	1	4.7	1.5	0.9	3.1	14.8	2.8	82.8	3.8	0.2
6389	2	4.4	22.8	3640	367	1190	6.7	8.7	10.3	87.8	23.6	13	41.9	22.9	63.2	349	46.5	7.1
6390	2	1.5	4.6	1540	148	197	1.7	10.8	6.4	3.4	1.5	1.3	4.9	8.1	2.4	63.5	2.4	0.5
6391	4	0.6	1.6	538	49	102	0.7	3	0.9	0.6	0.4	0.3	0.7	2.4	0.9	24.4	0.9	0.5
6392	3	1.1	4.2	1700	158	451	1.6	8.3	2.3	1.5	1	0.6	1.5	10.6	2.3	100	1.9	0.5
6393	4	2.2	15.2	7410	649	475	5.9	13.1	1.9	6.1	1.5	1.1	4.5	21.2	5.8	165	4.6	1.7
6394	2	1.4	5.2	607	82.8	119	2.6	3.5	2.2	6.5	6.3	2.8	10.1	8.5	8.8	76.9	13.2	0.5
6395	3	2.1	14.5	2810	349	143	0.75	11.9	5.2	2.2	2.3	1.8	3.8	36.3	4.4	0.75	5.1	0.75
6396	3	1	1.5	695	67.2	106	0.8	4.6	1.9	0.9	0.4	0.3	0.9	3.1	1	39.1	1.2	0.5
6397	3	1.7	9.2	7050	352	396	3.3	10.2	3.2	4.6	1.6	1	3	14.2	3.3	113	5.1	1.65
6375	3	1.1	4.4	2910	209	267	1.4	4.9	3.1	2	1.5	0.5	2.1	9.1	2.1	76.2	2	0.5
6399	2	0.4	1.5	528	50.9	136	0.5	1.5	1	0.7	0.6	0.3	0.8	2.8	1.1	40.3	0.9	0.5
6400	3	1.1	7.2	1870	211	287	2.9	8.1	15.3	2.8	1.9	2.3	3.3	11.6	5.3	124	3.5	0.5
6401	2	0.9	2.9	1150	78.3	178	1.2	4.9	4.6	0.9	0.8	0.7	1.3	4.8	1.3	49.9	1.3	0.5
6402	1	2.2	15.2	6900	599	686	6.3	8.7	7.7	6.3	2.8	1.6	5.9	27.3	5.2	156	6.4	0.2
6403	4	0.4	1.4	393	37.5	60.2	0.6	1.9	0.3	0.6	0.3	0.2	0.6	1.9	0.6	20.2	0.5	0.5
6404	3	0.9	6.1	2030	177	518	1.9	4	3	3.2	2.1	1.4	3.6	9.9	4	112	4.4	1.1
6405	2	0.9	5	1490	148	371	1.4	3.4	2.2	2.8	1.5	1	2.4	7.1	2.4	93	2.8	0.2
6406	2	1.4	9	3400	349	544	3	5.9	3.9	3.9	3	1.7	3.8	18.1	3.9	127	5.3	0.2
6407	2	1.7	30.8	12600	1200	625	7.9	5.8	3.6	11.2	3.3	2.1	5.8	55.1	4.8	170	11.2	0.4
6409	3	0.9	12.5	4230	394	498	5.6	5.5	4.3	7	1.6	1.1	4.4	20.4	3.4	121	4.5	0.5
6410	3	1.2	4.2	1660	144	277	1.3	3.5	1.9	2	1.2	0.8	2	7.6	2.2	74.9	2.4	0.5
6411	3	1.6	21.1	5290	504	674	7.8	9.2	7.9	7.2	4.7	2.6	8	26.6	6.9	173	8.3	0.4
6412	2	0.6	5.4	1260	40.8	26.6	1.1	1.4	1.2	0.5	1	0.6	0.5	2.3	0.5	7	0.5	0.5
6413	1	1.6	4.6	1280	134	169	1.1	2	5.5	1.9	3.9	2.1	2.5	8.5	2.6	43.4	4	0.2
6414	2	0.9	6.5	1950	200	417	2	3.9	2.7	3.3	2.3	1.3	3.8	11.7	3.9	130	6.9	0.5
6415	3	1.6	9.1	2900	287	588	2.4	6.5	7.4	3.2	4.2	4.2	4.9	17.9	4	138	8.4	0.5
6416	4	1.5	7	2370	288	253	1.5	2.8	1.3	2.3	1.1	0.5	2.3	19.8	1.6	82.8	3.8	0.5
6418	2	1.7	22.3	9870	1030	232	7.5	6.4	2.6	8.9	3.8	2.8	8.8	38	7.7	177	15.8	0.3
6419	3	0.5	3.4	2430	180	194	1.2	2.4	1.4	2.5	1.4	0.7	2.1	6	2.4	63.7	3.3	0.5
6420	2	3.6	19.5	6870	526	699	5.9	6.7	4.9	10.3	3.8	2.2	10	22.7	11.6	183	8.6	0.5
6421	3	3.4	40.2	12800	1080	930	16.3	13.4	2.6	21.7	3.7	2.3	16	43.6	12.1	352	15.3	0.4
6423	3	2	16.6	4180	415	311	5.1	6.2	5.7	6.7	2.6	1.6	7.7	20.9	5	132	7.2	0.3
6424	4	5	18.3	7930	655	339	6.5	9.2	3.7	4.5	2.2	1.1	6.7	26.3	8.2	172	6.8	0.9
6425	4	0.7	6.3	5070	183	281	2.3	3.6	1.2	3.1	0.9	0.7	2.6	8	2.1	83.4	3	0.5
6426	4	1.6	8.3	3450	376	258	2.8	3.6	2.3	3.9	1.9	1	3.4	15.2	3.2	91	4.3	0.2
6427	2	1.6	11.7	2660	298	321	3.9	6	3.9	4.8	4.7	2.1	5.7	15.8	5.1	125	7.2	0.5
6428	4	1	14.4	4060	460	423	4.2	5.3	5	3.5	2	1.4	4.5	34	4.3	129	4.8	0.65
6429	2	2.2	30.9	15800	1840	1450	10.1	11.3	5.7	27.6	6.2	4.4	14	61.2	9.9	323	22.8	1.1
6430	4	1.3	16.5	6240	720	330	4.7	4.4	2.9	5.7	2.8	1.5	5.9	31.1	4.9	135	6.1	0.2
6431	2	1.5	17.4	3790	403	585	7	6.4	7.4	11.8	7.1	5.2	15.1	20.2	9.2	279	26.6	0.8
6433	4	1.2	16.9	5590	779	297	3.6	4.9	3.3	4.3	2.4	1.5	4.1	44.3	3.5	102	6	0.2
6434	1	3.1	42.3	10400	1010	929	14.9	14.4	8.8	18.4	8.5	5.4	16.9	52.9	14.7	320	21.6	0.8

(continued)

Table A-1. (continued)

Episode	Tier	2,3,7,8-TCDD 1746016 (ng/kg)	1,2,3,7,8,9-HXCDD 19408743 (ng/kg)	OCDD 3268879 (ng/kg)	1,2,3,4,6,7,8-HPCDD 35822469 (ng/kg)	OCDF 39001020 (ng/kg)	1,2,3,4,7,8-HXCDD 39227286 (ng/kg)	1,2,3,7,8-PECDD 40321764 (ng/kg)	2,3,7,8-TCDF 51207319 (ng/kg)	1,2,3,4,7,8,9-HPCDF 55673897 (ng/kg)	2,3,4,7,8-PECDF 57117314 (ng/kg)	1,2,3,7,8-PECDF 57117416 (ng/kg)	1,2,3,6,7,8-HXCDF 57117449 (ng/kg)	1,2,3,6,7,8-HXCDD 57653857 (ng/kg)	2,3,4,6,7,8-HXCDF 60851345 (ng/kg)	1,2,3,4,6,7,8-HPCDF 67562394 (ng/kg)	1,2,3,4,7,8-HXCDF 70648269 (ng/kg)	1,2,3,7,8,9-HXCDF 72918219 (ng/kg)
6435	3	1.7	24.4	4890	604	473	7.3	11.2	4.6	8.9	6.6	3.6	10	47.6	8.9	179	11.8	0.4
6436	2	0.8	9.7	4190	426	282	3.4	3.5	2.3	4.6	2.4	1.5	3.7	16.2	3.4	71.7	5	0.3
6437	2	12.3	52.4	1120	271	4.5	4.5	85	1.5	0.8	2	1.9	2.2	128	7	28.2	2.5	0.3
6438	2	0.3	1.4	200	21.9	31.3	0.5	0.6	0.4	0.6	0.6	0.4	0.7	1.4	0.8	8.3	1	0.5

Table A-2. Appendix A 2001 National Sewage Sludge Survey Sampling Data for Coplanar Polychlorinated Biphenyls

Episode	Tier	PCB-118 31508006 (ng/kg)	PCB-77 32598133 (ng/kg)	PCB-105 32598144 (ng/kg)	PCB-169 32774166 (ng/kg)	PCB-189 39635319 (ng/kg)	PCB-167 52663726 (ng/kg)	PCB-126 57465288 (ng/kg)	PCB-123 65510443 (ng/kg)	PCB-81 70362504 (ng/kg)	PCB-114 74472370 (ng/kg)	PCB-156 & PCB-157 COELUTE (ng/kg)
6338	2	12300	312	5080	3	166	706	30.4	265	151	355	2320
6339	3	8580	194	3490	8.15	59.3	378	163.5	202	177	225	1320
6340	2	15900	964	6770	0.5	110	778	100	412	294	427	2530
6341	2	4460	24800	1920	450	40.7	230	501	105	85	124	747
6342	4	12000	832	5210	2.5	69.1	473	25.3	396	224	382	1670
6343	3	822	18.3	333	2.5	8.7	48.8	50	22.3	12.4	20.4	170
6344	3	3160	100	1280	2.5	31.3	169	50	96.2	37.5	75.8	553
6345	2	32200	1190	12200	90.8	1440	2740	256	670	465	998	8200
6346	1	14400	13800	6690	30.6	215	1040	114	457	262	580	3170
6347	2	16000	704	7080	4.3	138	843	36.1	377	189	432	2890
6348	3	11800	331	4810	3.7	77.7	574	50	414	138	323	2070
6349	1	18400	676	8030	5.7	340	1160	57.8	411	212	429	3780
6350	1	19200	873	8130	5.7	229	1120	60.6	483	216	519	3580
6351	4	1510	22.4	663	0.5	13.7	101	10	28.7	22.4	41.1	367
6370	2	5850	188	2460	1.5	39.3	281	50	349	89.5	159	933
6371	1	6800	319	2900	2	87.5	383	50	145	87.7	164	1240
6352	1	29700	1220	13200	8.5	1010	2380	93.9	672	277	864	6910
6353	1	15800	1030	7120	6.5	368	1100	71.5	484	320	490	3260
6354	3	3120	153	1240	1.2	22.3	138	8.5	117	36	83.1	512
6355	4	23900	700	10500	5.8	167	1350	68.3	554	392	680	4630
6356	3	9010	499	3890	21	62.9	430	60.4	268	213	257	1390
6357	1	25600	333	10800	2.5	141	1360	29.7	426	561	782	4250
6358	4	63600	13000	39200	11.7	527	2390	381	2140	1980	2500	8000
6359	3	11300	277	4190	4	53.7	439	400	226	170	263	1460
6360	3	6090	160	2520	1.3	37.6	268	11.3	157	66.8	165	978
6361	1	14700	901	5990	3.3	161	623	38.4	312	176	361	2250
6363	4	15300	525	6480	0.5	88.9	710	28.4	363	243	409	2680
6364	4	19500	458	7110	4.9	214	944	490	372	300	427	3200

(continued)

Table A-2. (continued)

Episode	Tier	PCB-118 31508006 (ng/kg)	PCB-77 32598133 (ng/kg)	PCB-105 32598144 (ng/kg)	PCB-169 32774166 (ng/kg)	PCB-189 39635319 (ng/kg)	PCB-167 52663726 (ng/kg)	PCB-126 57465288 (ng/kg)	PCB-123 65510443 (ng/kg)	PCB-81 70362504 (ng/kg)	PCB-114 74472370 (ng/kg)	PCB-156 & PCB-157 COELUTE (ng/kg)
6365	2	1120	51.5	481	0.5	8.2	47.5	10	33.8	18.2	30.7	178
6366	4	6770	279	2670	2.5	34.3	266	50	257	140	182	912
6367	4	6210	360	2490	2.5	63.3	290	50	261	128	180	999
6368	3	870	44.7	359	0.3	7.8	48.8	5.5	21.1	12.5	22.3	151
6369	3	15500	659	6680	4.9	107	832	400	391	146	317	2420
6372	3	8020	229	3480	1.6	55	511	19.6	330	113	225	1520
6373	2	11900	570	4920	2.5	88.6	564	50	413	266	362	1880
6374	2	4300	173	1630	2.5	26.4	178	50	165	104	126	599
6376	3	326	13.9	120	0.5	1.9	12.6	10	12.2	5.1	8.1	42.2
6377	3	5250	222	2180	2.5	41.6	267	18	177	142	161	893
6378	3	232	19.3	87.9	0.5	1.5	8.5	30	9.4	4.5	6.8	25.5
6379	3	22600	519	9880	3.6	153	1200	44.7	497	218	538	4300
6380	4	256	10.6	103	0.5	1.8	8.9	10	7.2	4.9	6.5	30.5
6381	2	8670	496	3640	2.5	131	475	29	231	194	298	1460
6382	2	5750	147	2370	2.5	31.5	273	8.3	133	127	149	909
6383	4	3620	146	1520	1.1	24.5	171	8.7	141	77.2	91.6	615
6384	3	4850	122	1660	2.5	33.9	210	8.3	140	101	100	694
6385	3	18700	214	7910	1	46.6	675	400	309	156	439	2060
6387	4	4360	214	1870	2.2	33.5	205	19.1	133	87.2	120	733
6386	3	4330	197	1820	1.7	35.4	251	13.3	126	66.1	117	807
6389	2	4750	267	1900	8.3	48.3	221	21.3	204	57.1	143	777
6390	2	9750	469	3960	2.5	67.9	459	34.4	420	223	288	1460
6391	4	3360	164	1420	2.5	23.8	149	50	150	62.7	103	533
6392	3	5450	355	2230	2.5	35.6	240	50	182	104	167	858
6393	4	1820	168	1240	4.2	47.7	209	26.7	75.8	23	69	686
6394	2	3340	81.3	1320	2.4	40.2	182	8.6	197	44	91.3	583
6395	3	5310	348	2740	3.8	44.4	306	76	303	100	144	995
6396	3	8880	337	2430	2.9	54.6	390	22.5	308	121	128	1280

(continued)

Table A-2. (continued)

Episode	Tier	PCB-118 31508006 (ng/kg)	PCB-77 32598133 (ng/kg)	PCB-105 32598144 (ng/kg)	PCB-169 32774166 (ng/kg)	PCB-189 39635319 (ng/kg)	PCB-167 52663726 (ng/kg)	PCB-126 57465288 (ng/kg)	PCB-123 65510443 (ng/kg)	PCB-81 70362504 (ng/kg)	PCB-114 74472370 (ng/kg)	PCB-156 & PCB-157 COELUTE (ng/kg)
6397	3	5110	253	2090	2.3	45.6	260	18.1	213	109	142	831
6375	3	870	19.4	327	0.5	5.7	39.3	10	26	18	25.5	139
6399	2	2660	121	1010	2.5	18.8	118	50	187	69.8	64.6	396
6400	3	5760	326	2340	5.9	55	297	36.6	948	79.8	164	1040
6401	2	3480	211	1420	2.5	30.9	180	50	392	66.6	104	601
6402	1	1320	73	551	0.6	14	71.5	7.9	90.5	20.1	36.1	228
6403	4	4210	180	1740	2.5	34.3	210	50	419	75.1	123	729
6404	3	3610	197	1320	10.35	33.8	162	206.5	280	73.3	122	645
6405	2	7880	363	3110	3.8	59.6	347	50	381	88.8	195	1140
6406	2	18700	683	7300	4.9	129	800	43.3	581	401	462	2770
6407	2	42600	3220	21300	9	576	2190	158	1030	692	1400	6800
6409	3	5140	251	1990	3.1	50.4	257	50	421	85.8	141	823
6410	3	7080	286	2840	3	58.8	338	24.1	364	161	180	1140
6411	3	25500	598	10800	4	158	1180	39.9	619	400	653	4100
6412	2	2800	163	1220	2.5	30.1	128	50	66.8	52.4	74.4	435
6413	1	9410	333	4000	2.3	82.2	458	50	213	125	246	1490
6414	2	1140	53.2	464	0.5	12.2	61.9	10	37.7	19	31.6	196
6415	3	33100	1730	15100	2.5	207	1490	72.3	1040	613	986	4930
6416	4	11300	203	4440	0.5	66.4	542	50	301	173	302	1830
6418	2	12800	574	5960	2.5	160	887	58.4	315	334	323	2750
6419	3	5990	234	2630	2.5	46.6	298	50	169	109	153	936
6420	2	23300	816	9120	6.4	665	1910	54	481	443	576	5820
6421	3	9720	493	3810	3	73.5	474	30.9	282	117	250	1480
6423	3	2160	116	847	0.5	15.3	102	7.7	49.8	33.4	53.5	320
6424	4	15200	455	6370	4.1	75.6	662	48.2	424	286	328	2140
6425	4	4660	346	1820	1.9	29.7	214	50	294	56.9	137	784
6426	4	13600	2030	6840	2.9	89.3	550	48.4	407	378	421	1730
6427	2	17300	1030	8290	5.4	140	862	69	476	432	549	2850

(continued)

Table A-2. (continued)

Episode	Tier	PCB-118 31508006 (ng/kg)	PCB-77 32598133 (ng/kg)	PCB-105 32598144 (ng/kg)	PCB-169 32774166 (ng/kg)	PCB-189 39635319 (ng/kg)	PCB-167 52663726 (ng/kg)	PCB-126 57465288 (ng/kg)	PCB-123 65510443 (ng/kg)	PCB-81 70362504 (ng/kg)	PCB-114 74472370 (ng/kg)	PCB-156 & PCB-157 COELUTE (ng/kg)
6428	4	819	18	340	0.55	6.8	43.3	11.5	24	12.3	18.7	163
6429	2	21400	980	8600	5.1	152	967	68.8	543	247	570	3150
6430	4	1580	34.7	629	0.6	14.6	85.3	12	44.7	21.8	35.4	286
6431	2	26200	1150	10600	6.1	213	1370	63.2	513	566	642	4400
6433	4	5230	150	2030	0.9	26.9	211	8.6	99.4	74.9	125	720
6434	1	5280	791	2730	1.1	81.2	228	22.2	141	110	213	684
6435	3	1880	87.7	777	0.6	16.4	90.4	10	39.2	28.3	49.7	292
6436	2	13500	1120	6490	2.5	76.7	497	46.1	342	310	404	1670
6437	2	5630	195	2270	0.5	39.6	260	50	150	96.8	143	947
6438	2	13500	915	6350	3.8	106	672	40.9	354	210	416	2220

Appendix B

2001 National Sewage Sludge Survey - Sample Selection Strategy

MEMORANDUM

TO: Charles White, EPA

FROM: Kathleen Stralka, SAIC WAM

CC: Amit Kumar, SAIC
Dana Greenwood, RTI

DATE: August 10, 2001

REFERENCE: EPA Contract No. 68-C-99-233; Work Assignment No. 2-14
SAIC Project No. 01-0813-08-1657-140

SUBJECT: 2001 NSSS - Survey weights

TD/Dv#: T140806a/D140810a

In response to your technical direction, we transmit information for projecting samples in the 2001 National Sewage Sludge Survey (2001 NSSS) to the Nation.

Stratum (h)	Sample Size(n_h)	Operating POTWs in Sample	Adjusted Stratum (N_h)	Sampling Fraction (n_h/N_h)	Stratum Weight (N_h/N)
1	11	11	27	11/27	27/7201
2	30	30	301	30/301	301/7201
3	36	35	1787	35/1787	1787/7201
4	24	22	5086	22/5086	5086/7201
∑	101	98	7201		1.000

Strata 3 and 4 population sizes reflect adjustments for out-of-business facilities. Please notice that of the 98 POTWs in the 2001 NSSS, only 94 report data for dioxin and furans. The four POTWs that do not report dioxin data are accounted for as follows:

- Stratum 2 - episode 6422 samples were treated as blanks.
- Stratum 3 - No data from Episodes 6388 or 6389
- Stratum 4 - No data from Episode 6417.

The attached file lists the POTWs in the 2001 NSSS according to their stratum.

R165ff01

The primary assumption underlying the statistical sample design of the 2001 NSSS is that the population consists of 7,714 Publicly Owned Treatment Works (POTWs) across four strata. These strata categorize the POTWs according to the average daily flow of influent wastewater. The strata definitions and the strata sizes based on the 1988 population are tabulated below.

Stratum	Stratum Definition	Number of POTWs in the Population Stratum
1	Flow Greater than 100 million gallons per day (MGD)	27
2	10 MGD<Flow ≤100 MGD	301
3	1 MGD<Flow ≤10 MGD	1838
4	Flow ≤1 MGD	5548
Total		7,714

From the POTWs sampled for the 1988 NSSS, a statistical sample of 101 POTWs was drawn to comprise the 2001 NSSS. The sampling fractions for the 2001 NSSS were derived using Bayes Theorem.

Define A_h as the event that a POTW was randomly drawn from the N_h POTWs in stratum h of the 1988 population of POTWs. Define B_h as the event that a POTW was randomly drawn for the 2001 NSSS. The event B/A indicates that a POTW in the 2001 NSSS was randomly selected from the sample of n_h POTWs in the 1988 NSSS to be included in the 2001 NSSS. The event AB is defined as the event that a POTW is in both the 1988 and 2001 NSSS. Thus, using Bayes Theorem,

$P[B_h|A_h]*P[A_h]=P[AB_h]$ applied to stratum 1 yields a sampling fraction ($P[AB_h]$) of 11/27 because $P[B_h|A_h]*P[A_h]$ =11/19*19/27.

Three POTWs from the 1988 NSSS that were drawn for the 2001 NSSS were no longer in business. One of these out-of-business POTWs was in stratum 3. The other two were in stratum 4. Thus, the population stratum size was adjusted to reflected closed POTWs.

Appendix C

Agricultural Parameters

Table C-1. Agricultural Field and Monofill Parameters for Source Partitioning Models and Fate and Transport Model

Parameter Code	Parameter Description	Value	Reference	Land Application Unit Model	Fate and Transport Model
CutOffYr	Operating life (year)	Triangular distribution: min - 1 max - 40 mode - 20	U.S. EPA, 1995 (p. 6)	✓	✓
C_crop	USLE cover factor for the crop (unitless)	0.1	U.S. EPA, 2000	✓	
C_pasture	USLE cover factor for the pasture (unitless)	0.3	U.S. EPA, 2000	✓	
effdust	Dust suppression control efficiency for controlled areas (unitless)	Normal distribution: min - 0 max - 1 mean - 0.5 stdev - 0.3	Best professional judgment, based on information in U.S. EPA, 1989	✓	
ER	Soil enrichment ratio (unitless)	3	U.S. EPA, 2000		✓
fcult_crop	Number of cultivations per application for the crop (unitless)	3	U.S. EPA, 1995 (p. 177)	✓	
fcult_pasture	Number of cultivations per application for the pasture (unitless)	1	U.S. EPA, 1995 (p. 177)	✓	

(continued)

Table C-1. (continued)

Parameter Code	Parameter Description	Value	Reference	Land Application Unit Model	Fate and Transport Model
fd_crop	Frequency of surface disturbance per month for active LAU on the crop (1/mo)	Nappl x fcult_crop / 12 months	Best professional judgment	✓	
fd_pasture	Frequency of surface disturbance per month for active LAU on the pasture (1/mo)	Nappl x fcult_crop / 12 months	Best professional judgment	✓	
fwmu	Fraction of waste in waste management unit (mass fraction)	1	Best professional judgment	✓	
Lc	Roughness ratio (cm/h)	Lognormal distribution: min - 0.0001 max - 0.001 mean - 0.0003 stdev - 0.304	Carsel and Parrish, 1988	✓	
load	Waste loading rate (dry) (Mg/y)	capacity/ CutOffYr	Best professional judgment		
mcW	Volumetric water content (waste on trucks) (volume percent)	Triangular distribution: min - 1 max - 75 mode - 40	Best professional judgment	✓	
mt_crop	Distance vehicle travels on crop surface (m)	(Width of farm / Width of truck) * Length of farm * fcult	U.S. EPA, 1995 (pp. 173, 177)	✓	

(continued)

Table C-1. (continued)

Parameter Code	Parameter Description	Value	Reference	Land Application Unit Model	Fate and Transport Model
mt_pasture	Distance vehicle travels on pasture surface (m)	(Width of farm / Width of truck) * Length of farm * fcult	U.S. EPA, 1995 (pp. 173, 177)	✓	
Nappl	Waste applications per year (1/year)	1/2	Best professional judgment, based on information in U.S. EPA, 1989	✓	
nv_crop	Vehicles per day on the crop (mean annual) (1/d)	fcult_crop/ 365 days	Best professional judgment	✓	
nv_pasture	Vehicles per day on the pasture (mean annual) (1/d)	fcult_pasture/ 365 days	Best professional judgment	✓	
P_crop	USLE erosion control factor for crop (unitless)	0.5	Wanielista and Yousef, 1993	✓	
P_pasture	USLE erosion control factor for pasture (unitless)	1	Wanielista and Yousef, 1993	✓	
Rappl	Wet waste application rate (Mg/m^2-year)	Equal probability: min - 2.5E-04 max - 5.0E-03	U.S. EPA, 1995 (pp. 199-200)	✓	
Runoff_LWS	Runoff from local watershed (m^3/d)	Output from source model (add crop and pasture)			✓

(continued)

Table C-1. (continued)

Parameter Code	Parameter Description	Value	Reference	Land Application Unit Model	Fate and Transport Model
Runoff_RWS	Runoff from regional watershed (m^3/d)	Output from source model			✓
SY	Start time exposure begins (year)	Uniform distribution capped at the operating life of the unit	Best professional judgment	✓	✓
veg	Fraction vegetative cover for inactive source (fraction)	Normal distribution: min - 0.8 max - 1.0 mean - 0.9 stdev - 0.1	Best professional judgment	✓	
vw	Vehicle weight (mean) (Mg)	payload x BDw x2 (payload assumed to be 10 cu yd)	Best professional judgment	✓	
zava	Upper depth average soil concentration (m)	0.01	Best professional judgment	✓	
zavb	Lower depth average soil concentration (m)	0.2	Best professional judgment	✓	
zruf_crop	Roughness height for crop (cm)	1	Best professional judgment, based on information in U.S. EPA, 1989	✓	
zruf_pasture	Roughness height for pasture (cm)	1	Best professional judgment, based on information in U.S. EPA, 1989	✓	

References

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U.S. EPA (Environmental Protection Agency). 2000. *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds. Volume 4: Site-Specific Assessment Procedures*. Draft. Exposure Assessment and Risk Characterization Group, Office of Research and Development, Washington, DC. September.

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Appendix D

Congener-Specific Parameters for Source Partitioning and Fate and Transport Models

Appendix D

Congener-Specific Parameters for Source Partitioning and Fate and Transport Models

The values for congener-specific data were collected for both the source partitioning model and the fate and transport model. Some parameters are used in both source model and the fate and transport model while others are unique to a particular model. Table D-1 presents the parameters used and which model they are used in.

Table D-1. Congener-Specific Parameters for Source Partitioning and Fate and Transport Models

Parameter	Source Partitioning Model	Fate and Transport Model
Air to plant biotransfer factor (Bv)		✓
Antoine’s B constant (AntB)	✓	
Antoine’s C constant (AntC)	✓	
Bioconcentration factor for cattle (BCF_cattle)		✓
Bioconcentration factor for eggs (BCF_egg)		✓
Bioconcentration factor for poultry (BCF_poultry)		✓
Biota to sediment accumulation factor (BSAF)		✓
Boiling point (tb)	✓	
Critical pressure (Pc)	✓	
Critical temperature (tc)	✓	
Degradation rate in sediment (kgs)	✓	✓

(continued)

Table D-1. (continued)

Parameter	Source Partitioning Model	Fate and Transport Model
Degradation rate in soil (Ksg)	✓	✓
Degradation rate in surface water (kgw)		✓
Diffusivity in air (Da)	✓	✓
Diffusivity in water (Dw)	✓	✓
Dry deposition velocity (Vdv)		✓
Fraction of wet deposition adhering to plant surface (Fw)		✓
Henry’s law constant (HLC)	✓	✓
Hydrolysis (Kh)	✓	✓
Melting point (MP)		✓
Molecular weight (MW)		✓
Organic carbon partition coefficient (Koc)	✓	✓
Plant surface loss coefficient for particulates (KpPar)		✓
Root concentration factor (RCF)		✓
Soil water partition coefficient (Kow)		✓
Solubility (S)	✓	✓
Toxicity equivalency factors (TEF)		✓
Vapor pressure (VP)	✓	✓

The primary source for data collection was the *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds* (U.S. EPA, 2000). Values for water solubility and vapor pressure were collected from U.S. EPA (1994) and ATSDR (1994) when data were not available in the Draft Dioxin Reassessment. Values for diffusivity in water were calculated based on Equation D-1 provided by *Processes, Coefficients, and Models for Simulating Toxic Organics and Heavy Metals in Surface Waters* (U.S. EPA, 1987):

$$Dw = 0.00022 \times MW^{(-2/3)} \quad \text{(D-1)}$$

Degradation (soil, sediment, surface water) and hydrolysis rates were assumed to be zero as recommended by the Dioxin Reassessment (U.S. EPA, 2000). Soil water partition coefficients are calculated the model using the following equation:

$$Kd = foc \times K_{OC} \qquad \text{(D-2)}$$

Parameters in the fate and transport model that were held constant for all congeners included KpPar, Fw, and Vdv.

Parameter	Definition	Value	Reference
Fw	Fraction of wet deposition adhering to plant surface (unitless)	0.6	U.S. EPA, 1997
KpPar	Plant surface loss coefficient for particulates (1/yr)	18.07	U.S. EPA, 1997
Vdv	Dry deposition velocity (cm/s)	0.2	Koester and Hites, 1992

Within the source model, temperature correction routines were instated for chemical diffusivity in air (D_a), chemical diffusivity in water (D_w), and Henry's law constant (H). The correction routine for D_a was derived from the FSG Method (Lyman et al.,1990, Ch. 17, Eq. 17-12, and the routine for D_w was derived from Eq 17-24 (Hayduk and Laudie) in Lyman et al. (1990). The temperature correction for H used estimates of the heat of vaporization from Lyman et al. (1990), Eq. 13-21. The Haggenmacher method (Lyman et al., 1990, Section 13-5) is used to determine the heat of vaporization at the boiling point. Temperature corrections for partitioning (K_d, K_{oc}), hydrolysis, and solubility were not included in the model. These routines use Antoine's constants B and C, the boiling temperature of the chemical, and the critical temperature and pressure for the chemical. Because there were no values for Antoine's constants or the critical temperature and pressure, default equations were used by the model.

Table D-2. Chemical-Specific Inputs for 2,3,3',4,4',5,5'-HpCB (CAS No. 39635-31-9)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	395.33	U.S. EPA, 2000
MP	Melting point (degrees C)	162	U.S. EPA, 2000
tb	Boiling point (degrees C)	400	ATSDR, 1998b
S	Water solubility (mg/L)	6.26E-05	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	1.31E-08	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	6.65E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.24E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.08E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	3.16E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	5.13E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	2.61E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	2.08	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.3	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.5	U.S. EPA, 2000

Table D-3. Chemical-Specific Inputs for 1,2,3,4,6,7,8-HpCDD (CAS No. 35822-46-9)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.01	U.S. EPA, 2000
MW	Molecular weight (g/mol)	425.31	U.S. EPA, 2000
MP	Melting point (degrees C)	264	U.S. EPA, 2000
tb	Boiling point (degrees C)	507.2	ATSDR, 1998a
S	Water solubility (mg/L)	2.40E-06	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	5.60E-12	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.26E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.09E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	3.89E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	6.17E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.00E+08	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	4.37E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	9.10E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.003	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	0.48	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	1.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	4.8	U.S. EPA, 2000

Table D-4. Chemical-Specific Inputs for 1,2,3,4,6,7,8-HpCDF (CAS No. 67562-39-4)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.01	U.S. EPA, 2000
MW	Molecular weight (g/mol)	409.31	U.S. EPA, 2000
MP	Melting point (degrees C)	236	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	1.35E-06	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	3.50E-11	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.41E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.17E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	3.99E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	1.55E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	2.51E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	1.51E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	8.30E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.001	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	0.55	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	1	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	3.1	U.S. EPA, 2000

Table D-5. Chemical-Specific Inputs for 1,2,3,4,7,8,9-HpCDF (CAS No. 55673-89-7)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.01	U.S. EPA, 2000
MW	Molecular weight (g/mol)	409.31	U.S. EPA, 2000
MP	Melting point (degrees C)	221	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	1.35E-06	U.S. EPA, 1994
VP	Vapor pressure (mm Hg)	1.07E-10	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.40E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.17E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	3.99E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	6.17E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.00E+08	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	4.37E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	8.30E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.035	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	1.32	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	0.9	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	2.2	U.S. EPA, 2000

Table D-6. Chemical-Specific Inputs for 2,3,3',4,4',5-HxCB (CAS No. 38380-08-4)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0005	U.S. EPA, 2000
MW	Molecular weight (g/mol)	360.88	U.S. EPA, 2000
MP	Melting point (degrees C)	129.5	U.S. EPA, 2000
tb	Boiling point (degrees C)	400	ATSDR, 1998b
S	Water solubility (mg/L)	4.10E-04	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	1.47E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	8.70E-04	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.44E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.34E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	8.91E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.45E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	9.84E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	3.97	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.5	U.S. EPA, 2000

Table D-7. Chemical-Specific Inputs for 2,3’,4,4’,5,5’-HxCB (CAS No. 52663-72-6)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.00001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	360.88	U.S. EPA, 2000
MP	Melting point (degrees C)	125	U.S. EPA, 2000
tb	Boiling point (degrees C)	400	ATSDR, 1998b
S	Water solubility (mg/L)	3.61E-04	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	1.95E-07	U.S. EPA, 2000
HLC	Henry’s Law Constant (atm-m3/mol)	1.10E-04	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.44E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.34E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	7.59E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.23E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	8.70E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	8.35	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.5	U.S. EPA, 2000

Table D-8. Chemical-Specific Inputs for 3,3',4,4',5,5'-HxCB (CAS No. 32774-16-6)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.01	U.S. EPA, 2000
MW	Molecular weight (g/mol)	360.88	U.S. EPA, 2000
MP	Melting point (degrees C)	208	U.S. EPA, 2000
tb	Boiling point (degrees C)	400	ATSDR, 1998b
S	Water solubility (mg/L)	3.61E-05	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	1.81E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	6.52E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.44E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.34E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	1.78E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	2.88E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	1.70E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	11.85	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	6.5	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	7.4	U.S. EPA, 2000

Table D-9. Chemical-Specific Inputs for 1,2,3,4,7,8-HxCDD (CAS No. 39227-28-6)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	390.87	U.S. EPA, 2000
MP	Melting point (degrees C)	273	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1998a
S	Water solubility (mg/L)	4.42E-06	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	3.80E-11	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.07E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.27E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.12E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	3.89E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	6.31E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	3.06E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	5.20E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.028	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.69	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	3.6	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	5.4	U.S. EPA, 2000

Table D-10. Chemical-Specific Inputs for 1,2,3,6,7,8-HxCDD (CAS No. 57653-85-7)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	390.87	U.S. EPA, 2000
MP	Melting point (degrees C)	285	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1998a
S	Water solubility (mg/L)	4.40E-06	U.S. EPA, 1994
VP	Vapor pressure (mm Hg)	3.60E-11	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.10E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.27E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.12E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	1.23E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	2.00E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	1.26E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	5.20E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.011	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.32	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	5.6	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	10.2	U.S. EPA, 2000

Table D-11. Chemical-Specific Inputs for 1,2,3,7,8,9-HxCDD (CAS No. 19408-74-3)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	390.87	U.S. EPA, 2000
MP	Melting point (degrees C)	243	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1998a
S	Water solubility (mg/L)	4.40E-06	U.S. EPA, 1994
VP	Vapor pressure (mm Hg)	4.90E-11	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.10E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.27E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.12E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	1.23E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	2.00E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	1.26E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	5.20E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.013	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.99	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	2.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	4.5	U.S. EPA, 2000

Table D-12. Chemical-Specific Inputs for 1,2,3,4,7,8-HxCDF (CAS No. 70648-26-9)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	374.87	U.S. EPA, 2000
MP	Melting point (degrees C)	225.5	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	8.25E-06	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	2.40E-10	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.43E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.36E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.23E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	6.17E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.00E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	7.41E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.62E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.007	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	3.12	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	4.8	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	7.4	U.S. EPA, 2000

Table D-13. Chemical-Specific Inputs for 1,2,3,6,7,8-HxCDF (CAS No. 57117-44-9)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	374.87	U.S. EPA, 2000
MP	Melting point (degrees C)	232	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	1.77E-05	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	2.20E-10	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	7.31E-06	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.36E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.23E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	6.17E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.00E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	7.41E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.62E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.017	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.67	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	5.3	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	8.2	U.S. EPA, 2000

Table D-14. Chemical-Specific Inputs for 1,2,3,7,8,9-HxCDF (CAS No. 72918-21-9)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	374.87	U.S. EPA, 2000
MP	Melting point (degrees C)	246	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	1.30E-05	U.S. EPA, 1994
VP	Vapor pressure (mm Hg)	3.74E-08	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.10E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.36E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.23E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	6.17E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.00E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	7.41E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.62E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.06	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.67	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	4.1	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.2	U.S. EPA, 2000

Table D-15. Chemical-Specific Inputs for 2,3,4,6,7,8-HxCDF (CAS No. 60851-34-5)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	374.87	U.S. EPA, 2000
MP	Melting point (degrees C)	239	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	1.30E-05	U.S. EPA, 1994
VP	Vapor pressure (mm Hg)	2.00E-10	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.10E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.36E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.23E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	6.17E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.00E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	7.41E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.62E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.057	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	2.37	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	2.1	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	3	U.S. EPA, 2000

Table D-16. Chemical-Specific Inputs for 1,2,3,4,6,7,8,9-OCDD (CAS No. 3268-87-9)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	460.76	U.S. EPA, 2000
MP	Melting point (degrees C)	325	U.S. EPA, 2000
tb	Boiling point (degrees C)	510	ATSDR, 1998a
S	Water solubility (mg/L)	7.40E-08	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	8.25E-13	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	6.75E-06	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	3.93E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	3.69E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	9.77E+07	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.58E+08	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	6.22E+04	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	2.36E+06	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.001	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	0.69	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	0.3	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	4.3	U.S. EPA, 2000

Table D-17. Chemical-Specific Inputs for 1,2,3,4,6,7,8,9-OCDF (CAS No. 39001-02-0)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	444.76	U.S. EPA, 2000
MP	Melting point (degrees C)	258	U.S. EPA, 2000
tb	Boiling point (degrees C)	537	ATSDR, 1994
S	Water solubility (mg/L)	1.16E-06	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	3.75E-12	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.88E-06	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.00E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	3.78E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	3.89E+08	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	6.31E+08	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	1.80E+05	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	2.28E+06	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.001	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	0.27	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	0.3	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	1.4	U.S. EPA, 2000

Table D-18. Chemical-Specific Inputs for 2,3,3',4,4'-PeCB (CAS No. 32598-14-4)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	326.44	U.S. EPA, 2000
MP	Melting point (degrees C)	116.5	U.S. EPA, 2000
tb	Boiling point (degrees C)	380	ATSDR, 1998b
S	Water solubility (mg/L)	1.90E-03	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	8.28E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	9.93E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.67E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.64E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	6.17E+05	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.00E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	1.26E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	4.18	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	1.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.5	U.S. EPA, 2000

Table D-19. Chemical-Specific Inputs for 2',3,4,4',5-PeCB (CAS No. 65510-44-3)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	326.44	U.S. EPA, 2000
MP	Melting point (degrees C)	134	U.S. EPA, 2000
tb	Boiling point (degrees C)	380	ATSDR, 1998b
S	Water solubility (mg/L)	1.64E-03	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	8.78E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.74E-04	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.67E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.64E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	3.39E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	5.50E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	4.68E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	6.4	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	1.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.5	U.S. EPA, 2000

Table D-20. Chemical-Specific Inputs for 2,3’,4,4’,5-PeCB (CAS No. 31508-00-6)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	326.44	U.S. EPA, 2000
MP	Melting point (degrees C)	111	U.S. EPA, 2000
tb	Boiling point (degrees C)	380	ATSDR, 1998b
S	Water solubility (mg/L)	1.59E-03	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	3.14E-07	U.S. EPA, 2000
HLC	Henry’s Law Constant (atm-m3/mol)	8.50E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.67E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.64E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	8.13E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.32E+07	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	9.17E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	3.59	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	1.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.5	U.S. EPA, 2000

Table D-21. Chemical-Specific Inputs for 2,3,4,4',5-PeCB (CAS No. 74472-37-0)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0005	U.S. EPA, 2000
MW	Molecular weight (g/mol)	326.44	U.S. EPA, 2000
MP	Melting point (degrees C)	98	U.S. EPA, 2000
tb	Boiling point (degrees C)	380	ATSDR, 1998b
S	Water solubility (mg/L)	2.85E-03	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	4.18E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	6.90E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.67E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.64E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	2.75E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	4.47E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	3.99E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	6.4	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	1.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6.5	U.S. EPA, 2000

Table D-22. Chemical-Specific Inputs for 3,3',4,4',5-PeCB (CAS No. 57465-28-8)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	326.44	U.S. EPA, 2000
MP	Melting point (degrees C)	160	U.S. EPA, 2000
tb	Boiling point (degrees C)	380	ATSDR, 1998b
S	Water solubility (mg/L)	1.03E-03	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	2.96E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	5.40E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.67E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.64E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	4.79E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	7.76E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	6.10E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	3.21	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	1.2	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	6.5	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	7.4	U.S. EPA, 2000

Table D-23. Chemical-Specific Inputs for 1,2,3,7,8-PeCDD (CAS No. 40321-76-4)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	356.42	U.S. EPA, 2000
MP	Melting point (degrees C)	240	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1998a
S	Water solubility (mg/L)	1.43E-04	U.S. EPA, 1994
VP	Vapor pressure (mm Hg)	4.40E-10	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	2.60E-06	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.47E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.38E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	2.69E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	4.37E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	3.92E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	2.39E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.083	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	5.55	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	6.8	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	6	U.S. EPA, 2000

Table D-24. Chemical-Specific Inputs for 1,2,3,7,8-PeCDF (CAS No. 57117-41-6)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.05	U.S. EPA, 2000
MW	Molecular weight (g/mol)	340.42	U.S. EPA, 2000
MP	Melting point (degrees C)	225	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	2.36E-04	U.S. EPA, 1994
VP	Vapor pressure (mm Hg)	1.70E-09	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	5.00E-06	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.57E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.51E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	3.80E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	6.17E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	5.11E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	9.75E+04	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.02	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	0.97	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	18	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	20.5	U.S. EPA, 2000

Table D-25. Chemical-Specific Inputs for 2,3,4,7,8-PeCDF (CAS No. 57117-31-4)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.5	U.S. EPA, 2000
MW	Molecular weight (g/mol)	340.42	U.S. EPA, 2000
MP	Melting point (degrees C)	196	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	2.36E-04	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	2.60E-09	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	4.98E-06	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.57E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.51E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	1.95E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	3.16E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	3.05E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	9.75E+04	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.144	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	4.13	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	7.4	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	7.8	U.S. EPA, 2000

Table D-26. Chemical-Specific Inputs for 2,3,7,8-TCDD (CAS No. 1746-01-6)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	321.98	U.S. EPA, 2000
MP	Melting point (degrees C)	305	U.S. EPA, 2000
tb	Boiling point (degrees C)	446.5	ATSDR, 1998a
S	Water solubility (mg/L)	1.93E-05	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	1.50E-09	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	3.29E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.70E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.68E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	3.98E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	6.31E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	5.20E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	6.55E+04	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.09	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	5.76	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	8.8	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	7.8	U.S. EPA, 2000

Table D-27. Chemical-Specific Inputs for 2,3,7,8-TCDF (CAS No. 51207-31-9)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.1	U.S. EPA, 2000
MW	Molecular weight (g/mol)	305.98	U.S. EPA, 2000
MP	Melting point (degrees C)	227	U.S. EPA, 2000
tb	Boiling point (degrees C)	500	ATSDR, 1994
S	Water solubility (mg/L)	4.19E-04	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	1.50E-08	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.44E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.82E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	4.85E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	7.76E+05	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	1.26E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	1.50E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	4.57E+04	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	0.072	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	1.25	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	3.1	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	2.7	U.S. EPA, 2000

Table D-28. Chemical-Specific Inputs for 3,3',4,4'-TeCB (CAS No. 32598-13-3)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	291.99	U.S. EPA, 2000
MP	Melting point (degrees C)	180	U.S. EPA, 2000
tb	Boiling point (degrees C)	360	ATSDR, 1998b
S	Water solubility (mg/L)	1.00E-03	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	4.47E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.70E-05	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.94E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	5.00E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	1.95E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	3.16E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	3.05E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	2.205	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	5.9	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	6.5	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	7.4	U.S. EPA, 2000

Table D-29. Chemical-Specific Inputs for 3,4,4',5-TeCB (CAS No. 70362-50-4)

Parameter	Definition	Value	Reference
TEF	Toxicity equivalency factors	0.0001	U.S. EPA, 2000
MW	Molecular weight (g/mol)	291.99	U.S. EPA, 2000
MP	Melting point (degrees C)	160	U.S. EPA, 2000
tb	Boiling point (degrees C)	360	ATSDR, 1998b
S	Water solubility (mg/L)	2.92E-03	U.S. EPA, 2000
VP	Vapor pressure (mm Hg)	7.85E-07	U.S. EPA, 2000
HLC	Henry's Law Constant (atm-m3/mol)	1.28E-04	U.S. EPA, 2000
Da	Diffusivity in air (cm2/s)	4.94E-02	U.S. EPA, 2000
Dw	Diffusivity in water (cm2/s)	5.00E-06	U.S. EPA, 1987
Koc	Organic carbon partition coefficient (unitless)	1.41E+06	U.S. EPA, 2000
Kow	Soil water partition coefficient (mL/g)	2.29E+06	U.S. EPA, 2000
RCF	Root concentration factor (ug/g WW plant)/(ug/mL soil water)	2.40E+03	U.S. EPA, 2000
Bv	Air-to-plant biotransfer factor (ug/g DW plant)/(ug/g air)	1.49E+05	U.S. EPA, 2000
BSAF	Biota-to-sediment accumulation factor (unitless)	1.005	U.S. EPA, 2000
BCF_cattle	Bioconcentration factor for cattle (unitless)	5.9	U.S. EPA, 2000
BCF_poultry	Bioconcentration factor for poultry (unitless)	6.5	U.S. EPA, 2000
BCF_egg	Bioconcentration factor for eggs (unitless)	7.4	U.S. EPA, 2000

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Appendix E

Site Data

Table E-1. Site Parameters Used by Source Partitioning Model and Fate and Transport Model

Parameter Code	Parameter Description	Value	References	Source Model	Fate and Transport Model
AirTemp	Long-term average air temperature (°C)	Met station specific (see Table E-2)	U.S. DOC and U.S. DOE, 1993	✓	
AquTemp	Average vadose zone temperature (°C)	Met station specific (see Table E-2)	Van der Leeden et al., 1990	✓	
CN	SCS curve number (unitless)	Uniform distribution: (see Table E-3)	Wanielista and Yousef, 1993	✓	
ConVs	Settling velocity (m/d)	Uniform distribution: min - 0.05 max - 1	Best professional judgment	✓	
Farm_area	Median area for the crop and pasture combined (m^2)	Met station specific (see Table E-2)	U.S. DOC, 1994	✓	✓
K	USLE soil erodibility factor	Met station specific	Schwarz and Alexander, 1995	✓	✓
LS	USLE length-slope factor	Site-specific (where L in LS = X flow site-specific)	Schwarz and Alexander, 1995	✓	✓
R	USLE rainfall/erosivity factor (1/yr)	Met station specific (see Table E-2)	NCDR, ERL, NWS, 1995		✓
SiteLatitude	Latitude (degrees)	Met station specific (see Table E-2)	U.S. DOC and U.S. DOE, 1993	✓	
T1	Start time exposure begins	Uniform distribution capped at the operating life of the unit		✓	✓
Td	Time period of deposition	Triangular distribution: min = 1 max = 40		✓	✓
uw	Mean annual wind speed (m/s)	Met station specific (see Table E-2)	U.S. DOC and U.S. DOE, 1993		✓
Watershed_area	Area of watershed for a third-order stream	Triangular distribution: min - 2.3E+07 max - 1.11E+08 mode - 5.96E+07	Keup, 1985	✓	✓
Wai_LWS	Imperviousness of watershed area for local watershed (%)	2	Center for Watershed Protection, 1998		✓
Wai_RWS	Imperviousness of watershed area for regional watershed (%)	Uniform distribution: min - 2 max - 20	Center for Watershed Protection, 1998		✓

Table E-2. Values for Met Specific Parameters

MetStation	AirTemp (°C)	AquTemp (°C)	Farm_area (m^2)	R (1/yr)	SiteLatitude (degrees)	uw (m/s)
Albuquerque	13.53	16	1878963	40	35.05	4.012
Asheville	12.6	17	224196.8	225	35.433	3.452
Atlanta	16.38	18	428563.8	310	33.65	3.938
Billings	8.64	9	5025002	20	45.8	4.998
Bismarck	6.15	8	3738501	60	46.767	4.328
Boise	10.89	13	786712.1	20	43.567	3.71
Boulder	10.11	12	2986592	50	40.0167	3.783
Burlington	7.29	9	644262.2	85	44.467	4.075
Casper	7.56	12	3357286	35	42.917	5.628
Charleston	18.18	19	325368.6	360	32.9	3.788
Chicago	9.69	12	718724.6	155	41.983	4.632
Cleveland	9.91	12	441918.5	120	41.417	4.593
Fresno	17.15	18	189393.7	50	36.767	2.791
Grand Island	10.74	12	1142028	130	40.967	5.039
Harrisburg	11.62	12	416018.5	150	40.217	3.078
Hartford	9.92	11	202343.7	150	41.933	3.693
Houston	20.04	24	499788.8	425	29.967	3.604
Huntington	12.8	14	350863.9	140	38.367	2.961
Las Vegas	19.91	23	394974.8	25	36.083	4.547
Little Rock	16.55	18	643857.5	310	34.733	3.138
Los Angeles	16.63	19	97934.33	60	33.933	3.592
Meridian	17.58	19	497765.4	400	32.333	2.689
Miami	24.31	26	160256.2	480	25.8	4.221
Minneapolis	8.3	8	844177.7	140	44.883	4.766

(continued)

Table E-2. (continued)

MetStation	AirTemp (°C)	AquTemp (°C)	Farm_area (m^2)	R (1/yr)	SiteLatitude (degrees)	uw (m/s)
Muskegon	8.63	10	473888.8	100	43.167	4.817
Nashville	15.61	16	382024.8	220	36.117	3.63
New Orleans	20.11	22	367860.8	555	29.983	3.531
Norfolk	15.75	16	394570.1	280	36.9	4.997
Philadelphia	12.24	12	157828	185	39.883	4.188
Phoenix	23.34	21	1374723	50	33.433	2.669
Portland	7.57	9	397402.9	115	43.65	3.918
Raleigh-Durham	14.94	16	345603	280	35.867	3.393
Salem	11.65	12	180490.5	35	44.917	3.295
Salt Lake City	11.12	12	580726.3	35	40.783	4.011
San Francisco	13.26	17	161065.5	50	37.617	4.849
Seattle	11	11	162279.6	35	47.45	3.859
Shreveport	18.18	20	448798.2	360	32.467	3.429
Tampa	22.12	24	271140.5	445	27.967	3.753
Tulsa	15.72	19	744624.6	270	36.2	4.551
Williamsport	9.9	11	514357.6	125	41.25	3.495
Winnemucca	9.58	13	656807.5	15	40.9	3.859

Table E-3. SCS Curve Number Values for Crop and Pasture Based on Hydrologic Group

Hydrologic Group	Crop	Pasture
A	72	39
B	81	61
C	88	74
D	91	80

Table E-4. Median Waterbody Temperatures by HUC Region

HUC Region	Waterbody Temperature (K)
1	287
2	289
3	294
4	287
5	290
6	291
7	288
8	293
9	283
10	286
11	290
12	294
13	289
14	282
15	290
16	282
17	284
18	288

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Appendix F

Source Model for Land Application Units

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Appendices

Figures

Tables

F-1.0 Introduction

A source term module was developed for land application units (LAUs) to provide estimates of annual average surface soil constituent concentrations and constituent mass emission rates to air, downslope land, and ground water. These estimates are then used in an integrated, multipathway module linking source term modules with environmental fate and transport and exposure/risk modules. Additionally, LAU source emission modules have been combined with a local watershed module (a “local” watershed is a sheet-flow-only watershed containing the LAU) to provide estimates of constituent mass flux rates from runoff and erosion to a downslope waterbody, as well as surface soil constituent concentrations in downslope buffer areas. Because the LAU source is assumed here to interact hydrologically with the local watershed of which it is an integral part, it is termed a “land-based” unit.

A soil column module was developed to describe the dynamics of constituent mass fate and transport within LAUs and near-surface soils in watershed subareas. It is referred to as the Generic Soil Column Module (GSCM). (The term “soil” is used loosely here to refer to a porous medium, whether it is waste in the LAU or near-surface soil in a watershed subarea.) Governing equations for the GSCM are similar to those used by Jury et al. (1983, 1990) and Shan and Stevens (1995). However, the analytical solution techniques used by these authors were not applicable to the source emission module developed here because of the need to consider the periodic addition of constituent mass and enhanced constituent mass loss rates in the surface soil (e.g., due to runoff, erosion, wind, and mechanical processes). A new solution technique has been developed for use that is computationally efficient and sufficiently flexible to allow consideration of the LAU. Use of the GSCM described here allows:

- Constituent mass balance
- Waste additions/removals to simulate active facilities
- Joint estimation of constituent mass losses due to a variety of mechanisms, including:
  - Volatilization of gas-phase constituent mass from the surface to the air
  - Leaching of aqueous-phase constituent mass by advection or diffusion from the bottom of the WMU or vadose zone

- First-order losses, which can include:
  - Abiotic and biodegradation
  - Suspension of constituent mass adsorbed to surface particles due to wind action and vehicular activity
  - Suspension of constituent mass adsorbed to surface particles due to water erosion
  - Surface runoff of aqueous-phase constituent mass.

Section 2 provides a description of the GSCM assumptions, governing equations, boundary conditions, and solution technique. Section 3 describes the application of the GSCM to the land-based LAU and its integration within the holistic local watershed module, including hydrology, soil erosion, and runoff water quality. Sections 4 and 5 describe the specifics of the application and integration for the LAU. Appendix A lists and defines all symbols used in Sections 2 through 6. Appendixes B and C provide supplementary information on determination of H’, D_a, and D_w for organic compounds and particulate emission equations.

F-2.0 Generic Soil Column Module

F-2.1 Assumptions

The following assumptions were made in the development of the Generic Soil Column Module used in the LAU:

- The contaminant partitions to three phases: adsorbed (solid), dissolved (liquid), and gaseous (as in Jury et al., 1983, 1990).

$$C_T = \rho_b C_S + \theta_w C_L + \theta_a C_G \qquad \text{(F-2-1)}$$

where

C_T	=	total contaminant concentration in soil (g/m^3 of soil)
ρb	=	soil dry bulk density (g/cm^3)
Cs	=	adsorbed phase contaminant concentration in soil (µg/g of dry soil)
θ_w	=	soil volumetric water content (m^3 soil water/m^3 soil)
C_L	=	aqueous-phase contaminant concentration soil (g/m^3 of soil water)
θ_a	=	soil volumetric air content (m^3 soil air/m^3 soil)
C_G	=	gas-phase contaminant concentration in soil (g/m^3 of soil air).

- The contaminant undergoes reversible, linear equilibrium partitioning between the adsorbed and dissolved phases (as in Jury et al., 1983, 1990).

$$C_S = K_d C_L \qquad \text{(F-2-2)}$$

where K_d is the linear equilibrium partitioning coefficient (cm^3/g). For organic contaminants:

$$K_d = foc \cdot K_{oc} \qquad \text{(F-2-3)}$$

where foc is the organic carbon fraction in soil and K_{oc} is the equilibrium partition coefficient, normalized to organic carbon. Alternatively, K_d can be specified as an input parameter for inorganic contaminants. (It is implicit in this linear equilibrium partitioning assumption that the sorptive capacity of the soil column solids is considered to be infinite with respect to the total mass of contaminant over the duration of the simulation, i.e., the soil column sorptive capacity does not become exhausted.)

- Contaminant in the dissolved and gaseous phases is assumed to be in equilibrium and to follow Henry's law (as in Jury et al., 1983, 1990).
  where H′ is the dimensionless Henry's law coefficient.

$$C_G = H' \; C_L \qquad \text{(F-2-4)}$$

- The total contaminant concentration in soil can also be expressed in units of µg of contaminant mass per g of dry soil (µg/g):

$$C_T' = \frac{C_T}{\rho_b} \qquad \text{(F-2-5)}$$

- Using the linear equilibrium approximations in Equations F-2-2 through F-2-5, C_T can be expressed in terms of C_L, C_S , or C_G:

$$C_T = K_{TL} C_L = \frac{K_{TL}}{K_d} C_S = \frac{K_{TL}}{H'} C_G \qquad \text{(F-2-6)}$$

where

$$K_{TL} = \rho_b K_d + \theta_w + \theta_a H' \qquad \text{(F-2-7)}$$

K_{TL} is the dimensionless equilibrium distribution coefficient between the total and aqueous-phase constituent concentrations in soil.

- The total water flux or infiltration rate (I, m/d) is constant in space and time (as in Jury et al., 1983, 1990) and greater than or equal to zero. It is specified as an annual average.

- Material in the soil column (including bulk waste) can be approximated as unconsolidated homogeneous porous media whose basic properties (ρ_b, foc, θ_w, θ_a, and η -- the total soil porosity) are average annual values, constant in space.

- Contaminant mass may be lost from the soil column due to one or more first-order loss processes.

- The total chemical flux is the sum of the vapor flux and the flux of the dissolved solute (as in Jury et al., 1983, 1990).

- The chemical is transported in one dimension through the soil column (as in Jury et al., 1983, 1990).

- The vapor-phase and liquid-phase porosity and tortuosity factors obey the module of Millington and Quirk (1961) (as in Jury et al., 1983, 1990). (See equation F-2-9a below).

- The modeled spatial domain of the soil column remains constant in volume and fixed in space with respect to a vertical reference, e.g., the water table.

F-2.2 Governing Mass Balance Equation

Under the above assumptions, the governing mass fate and transport equation can be written as follows:

$$\frac{\partial C_T}{\partial t} = D_E \frac{\partial^2 C_T}{\partial z^2} - V_E \frac{\partial C_T}{\partial z} - kC_T \qquad \text{(F-2-8)}$$

where k (1/d) is the total first-order loss rate, D_E (m^2/d) is the effective diffusivity in soil calculated as follows:

$$D_E = \frac{(\theta_a^{10/3} D_a H' + \theta_w^{10/3} D_w)\ 8.64}{\eta^2 K_{TL}} \qquad \text{(F-2-9a)}$$

where D_a and D_w (cm^2/s) are air and water diffusivities, respectively, and 8.64 is a conversion factor (m^2-s/cm^2-d). D_E can be considered to be the sum of the effective gaseous and water diffusion coefficients in soil, $D_{E,a}$, and $D_{E,w}$, respectively, where

$$D_{E,a} = \frac{\theta_a^{10/3} D_a H'\ 8.64}{\eta^2 K_{TL}} \qquad \text{(F-2-9b)}$$

$$D_{E,w} = \frac{\theta_w^{10/3} D_w\ 8.64}{\eta^2 K_{TL}} \qquad \text{(F-2-9c)}$$

The effective solute convection velocity (V_E, m/d) is equal to the water flux corrected for the contaminant partitioning to the water phase as follows:

$$V_E = \frac{I}{K_{TL}} \qquad \text{(F-2-10)}$$

F-2.3 Parameter Estimation Methodologies

- Water content (θ_w) is estimated as a function of the annual average infiltration rate (I, m/d) using (Clapp and Hornberger, 1978):

$$\theta_w = \eta \cdot \left(\frac{I}{0.24 K_{sat}} \right)^{1/(2SM_b+3)} \qquad \text{(F-2-11)}$$

  where K_{sat} (cm/h) is saturated hydraulic conductivity, SM_b is a unitless exponent specified by soil-type, and 0.24 (h-m/d-cm) is a unit conversion factor.

- Volumetric air content is estimated using:

$$\theta = \eta - \theta_w \ . \qquad \text{(F-2-12)}$$

- H′, D_a, and D_w can be either estimated as a function of temperature in the soil column (T_{sc}, °C) using the methods described in Appendix B or specified directly as input parameters if preadjusted values are available.

F-2.4 Solution Technique

F-2.4.1 Background

A solution of the complete convective-diffusive-decay concentration module (Equation F-2-8) was undertaken to evaluate, in a soil column of depth z_{sc}

- Total contaminant concentration as a function of time, t, and depth below the surface, z, for an arbitrary chemical

- Contaminant mass fluxes across the upper (z = 0) and lower boundaries ($z = z_{sc}$) of the soil column.

A numerical solution of Equation F-2-8, with zero concentration boundary condition at the surface and zero gradient lower boundary condition, was first examined as a straightforward explicit finite difference method. This approach resulted in such a high numerical diffusion that it was impossible to distinguish diffusion effects. By subdividing each section into relatively thinner sections, the numerical diffusion could be reduced to more acceptable levels, but then smaller time steps were required, and the computation time became quite long. In addition, the numerical solution was not stable in the extremes (e.g., high/low V_E or D_E).

An alternative, quasi-analytical approach was developed that allows for relative computational speed and significantly reduces concern about numerical diffusion and lack of stability. The tradeoff is a loss of ability to evaluate short-term trends in concentration and diffusive flux profiles. The method was developed to allow estimation of long-term (i.e., annual average) contaminant concentration profiles and mass fluxes.

The alternative approach developed consists of a superposition of analytic solutions of the three components of the governing equation (Equation 2-8) on the same grid. The solution for the simplified case where the soil column consists of one homogeneous zone, whose properties are uniform in space and time, is described below. Adaptations of the solution technique to account for variations from this simplified case (e.g., more than one homogeneous zone as for a landfill with cover soil zone atop the waste zone) are described in the module-specific sections.

F-2.4.2 Description of Quasi-analytical Approach

A quasi-analytical approach was developed that is a step-wise solution of the three components of the governing equation (Equation F-2-8) on the same grid. Boundary conditions of C_T=0 at both the upper and lower boundaries of the soil column are assumed, although some flexibility exists in specifying the lower boundary condition as discussed below. That is, the following equations are solved individually:

$$\frac{\partial C_T}{\partial t} = D_E \frac{\partial^2 C_T}{\partial z^2} \qquad \text{(F-2-13)}$$

$$\frac{\partial C_T}{\partial t} = - V_E \frac{\partial C_T}{\partial z} \qquad \text{(F-2-14)}$$

$$\frac{\partial C_T}{\partial t} = - kC_T \qquad \text{(F-2-15)}$$

Equations F-2-13 through F-2-15 each have an analytical solution that can be combined to obtain a pure diffusion solution that moves with velocity V_E through the porous medium (Jost, 1960). The solution of the general differential equation then has the form of the solution of the diffusive portion with its time dependence, translating in space with velocity V_E, and decaying exponentially with time.

The first two solutions for a point source are graphically depicted in Figures F-2-1a and F-2-1b for illustration. If it were possible to compute such point source solutions for each position in the soil column and each time of interest, then the contributions at each point could be added to obtain a global solution because the governing differential equations are linear. That is, each point in the soil column could be treated as if it were the only point for which there is a nonzero concentration.

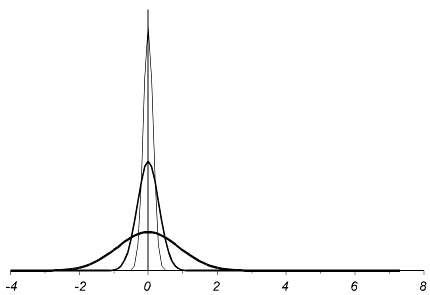

Figure F-2-1a. Development of diffusive spreading from a point source with time, corresponding to times of 0.01, 0.05, and 0.4.

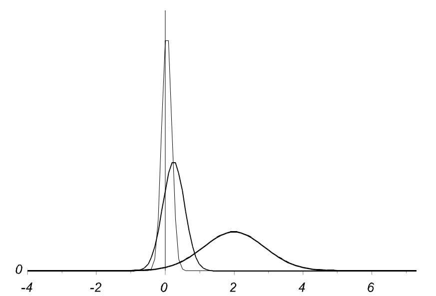

Figure F-2-1b. Diffusive spreading from a point source with a constant velocity to the right at times of 0.01, 0.05, and 0.4.

To make the analysis tractable, instead of a point source, the soil column is divided into layer sources each of depth dz (i.e., a grid). A layer source can be thought of as multiple point sources packed closely together. In such a case, Equation F-2-13 has a solution for one-dimensional diffusion, with the concentration at any point and any time given by

$$C_T(z',t) = \frac{C_{T0}}{2}\left[erf\left(\frac{z' + dz/2}{\sqrt{4D_E t}}\right) + erf\left(\frac{dz/2 - z'}{\sqrt{4D_E t}}\right)\right] \qquad \text{(F-2-16)}$$

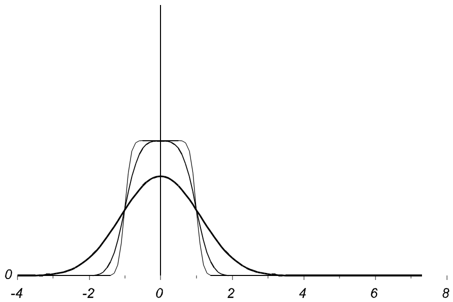

Figure F-2-2a. Development of diffusive spreading from a layer source with time, corresponding to times of 0.01, 0.05, and 0.4.

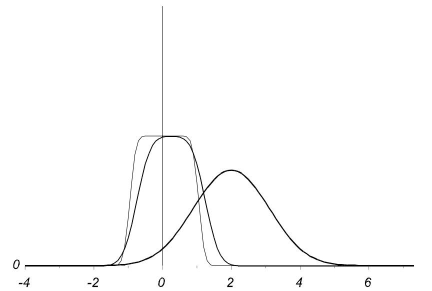

Figure F-2-2b. Diffusive spreading from a layer source with a constant velocity to the right at times of 0.01, 0.05, and 0.4.

for a layer of width dz centered at z′ = 0 (Jost, 1960). The concentration profile is assumed to be initially uniform from z′ = -dz/2 to z′ = +dz/2 and zero everywhere else. With time, the profile spreads outward and the concentration at the origin decreases, as shown in Figure F-2-2a for dz=2. With a positive velocity V_E, the concentration profile also moves down the soil column as illustrated in Figure F-2-2b. The use of layer solutions requires that we assume uniform average concentrations within each layer. Thus, the thickness of the layers determines the spatial resolution available.

The total amount of material, m, in g/m^2 that has passed any ordinate z′ after time t is given by the integral of the concentration from z′ to ∞ with half leaving to the left (negative z′ values) and half to the right (positive z′ values) :

$$m(z',t) = 2\int_{z'}^{\infty} C_T(z,t)dz \qquad \text{(F-2-17)}$$

The integral in Equation (2-17) can be derived as

$$m(z',t) = C_{T0}\sqrt{4D_E t}\left[\int_{(z'-dz/2)/\sqrt{4D_E t}}^{\infty} erfc(y)\,dy - \int_{(z'+dz/2)/\sqrt{4D_E t}}^{\infty} erfc(y)\,dy\right] \qquad \text{(F-2-18)}$$

which is evaluated using the relationship (Abramowitz and Stegun, 1970):

$$\int \mathrm{erfc}(x)dx = x\,\mathrm{erfc}(x) - \frac{1}{\sqrt{\pi}}\exp\left(-x^2\right) + \text{constant} \qquad \text{(F-2-19)}$$

The fraction of the original mass that diffuses past a boundary at z′ in any time period 0 to t, Df(z′,t), is one-half m(z′,t) divided by the amount of mass initially present in g/m^2 in the source layer (C_{T0}·dz):

$$Df\,(z',t) = 0.5 \cdot \frac{\sqrt{4D_E\,t}}{dz}\left[\int_{(z'-dz/2)/\sqrt{4D_E t}}^{\infty} erfc(y)\;dy - \int_{(z'+dz/2)/\sqrt{4D_E t}}^{\infty} erfc(y)\;dy\right] \qquad \text{(F-2-20)}$$

The fraction of mass that remains in the original layer of width dz after diffusion in the time period 0 to t, $Df_0(t)$, is:

$$Df_0\,(t) = 1 - 2 \cdot Df\,(z' = 0.5dz, t) \qquad \text{(F-2-21)}$$

By means of evaluations at all the layer boundaries (z′=0.5dz, 1.5dz, 2.5dz, ...), the amount of contaminant mass transported to any layer via diffusion after time t can be calculated as the difference between the amount outside the upstream boundary and the amount outside the downstream boundary. For example, the fraction of mass originally present in the source layer that ends up in the layer adjacent to the source layer in time t is Df(z′=0.5dz, t) -Df(z′=1.5dz, t). The integrated amounts of material that have crossed the layer boundaries and the amount that remains in the source layer after time t are given directly by Equations F-2-20 and F-2-21, respectively, and only have to be computed once for fixed time steps and layer thicknesses.

The amount of mass that diffuses from a given layer out the lower boundary of the soil column in time t can be tracked by multiplying Df(z’,t), evaluated at the point where, for that layer, z’ is at the bottom of the soil column ($z = z_{sc}$) by (C_{T0} ·dz) for that layer. Diffusive losses across the bottom boundary from all the soil column layers are summed to get the total diffusive (aqueous and gaseous phase) loss across the bottom boundary, $M_{lchd}(t)$ (g/m^2) in time t.

$$M_{vol}(t) \;=\; M_0(t) \,\cdot\, \frac{D_{E,a}}{D_E} \qquad \text{(F-2-22)}$$

Likewise, by summing the total diffusive losses across the upper boundary from each layer, the total diffusive loss out the top of the soil column, $M_0(t)$ (g/m^2), is determined. The volatilization loss from the surface of the soil column, $M_{vol}(t)$ (g/m^2), is assumed to be due to gaseous phase diffusion only and is determined by

where ($D_{E,a}/D_E$) is the fraction of the total diffusive loss from any layer that is due to diffusion in the gaseous phase in the soil. It is assumed that mass is not lost across the top boundary due to diffusion in the aqueous phase in the soil. In order to maintain mass balance, mass calculated to be lost this way is added back into the top layer in the soil, augmenting the total contaminant concentration there by
($M_0(t) \cdot D_{E,w}/D_E$). This method of obtaining $M_{vol}(t)$ is an approximation, justified on the basis of computational efficiency. A more rigorous treatment would include a mathematical transition

layer across which diffusion from the soil to the air occurs. However, use of such a transition layer would require a more computationally intensive solution technique as well as specification of the thickness of the transition layer. Without this approximation (i.e., if $M_{vol}(t) = M_0(t)$), $M_{vol}(t)$ could be greater than zero for non-volatile contaminants ($D_a = H' = 0$) due to the possible contribution to M_0 from the aqueous phase diffusive flux. It is believed that this method of estimating $M_{vol}(t)$ and augmenting the total contaminant concentration in the surface layer, while not theoretically rigorous, does represent a reasonable approximation of what actually occurs. That is, contaminant mass diffuses to the surface in both the aqueous and gaseous phases. While the contaminant mass in the gas phase volatilizes out the surface of the soil column, the contaminant mass in the aqueous phase is left behind, concentrating the contaminant mass in surface soil (approximated here as the surface soil column layer).

To account for decay, Equation F-2-15 is solved readily by the technique of separation of variables (Jost,1960). It has a solution of the form

$$C_T = C_{T0} \exp(-kt) \qquad \text{(F-2-23)}$$

As Equation 2-23 is applied to each layer, the amount of mass lost due to first-order decay in time, t, M_{loss} (g/m^2), can be tracked using:

$$M_{loss}(t) = \left(1 - \exp(-kt)\right) C_{T0} \cdot dz \qquad \text{(F-2-24)}$$

Where multiple first-order loss processes may occur (i.e., $k = \sum k_j$), the fraction of initial mass present lost due to each process j is determined using:

$$M_{loss,j}(t) = \frac{k_j}{k} M_{loss}(t) \qquad \text{(F-2-25)}$$

A potential difficulty with the layer solution is that the convection of material leads to an artificial numerical diffusion because the concentration within each layer can only be expressed as an average value. This component of numerical diffusion can be avoided completely if the contents of each layer are transferred completely to the next layer at the end of each time step by making the time step equal to the layer thickness divided by the effective velocity, V_E.

$$dt = \frac{dz}{V_E} \qquad \text{(F-2-26)}$$

The contaminant mass in the bottom layer is convected out of the lower boundary. Total mass lost due to advection in dt, M_{lcha} (g/m^2), is simply C_{T0} in the lowest soil column layer times dz.

F-2.4.2.1 <u>Boundary Conditions</u>. Zero concentration is assumed at the upper boundary of the soil column. This is consistent with the assumption that the air is a sink for volatilized contaminant mass, but requires the approximate method for estimating $M_{vol}(t)$ described above.

At the lower boundary of the soil column, the flexibility exists with this solution technique to specify a value between zero and one for the ratio (bcm) of the total contaminant concentration in the soil directly below the modeled soil column and in the soil column. A ratio of one (bcm=1) corresponds to a zero gradient boundary condition ($dC_T/dz=0$). A ratio of zero (bcm=0) corresponds to a zero concentration boundary condition ($C_T=0$).

When bcm is equal to zero, diffusive fluxes at the upper and lower boundaries of the soil column are calculated directly as described above. When bcm is greater than zero, a reflection of the soil column is created. The contaminant concentrations in the reflected soil column cells are set equal to bcm times the contaminant concentration in the soil column cell being reflected (i.e., the concentration in the first cell of the reflected soil column is set to bcm times the contaminant concentration in the lowest cell of the actual soil column). The upward diffusive flux from the reflected soil column cells: (1) offsets the diffusive flux out the lower boundary of the soil column, (2) increments the contaminant concentrations in the soil column, and (3) augments the diffusive flux out the upper boundary of the soil column. Hence, when bcm is equal to one (the no diffusion boundary condition), the downward diffusive flux out the bottom boundary of the soil column is completely offset by the upward diffusive flux across the same boundary from the reflected soil column cells.

F-2.4.2.2 <u>Algorithm</u>. The general algorithm for applying the individual solutions to Equations F-2-13 through F-2-15 is as follows for a homogeneous soil column and an averaging time period of 1 year.

1. Specify

   - Lower boundary condition multiplier (bcm)
   - Initial conditions in soil column (C_{T0})
   - Soil column size (z_{sc}) and properties (ρ_b, foc, η, K_{sat}, SM_b)
   - First-order loss rates (k_j)
   - Chemical properties (K_{oc}, H', D_a, D_w)
   - Upper and lower averaging depths (z_{ava}, z_{avb}).

2. Calculate/read K_d. K_d is internally calculated for organics, and read as a user input for metals.

3. Subdivide the soil column into multiple layers of depth, dz, that are an integral fraction of z_{sc}. Calculate the total number of layers, $N_{dz} = z_{sc}/dz$.

4. Get annual average infiltration rate (I) for the year.

5. Calculate θ_w, θ_a, K_{TL}, D_E, V_E.

6. Calculate the time to cross a single layer at velocity V_E (Equation F-2-26). This is the convection-based computing time step, dt. See also note below.

7. Evaluate the fraction of mass that remains in a layer (Equation F-2-23) and that diffuses across layer boundaries z′= 0.5dz, 1.5dz, 2.5dz,... (Equation F-2-22) at t=dt. (These fractions are constant for a fixed dt.)

8. Calculate the amount of mass present in the soil column at the beginning of the year (M_{col1}, g/m^2).

9. Initialize cumulative mass loss variables (M_{vol}, M_{lchd} , M_{lcha}, $M_{loss,j}$).

10. Diffusion. Adjust the concentration profile to reflect diffusive fluxes for one time step. This redistributes material throughout the whole soil column. Increment M_{vol} and M_{lchd}.

11. First-order losses: Allow the concentration profile to decay in each layer (Equation F-2-25) for one time step. Increment mass lost due to all applicable first- order loss processes, j, $M_{loss,j}$ (Equation F-2-23).

12. Convection: Propagate the concentration profile one layer downstream. Increment M_{lcha}.

13. Repeat Steps 10 through 12 until it is time to add and/or remove contaminant mass (go to Step 14) or until the end of the year (go to Step 15).

14. To account for the addition of contaminant mass, update the contaminant concentrations in the affected layers. Track total mass added (M_{add}, g/m^2) and/or removed (M_{rem}, g/m^2). Begin the algorithm again at Step 10.

15. At end of the year, calculate/report:

- Total mass in the soil column (M_{col2}, g/m^2)
- Mass balance error for the year (M_{err}, g/m^2):

$$M_{err} = M_{col2} - M_{col1} - M_{add} + M_{rem} + M_{vol} + M_{lcha} + M_{lchd} + \sum_j M_{loss,j} \quad \text{(F-2-27)}$$

- Annual average total concentration in surface layer
- Annual, depth-weighted average total concentration ($z_{ava} \le z \le z_{avb}$)
- Annual average volatilization flux (J_{vol}, g/m^2/d)
- Annual average leaching flux (J_{lch}, g/m^2/d):

$$J_{vol} = \frac{M_{vol}}{365} \quad \text{(F-2-28)}$$

$$J_{lch} = \frac{M_{lchd} + M_{lcha}}{365} \qquad \text{(F-2-29)}$$

16. Begin the algorithm again at Step 4 until mass is no longer added to the soil column and mass has been depleted from the soil (i.e., M_{col2} =0).

Note that the convection time step cannot be any greater than the length of time between mass additions or removals (e.g., waste applications in an LAU). For example, if contaminant mass is added every 30 days, this is the maximum time step, regardless of how small the velocity is. When dt is limited in this fashion, the number of time steps required before a convective transfer can take place is determined, and the convective transfer step is performed on an "as-needed" basis. If the calculated convective time step is 60 days, in this example, the convective transfer would occur every other time step. This will result in a temporal distortion of the concentrations within the layers, but over several steps and, by the end of the year, preliminary module runs show that the effects average out.

The primary means by which the performance of the solution algorithm is checked is via the annual mass balance check (Equation F-2-27) to ensure that the change in mass in the system over the year is equal to the difference between mass additions and losses. If M_{err} is greater than 10^{-8} g/m^2, a message is written to the warning file.

F-2.5 Limitations Related to Use of GSCM

The following limitations are noted for the GSCM:

- The GSCM was developed originally for organic contaminants, and assumes that the partition efficient, K_d, is linear and is estimated as the product of K_{oc} and f_{oc}. Partitioning for metals involves complex chemistry, including the dynamic effects of aqueous-phase contaminant concentration, precipitation, dissolution, adsorption/desorption, and the geochemistry of media (e.g., oxidation-reduction conditions) on the value of K_d and the fate and transport behavior of metals in general. This complexity is not modeled by the GSCM for metals partitioning; rather, K_d is externally provided as a randomly sampled value by the chemical properties processor (CPP).

- With organic contaminants, the GSCM is not applicable if nonaqueous phase liquid (NAPL) is present. Similarly, with metals, the presence of a precipitate is not allowed. The presence of NAPL (precipitate) is determined by comparing C_T to the theoretical maximum contaminant concentration in soil without NAPL (precipitate), determined by the aqueous solubility, saturated soil-gas concentration of the contaminant, and the sorptive capacity of the soil. The limit on C_T is estimated using

$$C_T < K_{TL} C_L^{sol} \qquad \text{(F-2-30)}$$

where C_L^{sol} (g/m^3) is the aqueous solubility. It is expected that in most circumstances exit levels will be sufficiently low that the presence of NAPL (precipitate) would be precluded.

- The algorithm is being applied to develop source release estimates on an annual average basis, to support estimation of chronic (long-term average) risk estimates. Some of the inputs used (e.g., infiltration) are long-term annual average estimates, while others are annual average. Accordingly, the outputs are not strictly applicable to individual years.

- The module allows consideration of only one contaminant at a time and does not simulate fate and transport of reaction products in its current form. With further module development, it would be possible to track the production of reaction products in each soil column layer and use basically the same algorithm that is used for the parent compound to module the fate of reaction products.

- The solution technique used, sequential solutions to the three-component differential equations of the governing differential equation, allows computational efficiency. However, systematic errors could result from the choice of the order in which these solutions are applied. The size of the error would be dependent on the relative loss rates associated with the three processes. For example, if the first-order loss rate due to degradation were high and losses due to degradation were calculated first, then less contaminant mass would be available for diffusive and advective losses. The current algorithm prioritizes diffusive losses since the diffusion equation is solved first. This is followed by first-order losses and advection in that order.

- As discussed, a boundary condition at the soil/air interface of $C_T = 0$ was assumed in developing this solution technique. This is consistent with the assumption that the air is a sink for volatilized contaminant mass. However, as discussed in Section F-2.4.1, because the diffusion coefficient used in the governing equation (Equation F-2-8) includes diffusion in both the air and aqueous phases of the soil, contaminant mass that is transported upward in the soil column via diffusion can include mass in both the air and aqueous phases. While this is appropriate within the soil where the ratio of air to water is relatively constant, the assumption breaks down at the soil/air interface itself. To account for the fact that contaminant mass in the aqueous phase should not be lost out of the surface of the soil column—which, for example, would lead to nonzero volatilization fluxes for nonvolatile contaminants ($D_a = H' = 0$)— the volatilization flux at the surface is assumed to include only the diffusive flux due to gas-phase diffusion. Mass estimated to be lost from the surface due to aqueous-phase diffusion is added back into the surface soil column layer, augmenting the contaminant concentration there and maintaining mass balance. This is an approximation, justified on the basis of computational efficiency; nonetheless, the approximation should be in reasonable agreement with what actually occurs in nature.

F-3.0 Local Watershed/Soil Column Module

F-3.1 Introduction

The LAU source emissions module is required to provide annual average contaminant mass flux rates from the surface of the LAU and its subsurface interface with the vadose zone, total contaminant concentration in the surface material, and contaminant mass emission rate due to particulate emissions. In addition, because these LAUs are on the land surface, they are integral land areas in their respective watersheds and, consequently, are not only affected by runoff and erosion from upslope land areas, but also affect downslope land areas through runoff and erosion. Indeed, after some period of time during which runoff and erosion has occurred from a LAU, the downslope land areas will have been contaminated and their surface concentrations could approach (or conceivably even exceed long after LAU operation ceases) the residual chemical concentrations in the LAU at that time. Thus, after extensive runoff and erosion from a LAU, the entire downslope surface area can be considered a “source” and it becomes important to consider these “extended source” areas in the risk assessment. It is for this reason that a holistic modeling approach has been taken with the LAU source module to incorporate them into the watershed of which they are a part.

The watershed including an LAU is termed here the “local” watershed, and is illustrated in Figure F-3-1. A local watershed is defined as that drainage area that just contains the LAU (or a portion thereof — there can be multiple local watersheds) in the lateral (perpendicular to runoff flow) direction, and in which runoff occurs as overland flow (sheet flow) only. Thus, a local watershed extends downslope only to the point that runoff flows and eroded soil loads would enter a well-defined drainage channel, e.g., a ditch, stream, lake, or some other waterbody. The sheet-flow-only restriction is based on the assumption that any subareas downslope of the LAU subarea are subject to chemical contamination from the LAU through overland runoff and soil erosion.

Figure F-3-2 illustrates how the local watershed is conceptualized for the combined Local Watershed/Soil Column Module, that is, as a two-dimensional, two-medium system. The dimensions are longitudinal, i.e., downslope or in the direction of runoff flow, and vertical, i.e., through the soil column. The media are the soil column and, during runoff events, the overlying runoff water column. The local watershed is assumed to be made up of, in the longitudinal direction, an arbitrary number of land subareas that may have differing surface or subsurface characteristics, e.g., land uses, soil properties, and chemical concentrations. For example, subarea 2 might be a LAU, subarea 1 would then represent an upslope area, and subareas 3 through N would be downslope buffer areas extending to the waterbody.

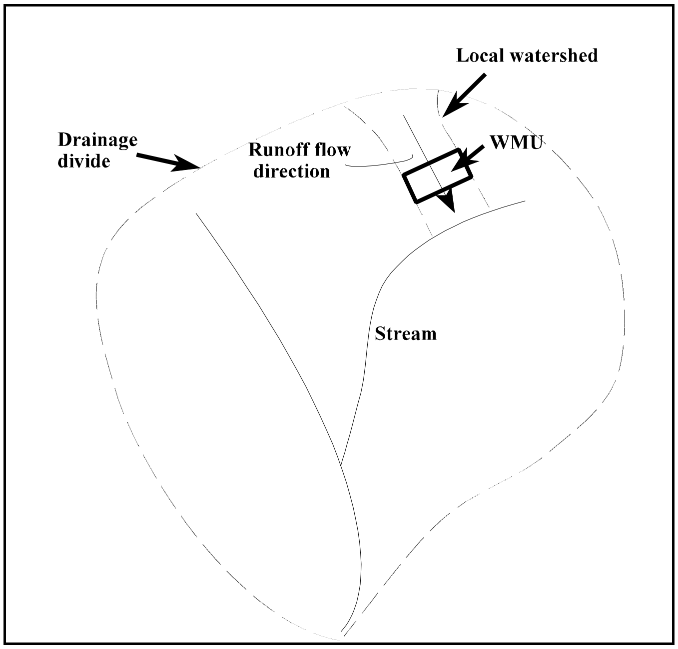

Figure F-3-1. Local watershed containing WMU.

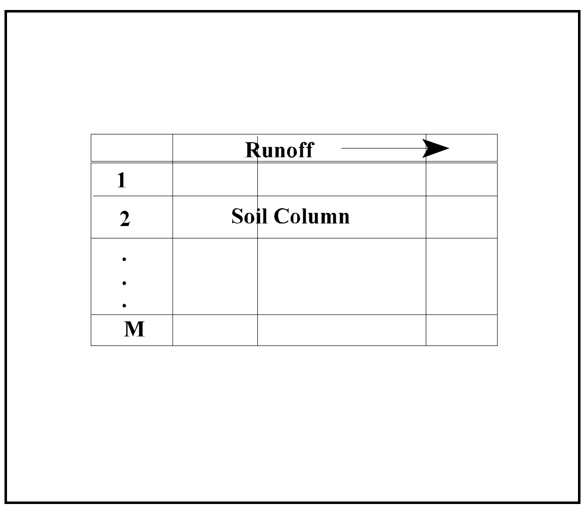

Figure F-3-2b. Cross-section view.

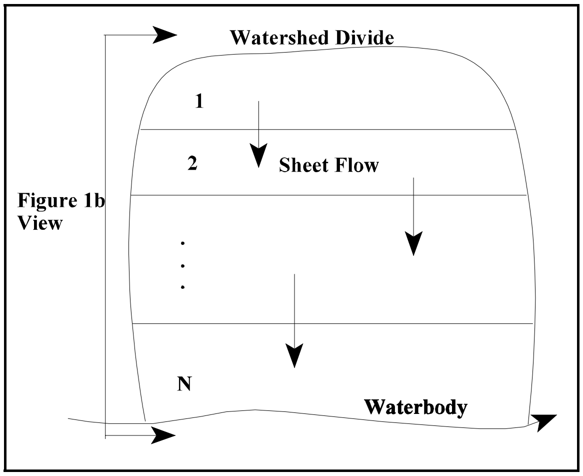

Figure F-3-2a. Local watershed.

F-3.2 Hydrology

F-3.2.1 Overview

Hydrologic modeling is performed to simulate watershed runoff and ground water recharge (termed here "infiltration"). The hydrology module is based on a daily soil moisture water balance performed for the root zone of the soil column. At the end of a given day, t, the soil moisture in the root zone of an arbitrary watershed subarea, i, is updated as

$$SM_{i,t} = SM_{i,t-1} + P_t + RO_{i-1,t} - RO_{i,t} - ET_{i,t} - IN_{i,t} \qquad \text{(F-3-1)}$$

where

$SM_{i,t}$	=	soil moisture (cm) in root zone at end of day t for subarea i
$SM_{i,t-1}$	=	soil moisture (cm) in root zone at end of previous day for subarea i
P_t	=	total precipitation (cm) on day t
$RO_{i-1,t}$	=	storm runoff (cm) on day t coming onto subarea i from i-1
$RO_{i,t}$	=	storm runoff (cm) on day t leaving subarea i
$ET_{i,t}$	=	evapotranspiration (cm) from root zone on day t for subarea i
$IN_{i,t}$	=	infiltration (ground water recharge) on day t (cm) for subarea i.

Precipitation is undifferentiated between rainfall and frozen precipitation; that is, frozen precipitation is treated as rainfall. Runoff, evapotranspiration, and infiltration losses from the root zone are discussed in subsequent sections. The equations presented in these sections refer to "day t and subarea i" in accordance with the above water balance equation (Equation F-3-1).

F-3.2.2 Runoff

F-3.2.2.1 **Governing Equations.** Daily runoff is based on the Soil Conservation Service's (SCS) widely used "curve number" procedure (USDA, 1986) and is a function of current and antecedent precipitation and land use. Land use is considered empirically by the curve numbers, which are catalogued by land use or cover type (e.g., woods, meadow, impervious surfaces), treatment or practice (e.g., contoured, terraced), hydrologic condition, and hydrologic soil group.

Runoff depth is calculated by the SCS procedure as

$$RO = \frac{(P - Ia)^2}{P - Ia + S} \quad for \; P \geq Ia \qquad \text{(F-3-2)}$$

where

RO = runoff depth (cm)
P = precipitation depth (cm)
Ia = initial abstraction (threshold precipitation depth for runoff to occur) (cm)
S = watershed storage (cm).

By experimentation with over 3,000 soil types and cover crops, the SCS developed the following relationships for watershed storage as a function of CN and initial abstraction as a function of storage.

$$S = \frac{2540}{CN} - 25.4 \qquad \text{(F-3-3)}$$

$$Ia = 0.2S \qquad \text{(F-3-4)}$$

Combining Equations F-3-2 and F-3-3 results in

$$RO = \frac{(P - 0.2S)^2}{P + 0.8S} \quad for \; P \geq 0.2S \qquad \text{(F-3-5a)}$$

$$RO = 0 \quad for \; P < 0.2S \qquad \text{(F-3-5b)}$$

where S is given by Equation 3-3. For impervious surfaces (CN = 100), it can be seen that RO = P.

Three antecedent moisture classes (AMCs) have been defined for use in adjusting the SCS curve numbers as shown in Table F-3-1. The growing season is assumed to be June through August (Julian Day 152 to 243) throughout the country.

Table F-3-1. Antecedent Moisture Classes for SCS Curve Number Methodology

AMC Class	Total 5-day Antecedent Rainfall (cm)	
	Dormant Season	**Growing Season**
I	< 1.3	< 3.6
II	1.3 to 2.8	3.6 to 5.3
III	> 2.8	> 5.3

Source: U.S. EPA et al. (1985).

Curve numbers are typically presented in the literature assuming average antecedent moisture conditions (AMC II) and can be adjusted for drier (AMC I) or wetter (AMC III) conditions as (Chow et al., 1988).

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)} \qquad \text{(F-3-6)}$$

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)} \qquad \text{(F-3-7)}$$

These adjustments have the effect of increasing runoff under wet antecedent conditions and decreasing runoff under dry antecedent conditions, relative to average conditions.

F-3.2.2.2 Implementation. Recall the conceptual module for the local watershed (Figure F-3-2), where the subareas may have different land uses and different curve numbers for each subarea. Equation F-3-5 is nonlinear in the curve number; therefore, the method by which the SCS procedure is applied to multiple subareas can make a significant difference in the resulting cumulative runoff values for downslope subareas. There are essentially two options for implementing the procedure. The first is based on runoff **routing** from each subarea to the next downslope subarea. That is, the runoff depth from subarea 1 would first be calculated from Equation F-3-5. The cumulative runoff depth from subareas 1 and 2 would then be calculated by applying Equation F-3-5 to subarea 2 and adding (routing) the runoff depth from subarea 1. This would be repeated for all subareas. This method is **not** appropriate for the sheet flow assumption of the local watershed and can give much higher cumulative runoff depths (volumes) than would actually occur under the sheet flow assumption. (The implicit assumption of the routing method is that the subareas are not hydrologically connected, e.g., runoff from subarea 1 is captured in a drainage system (non-sheet-flow) and diverted directly to the watershed outlet without passing through/over downslope subareas.)

A different, nonrouting method is appropriate for implementing the SCS procedure for the local (sheet flow) watershed. The method is based on determining composite curve numbers and is analogous to the nonsoil routing implementation of the Universal Soil Loss Equation (USLE) soil erosion module presented in Section 3.3. The methodology used for implementing this method is illustrated by the following pseudo-code.

FOR i = 1,...,N (subareas)
- $CNeff_i$ = area-weighted composite CN_i for all subareas j, j=1,...,i
- Calculate S_i from equation (3.2.2-2) using $CNeff_i$
- Calculate RO_i from equation (3.2.2-1) using S_i. (RO_i is the ***average*** runoff depth over all upslope subareas j, j=1,...,i).
- Calculate $Q_i = RO_i*WSA_i$ where Q_i is cumulative runoff volume and WSA_i is cumulative area.
- IF i = 1 THEN
- $H1_i = RO_i$ where $H1_i$ is subarea-specific runoff depth for subarea i, i.e. $RO_i - RO_{i-1}$
- ELSE
- $H1_i = (Q_i - Q_{i-1})/A_i$ where A_i is subarea-specific surface area
- IF $H1_i < 0$ THEN $H1_i = 0$
- END IF

NEXT i

F-3.2.3 Evapotranspiration

Potential evapotranspiration (PET) is the demand for soil moisture from evaporation and plant transpiration. When soil moisture is abundant, actual evapotranspiration (ET) equals PET. When soil moisture is limiting, ET will be less than PET. The extent to which it is less under limiting conditions has been expressed as a function of PET, available soil water (AW), and available soil water capacity (AWC) as (Dunne and Leopold, 1978).

$$ET = PET * f\left(\frac{AW}{AWC}\right) \quad \text{(F-3-8)}$$

$$AW = (SM - WP)\frac{DRZ}{100} \quad \text{(F-3-9)}$$

$$AWC = (FC - WP)\frac{DRZ}{100} \qquad \text{(F-3-10)}$$

where

f = a functional relationship of the arguments.

and

WP = soil wilting point (% volume), which is the minimum soil moisture content that is available to plants. (Plants can exert a maximum suction of approximately 15 atmospheres. The wilting point is that moisture that would not be available at 15 atmospheres.)

FC = soil field capacity (% volume), which is the maximum soil moisture content that can be held in the soil by capillary or osmotic forces. Soil moisture above the field capacity is readily drained by gravity.

$$ET = \min[PET,\ PET(\frac{SM - WP}{FC - WP})] \qquad \text{(F-3-11)}$$

DRZ = depth of the root zone (cm).

The functional relationship in Equation 3-8 is assumed here to be linear, so that ET (cm) is calculated as

PET is estimated as described below.

The more theoretically based modules for daily evapotranspiration (e.g., the Penman-Monteith equation [Monteith, 1965]) rely on the availability of significant daily meteorological data, including temperature gradient between surface and air, solar radiation, windspeed, and relative humidity. All of these variables may not be readily available for all application sites. Therefore, a less data-demanding module, the Hargreaves equation (Shuttleworth, 1975), is proposed. As compared with the most theoretical modules, some accuracy will be sacrificed. Nonetheless, the Hargreaves method, which is primarily temperature-based, has been shown to provide reasonable estimates of evaporation (Jensen, 1990)—presumably because it also includes an implicit link to solar radiation through its latitude parameter (Shuttleworth, 1993).

The Hargreaves equation is

$$PET = 0.0023 S_0 \Delta_T^{0.5} (T + 17.8) * 0.1 \qquad \text{(F-3-12)}$$

where

PET = potential evapotranspiration (cm/d)

T = mean daily air temperature (° C)

Δ_T = difference in mean monthly maximum and mean monthly minimum air temperature

S_0 = water equivalent of extraterrestrial radiation (mm/d) and is given as (Duffie and Beckman, 1980)

$$S_0 = 15.392 d_r (\varpi_s Sin\phi Sin\theta + Cos\phi Cos\theta Sin\varpi_s) \qquad \text{(F-3-13)}$$

where

$$d_r = 1 + 0.033 Cos(\frac{2\pi}{365} J) \qquad \text{(F-3-14)}$$

and

J = Julian day
ϖ_s = sunset hour angle (radians) given by

$$\varpi_s = Arccos(-Tan\phi Tan\theta) \qquad \text{(F-3-15)}$$

ϕ = site latitude (positive for northern hemisphere, negative for southern)

θ = solar declination (radians) given by

$$\theta = 0.4093 Sin(\frac{2\pi}{365} J - 1.405) \qquad \text{(F-3-16)}$$

F-3.2.4 Infiltration (Recharge)

Soil moisture in excess of the soil's field capacity (FC), if not used to satisfy ET, is available for gravity drainage from the root zone as infiltration to subroot zones (Dunne and Leopold, 1978). This infiltration rate will, however, be limited by the root zone soil's saturated hydraulic conductivity. Accordingly, infiltration is calculated as

$$IN = \min[Ksat,\ (SM - FC)\frac{DRZ}{100}] \qquad \text{(F-3-17)}$$

where

IN = infiltration rate (cm/d)
Ksat = saturated hydraulic conductivity (cm/d).

In the event that infiltration is limited by Ksat, the hydrology algorithm includes a feedback loop that increases the previously calculated runoff volume by the amount of excess soil moisture, i.e., the water above the field capacity that exceeds Ksat. This adjustment is made to preserve water balance and is based on the assumption that the runoff curve number method, which is only loosely sensitive to soil moisture (through the antecedent precipitation adjustment) has admitted more water into the soil column than can be accommodated by ET, infiltration, and/or increased soil moisture. After the runoff is increased for this excess, the ET, infiltration, and soil moisture are updated to reflect this modification and preserve the water balance.

F-3.3 Soil Erosion

F-3.3.1 General

The Soil Erosion Module is based on the Universal Soil Loss Equation, an empirical methodology (see, e.g., Wischmeier and Smith, 1978) based on measured soil losses for experimental field-scale plots in the United States for some 40,000 storms. The USLE predicts sheet and rill erosion from hillsides upslope of defined drainage channels, such as streams. It does not predict streambank erosion. Let SL (kg/m^2-time) denote the eroded soil flux (unit load) from a hillside area over some time period. SL is predicted by the USLE as the product of six variables:

$$SL = R \times K \times C \times P \times LS \times Sd \qquad \text{(F-3-18)}$$

These variables are discussed below.

R is the rainfall factor with units of 1/time. The rainfall factor accounts for the erosive (kinetic) energy of falling raindrops, which is essentially measured by rainfall intensity. The kinetic energy of an individual storm times its maximum 30-minute intensity is sometimes called the erosivity index (EI) factor. R factors have been compiled throughout the United States on a long-term annual average basis. These R factors were developed by cumulating these individual storm EI factors.

$$LS_i = (.045X_i)^b(65.41Sin^2\theta + 4.56Sin\theta + .065) \qquad \text{(F-3-19)}$$

K is the soil erodibility factor with units of kg/m^2. Soil erodibility is an experimentally determined property and is a function of soil type, including particle size distribution, organic content, structure, and profile. K values are reported by soil type in the literature.

C is the dimensionless "cropping management" factor that varies between 0 and 1. It accounts for the type of cover (e.g., sod, grass type, fallow) on the soil. C is used to correct the USLE prediction relative to the cover type for which the experimentally determined K values were measured (fallow).

$$\theta = \arctan(S/100) \qquad \text{(F-3-20)}$$

P is the dimensionless practice factor and accounts for the effect of erosion control practices, e.g., contouring or terracing. P is never negative, but could be greater than 1.0 if land practices actually encourage erosion relative to the original experimental plots on which K was measured.

LS is the combined "length-slope"factor and is given by (U.S. EPA, 1985b) as where

X_i = flow distance (m) from the point at which sheet flow originates (the upslope drainage divide) to the point of interest on the hillside.

θ = slope angle (degrees), where θ may be calculated from percent slope, S, as

and b, the exponent, is determined as a function of S as:

b = 0.5, if S > .05
b = 0.4, if .035 <= S <= .045
b = 0.3, if .01 <= S < .035
b = 0.2, if S < .01.

LS increases with increasing flow distance because runoff quantity generally increases with distance. It increases with slope because runoff velocity generally increases with slope.

Sd is the "sediment delivery ratio," which estimates the fraction of onsite eroded soil that reaches a particular downslope or downstream location in the subbasin (Shen and Julien, 1993). The sediment delivery ratio is here used to account for deposition of eroded soil from the local watershed in ditches, gullies, or other depressions. Vanoni (1975) developed the sediment delivery ratio as a function of watershed drainage area. That formulation is

$$Sd = a \times A^{-.125} \qquad \text{(F-3-21)}$$

where

Sd	=	sediment delivery ratio (dimensionless)
A	=	subbasin area (m^2)
a	=	normalized to give Sd = 1.0 for an area of 0.001 mi^2 as per Vanoni (1975). (For area in m^2, a = 2.67.).

F-3.3.2 MUSLE Implementation

The USLE is implemented on a storm event basis, i.e., the "modified" USLE (MUSLE) is used. This implementation requires determining an R value (with units of 1/day) for each daily storm event that specifies the erosivity of that individual storm. Let the storm-event-specific R value be denoted as R_t for storm event t, so that the pseudo-code presented above is applied for a given daily storm event. Several methods have been proposed for estimating R_t and are summarized below. Method 4 is used in this application.

Method 1 — R_t as a Function of Total Daily Precipitation. This method (Richardson et al., 1983) predicts R_t as a function of total daily precipitation by means of a two-parameter regression module (a power function). The parameters were estimated by Richardson et al. from long-term records of daily "erosivity index" (EI, which is operationally equivalent to R) and total daily precipitation for 11 sites, all located east of the Rocky Mountains. (Western sites were not included in the data "... so that the relationships would not be influenced by the complex orographic effects of mountainous terrain.") It was determined that one of the parameters (the exponent) was statistically invariant with respect to site, while the other parameter did vary by site. In addition, the variance of the prediction error was also found to be a predictable function of site location. Thus, tables relating the varying regression parameter and its prediction error variance were generated from the regression data by site. Several methods were considered for correlating those 11 sites to western sites (e.g., correlation by average storm intensity), but were rejected as either too data-intensive or too uncertain.

Method 2 — R_t as a Function of Storm Runoff. This method (used by PRZM) predicts R_t as a function of daily storm event runoff and peak storm runoff (Williams, 1975). Although total runoff from the (daily) storm event is available (from the SCS Curve Number module), the shape and duration of the runoff hydrograph for the storm is not calculated and, thus, the peak runoff from the storm is not available.

Method 3 — R_t Calculated from Hourly Erosivity Index Values. This method (Wischmeier and Smith, 1978) is the most rigorous MUSLE approach. It is not based on regression analysis of presumed correlated independent variables, but rather predicts R_t directly by aggregating hourly EI calculations over the storm's duration. The EI values are calculated from hourly average rainfall intensity data. This is the method that has been used to estimate long-term annual total R values for the classical (annual total) use of the USLE. Because hourly precipitation data are available from the SAMSON files, this method is feasible. Method 4 below is essentially based on this method, although the method allocates the (published) long-term annual R values down to hourly R (and then up to daily R_t) instead of building up the long-term annual R from the hourly data.

Method 4 — R_t Allocated from Published Long-Term Annual Total R Values. Because published values of long-term annual total R values exist in the form of isopleths across the country, it seems appropriate to use these annual total R data and disaggregate them down to a daily basis for the MUSLE. This is the method used for the LAU. Pseudo-code to implement this method is:

Given: Long-term annual total R, Rann, for a site.
Given: Number of years in the simulation, NYR.
Given: Hourly time series of precipitation amounts for the complete record of NYR years.

1. Compute cumulative R over record, R_{total} = Rann x NYR

2. Compute cumulative precipitation over NYR years, PPT_{total}

3. For each hourly precipitation value in the record, allocate R_{total} to that hour based on the fraction of PPT_{total} represented by the hourly precipitation. Denote an hourly allocation as R_{hour}.

4. For each day of the record, cumulate all R_{hour} values to the daily total. The result is R_t for each day of the NYR record.

F-3.3.3 Spatial Implementation

For the local watershed application, the USLE is applied spatially to a hillside that comprises N subareas (see Figure 3-2a). Pseudo-code for this application is:

```
LET CSL_i = cumulative soil load (kg/day) for subarea i, i.e. eroded load from subarea i
and all upslope subareas j, j = 1,...,i
LET WSA_i = cumulative land area (m^2) upslope of and including subarea i

FOR i=1,...,N
        Keff_i = area-weighted K_i for all subareas j, j=1,...,i
        Ceff_i = area-weighted C_i for all subareas j, j=1,...,i
        Peff_i = area-weighted P_i for all subareas j, j=1,...,i
        CSL_i = R*WSA_i*Keff_i*Ceff_i*Peff_i*LS_i*Sd_i
NEXT i
```

The assignment of the sheet-flow distance parameter, X_i, within the LS_i factor (see Equation F-3-19) merits discussion in the context of the "local watershed" conceptual module. This local watershed construct (see Figure F-3-1) was developed to simulate the downslope transport of contaminant due to storm water runoff and soil erosion from the LAU. The use of the USLE equation for estimating soil erosion (and associated chemical load) assumes that runoff is essentially sheet flow and that erosion results from sheet, or, at most, rill (very small channels) erosion; i.e., runoff does not occur in significantly defined drainage channels (e.g., ditches, swales) within the local watershed. The delineation of the sheet-flow-only local watershed is accomplished by geographic information system (GIS) analysis, and a key component of this analysis with respect to the sheet-flow-only assumption is the correct generation of the waterbody network such that the waterbody delineated as lying downslope of the local watershed is in fact the first "defined drainage channel" that the runoff would encounter. That is, runoff upslope of the GIS-defined waterbody is essentially sheet flow, in accordance with the conceptual module and the underlying assumptions of the USLE. The criterion used for terminating (headwater) the GIS-delineated streams is a tributary drainage area of 700,000 m^2, which has been estimated to coincide with "first-order" stream headwaters. Thus, the 700,000-m^2 criterion provides an upper bound on the area of a local watershed.

The issue here, however, is that within this 700,000-m^2 upper bound there is ample opportunity for the length of the sheet-flow path (measured in the direction of the steepest gradient) of any given local watershed to greatly exceed a distance at which one could reasonably expect to maintain sheet-flow conditions; that is, a ditch or swale (but not necessarily a first-order stream) would have been encountered. That distance is dependent on many factors such as slope, soil type, and runoff intensity, but has been estimated to be no more than approximately one-quarter of a mile (400 m) (Wischmeier and Smith, 1978). Indeed, more recent data (Lightle and Weesies, 1998) have suggested even more restrictive limits that vary nonlinearly with slope, e.g., 30.5 m for a slope of 0.5 percent, 91 m for slope of 2 percent and 15 m for slopes exceeding 17 percent. Thus, to the extent that a GIS-delineated flow path distance greatly exceeds a reasonable maximum sheet-flow-only distance, application of the sheet-flow-only module to that entire local watershed becomes inconsistent with what might actually be occurring at that site. The implications of such an inconsistency are the following:

- Soil erosion (and associated contaminant loss) would be overestimated, because erosion is an increasing function of flow distance (see Equation F-3-19).

- Contamination in a downslope buffer would be overestimated. (The runoff/erosion may instead be channeled directly into the waterbody via a ditch or swale before it reaches the buffer area.)

The obvious solution to this issue is to further disaggregate the local watershed into a series of sublocal watersheds, each defined by a flow distance not exceeding the maximum, and apply the module sequentially to each sublocal watershed. There are a number of difficulties associated with this option, however, including:

- The impracticality of implementation in GIS in an automated manner.

- The increased computational burden.

- Is soil/chemical "piped" directly to the waterbody at the outlet of each sublocal watershed or assumed to be deposited in the ditch or swale? If deposited, when would it finally be transported to the waterbody?

- The inherent uncertainty in spatial resolution of the WMU within the local watershed in the first place.

In short, while this solution is appealing from a conceptual point of view, it is believed to be impractical and, indeed, an inappropriate complexity. The resolution used is to simply limit the flow distance to a reasonable maximum when the GIS-delineated distance exceeds that maximum. The conceptual module corresponding to this approach is that the runoff water itself may be diverted by swales or ditches, but the soil and chemical being eroded are maintained on the local watershed surface, to be transported downslope over time across the buffer and into the waterbody. This resolution is environmentally conservative with respect to contamination in the buffer. Depending on the actual residence time of a chemical deposited in a swale or ditch within the local watershed, it is not necessarily conservative with respect to chemical loadings to the waterbody. Nonetheless, mass balance is conserved.

F-3.4 Chemical Fate and Transport

F-3.4.1 Runoff Compartment

F-3.4.1.1 <u>Introduction</u>. A module of chemical and suspended solids concentrations in storm event runoff is presented in this section. The module is based on mass balances of solids and chemical in the runoff and the top soil column layer of thickness dz. The soil compartment is external to this module (see Section F-3.4.2) and results from that compartment are called as needed by the software. A simplifying assumption is made that solids and chemical concentrations in the runoff are at instantaneous steady-state during each individual runoff event, but can vary among runoff events, i.e. a quasi-dynamic approach is used. While assumption of instantaneous steady-state for each storm event is not strictly accurate, it was felt appropriate for the following reasons:

- Run time considerations (i.e., maximize the numerical time step).
- Data will not be available at the temporal scale to accurately track within-storm event conditions (e.g., rainfall hyetographs).
- Because of the anticipated relatively small surface areas of the watershed subareas and the associated relatively small runoff volumes, the actual time to steady-state may not differ significantly from the one day or less implicitly assumed here. (A sensitivity analysis was performed using a dynamic form of the runoff compartment module that suggested relatively little difference in soil concentrations as a function of the steady-state versus dynamic assumption.)
- To the extent that the actual time to steady-state would be greater than 1 day, the module is biased toward overestimating downslope concentrations and waterbody loads (i.e., it is risk-conservative).

Figure F-3-3 presents the conceptual Runoff Quality Module showing the two compartments and the fate and transport processes considered. Development of mass balance equations for solids and chemical follow. (It should be noted that hydrolysis, volatilization, and biodegradation processes are not simulated in the runoff compartment. The percentage of time

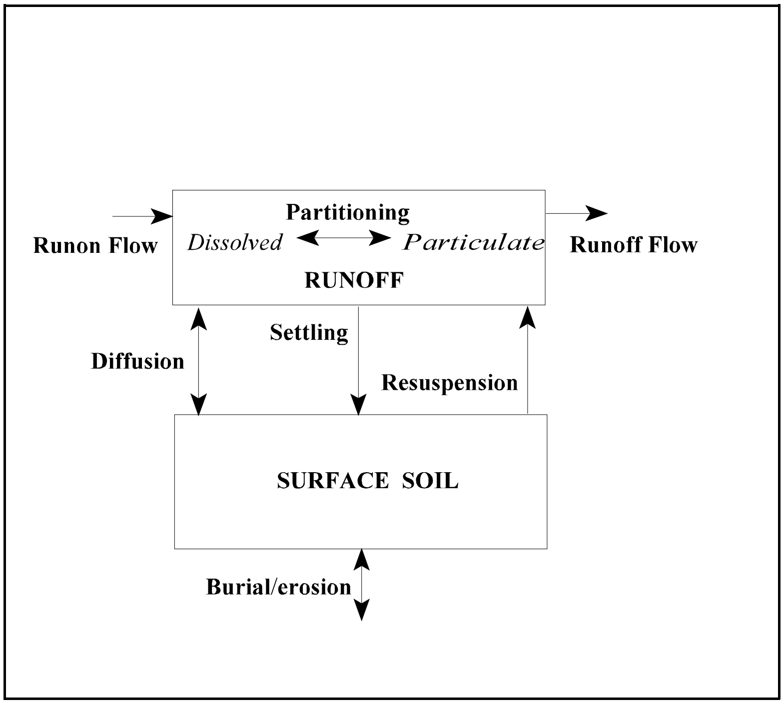

Figure F-3-3. Runoff quality conceptual model.

that runoff is actually occurring will be sufficiently short that any additional losses from these processes should be minimal. In addition, these processes are continuously simulated in the surface layer of the soil column. To also include them in the runoff compartment would be "double-counting.")

F-3.4.1.2 <u>Solids in Runoff Compartment</u>. A steady-state mass balance of solids in the runoff, i.e. suspended solids from erosion, written for arbitrary local watershed subarea i is given by the following equation. (In the subsequent module development, units are presented in general dimensional format, i.e., M(ass)-L(ength)-T(ime), for simplicity of presentation.)

$$0 = Q'_{i-1} m_{1,i-1} - Q'_i m_{1,i} - vs_i A_i m_{1,i} + vr_i A_i m_2 \quad \text{(F-3-22a)}$$

$$Q'_{i-1} = Q_{i-1} + \frac{CSL_{i-1}}{\rho} \quad \text{(F-3-22b)}$$

$$Q'_i = Q_i + \frac{CSL_i}{\rho} \quad \text{(F-3-22c)}$$

where

$m_{1,i}$ = solids concentration (M/L^3) in the subarea i runoff (suspended solids)

m_2	=	solids concentration (M/L^3) in the top soil column layer of subarea i
Q_i	=	runoff flow (L^3/T) leaving subarea i
Q_{i-1}	=	runon flow (L^3/T) from subarea i-1
A_i	=	surface area (L^2) of subarea i
vs_i	=	settling velocity (L/T)
vr_i	=	resuspension velocity (L/T)
Q'_i	=	total runoff flow volume (L^3/T) (water plus solids) leaving subarea i
CSL_i	=	cumulative soil load leaving subarea i (M/T)
ρ	=	particle density (M/L^3) (i.e., 2.65 g/m^3).

(Note: subscript “1" denotes the runoff compartment while “2" denotes the top soil column layer compartment.) The first term in Equation F-3-22a is the flux of soil across the upslope interface of subarea i. The second term is the flux of soil across the downslope interface. The third term is an internal sink of soil due to settling while the fourth term is an internal source due to resuspension.

3.4.1.3 <u>Solids in Soil Compartment</u>. The GSCM does not consider chemical mass transport among watershed subareas due to soil erosion, because it is based on a single subarea only. Therefore, that transport is considered here. The assumption is made that solids mass transport from or to the soil compartment of any given watershed subarea occurs only in a vertical direction, i.e., no downgradient advection of the top soil column layer itself is considered. (This is analogous to the assumption of a stationary sediment bed in stream/sediment quality modules.) The downslope mass transport of soil occurs due to vertical erosion or resuspension of soil followed by advective transport of the soil in the runoff water as suspended solids. The transport is described in terms of three parameters — settling, resuspension, and burial/erosion velocities. Under the assumption of no advective transport of the soil column layer, the steady-state mass balance equation for the surficial soil layer is

$$0 = vs_i m_{1,i} A_i - vr_i m_{2,i} A_i - vb_i m_{2,i} A_i \qquad \text{(F-3-23)}$$

where

vb_i = burial/erosion velocity (L/T).

The first term of Equation (F-3-23) is a source of soil mass to the surficial soil column layer due to settling from the overlying runoff water. The second term is a sink from resuspension. The third term is either a source or a sink depending on the sign of the burial/erosion velocity as described subsequently.

Consider the solids balances in the runoff and soil compartments, Equations F-3-22 and F-3-23, respectively. These two equations involve three parameters—vs, vr, and vb—and two solids concentrations—m_1 and m_2. Which of these five variables is known for arbitrary subarea i? It can be assumed that the solids concentration in the soil (m_2) is a known value — it is simply the bulk soil density. Consider now the suspended solids concentration in subarea i, $m_{1,i}$. From the Soil Erosion Module, the total solids mass fluxes moving across both the upslope and downslope interfaces of subarea i are known, and these two fluxes are, respectively, the first two terms on the right side of Equation F-3-22 $m_{1,i}$ can then be determined as

$$m_{1,i} = CSL_i / Q'_i \quad \text{(F-3-24)}$$

where CSL_i is the cumulative soil load leaving subarea i, as determined by the Soil Erosion Module, and Q'_i is the cumulative runoff flow volume (including solids' volume) leaving subarea i, as determined by the Runoff Quantity Model. Therefore, because the soil concentration (m_2) is assumed to be known and the Soil Erosion and Runoff Quantity modules can be used to determine the suspended solids concentrations (the $m_{1,i}$), Equations F-3-22 and F-3-23 can now be considered as two equations in three unknowns, vs, vr, and vb.

The settling (vs) and resuspension (vr) parameters reflect processes internal to subarea i, while the burial/erosion parameter (vb) reflects net changes across subarea i and is completely determined by the difference in the soil fluxes entering and leaving subarea i. This can be seen by adding the right-hand-sides of Equations F-3-22 and F-3-23 and setting the result to zero. All terms involving vs and vr cancel, and the burial/erosion velocity is then given by
where CSL_{i-1} and CSL_i denote the soil fluxes into and out of subarea i, respectively, as discussed

$$vb_i = \frac{CSL_{i-1} - CSL_i}{A_i m_2} \quad \text{(F-3-25)}$$

above. From Equation 3-25 it can be seen that, if the soil load entering subarea i (CSL_{i-1}) is greater than the soil load leaving (CSL_i), then the burial/erosion velocity is positive and soil is being deposited (buried). Conversely, as will typically be the case, if the load leaving is greater than the load entering, then the burial/erosion velocity will be negative and erosion is occurring in an upward direction.

Consider now vs and vr. With the net soil flux across the subarea having been determined, Equations F-3-22 and F-3-23 are in fact the same equation—the burial velocity term is explicitly shown in Equation F-3-23 and implicitly shown in Equation F-3-22. Thus, either Equation F-3-22 or F-3-23 represents one equation in two unknowns, vs and vr. If one of these is known, the other can be solved for. Of the two, the resuspension velocity would be very difficult to obtain estimates for, while the settling velocity could be assumed similar to, for example, hindered or compaction settling in sludge thickeners. Accordingly, vr as a function of vs (and vb, which is determined as per Equation F-3-25 is given for subarea i by

$$vr_i = vs_i \frac{m_{1,i}}{m_2} - vb_i \quad \text{(F-3-26)}$$

The settling velocity, vs, is assigned values from a uniform random distribution between the range 0.05 and 1.0 m/d, based on observed settling velocities for "mineral" sludges in sludge thickening experiments.

In summary, because m_2 is assumed known and m_1 is calculated from results of the Soil Erosion and Runoff modules, the solids mass balance equations are used to determine the burial/erosion and resuspension parameters for subsequent use in the chemical (contaminant) model.

F-3.4.1.4 <u>Contaminant in Runoff Compartment</u>. As illustrated in Figure F-3-3, a steady-state mass balance of contaminant in the runoff results in the equation

$$0 = Q'_{i-1} c_{1,i-1} - Q'_i c_{1,i} - vs_i A_i Fp_{1,i} c_{1,i} + vr_i A_i Fp_{2,i} Er_i c_{2,i} + vd_i A_i \left(\frac{Fd_{2,i}}{\Phi_2} c_{2,i} - \frac{Fd_{1,i}}{\Phi_{1,i}} c_{1,i} \right) \qquad \text{(F-3-27)}$$

where

$c_{1,i}$ = total contaminant concentration (particulate + dissolved) in runoff in subarea i (M/L^3)

$c_{2,i}$ = total contaminant concentration in soil (M/L^3)

$V_{1,i}$ = subarea-specific (not cumulative) runoff volume for subarea i (L^3)

$Fp_{1,i}$ = fraction particulate in runoff

$Fd_{1,i}$ = fraction dissolved in runoff ($1-Fp_{1,i}$)

vd_i = diffusive exchange velocity (L/T)

Er_i = enrichment ratio

$\Phi_{1,i}$ = is the porosity of the runoff, calculated as

$$\Phi_{1,i} = 1 - \frac{m_{1,i}}{\rho} \qquad \text{(F-3-28)}$$

$$\Phi_2 = 1 - \frac{m_2}{\rho} \qquad \text{(F-3-29)}$$

where ρ is the density (M/L^3) of suspended solids (e.g., 2.65 g/cm^3).

Φ_2 = soil porosity, calculated as

Note that ϕ_2 is equivalent to porosity (η) in the GSCM.

Equation (F-3-27) can be used to express $c_{1,i}$ as a function of $c_{1,i-1}$ and $c_{2,i}$ as

$$c_{1,i} = \frac{Q'_{i-1} c_{1,i-1} + [vr_i A_i Fp_{2,i} Er_i + vd_i A_i (Fd_{2,i}/\Phi_2)]\, c_{2,i}}{Q'_i + vs_i A_i Fp_{1,i} + vd_i A_i (Fd_{1,i}/\Phi_{1,i})} \quad \text{(F-3-30)}$$

where $c_{2,i}$ is determined by the GSCM as described in Section 2. Determination of the individual terms constituting this equation are described below.

$Fp_{1,i}$ is calculated as (Thomann and Mueller, 1987)

$$Fp_{1,i} = \frac{(k_d/\Phi_{1,i}) m_{1,i}}{1 + (k_d/\Phi_{1,i}) m_{1,i}} \quad \text{(F-3-31)}$$

where

k_d = chemical-specific partition coefficient (L^3/M) (Note: k_d is divided by porosity to attain the porosity-corrected k_d with units of mass per total [liquid plus solids] volume.)

$Fp_{2,i}$ is similarly calculated as

$$Fp_{2,i} = \frac{(k_d/\Phi_2) m_2}{1 + (k_d/\Phi_2) m_2} \quad \text{(F-3-32)}$$

where it can be seen that Fp_2 (and Fd_2) will be constant among all subareas i.

$Fd_{1,i}$ and $Fd_{2,i}$ are then determined as

$$Fd_{1,i} = 1 - Fp_{1,i} \quad \text{(F-3-33)}$$

$$Fd_{2,i} = 1 - Fp_{2,i} \quad \text{(F-3-34)}$$

Under the assumption that resistance to vertical diffusion is much greater in the soil than in the runoff, the diffusive exchange velocity, vd_i, can be expressed as (Thomann and Mueller, 1987, p. 548)

$$vd_i = \frac{Dw}{\Phi_2 Lc} \tag{F-3-35}$$

where

Dw = water diffusivity (L^2/T).
Lc = characteristic mixing length (L) over which a concentration gradient exists; assumed to be the depth of the runoff including the solids (H1'):

$$Lc = H1'_i = \frac{Q'_i}{A_i} \tag{F-3-36}$$

The enrichment ratio, Er_i, is used to account for preferential erosion of finer soil particles — with higher specific surface areas and more sorbed chemical per unit area — as rainfall intensity decreases. That is, large (highly erosive) runoff events may result in average eroded soil particle sizes and associated sorbed chemical loads that do not differ much from the average sizes/loads in the surficial soil column layer. However, less intense runoff events will erode the finer materials and resulting chemical loads could be significantly higher than represented by the average soil concentration. U.S. EPA et al. (1985) give the storm event-specific enrichment ratio as a power function of sediment discharge flux (M/L^2). This formulation results in:

$$Er_i = \frac{a}{(CSL_i/WSA_i)^{0.2}} \tag{F-3-37}$$

where a = 7.39 for CSL_i/WSA_i in kg/ha (U.S. EPA et al., 1985). (CSL_i is the event soil load leaving subarea i and WSA_i is the local watershed surface area from the drainage divide down to and including subarea i.) It should be noted that the enrichment ratio is greater than or equal to 1.0. Should specific values of the sediment discharge (the denominator) result in an enrichment ratio less than 1.0, it is reset to 1.0 in the code.

F-3.4.2 Soil Compartment

The GSCM (see Section F-2.2) is coupled to the Runoff Compartment Module (see Section F-3.4.1) in this section and applied to the several subareas that constitive the sheet flow local watershed of which the LAU or wastepile is an integral part. Continuing the chemical concentration indexing scheme (i.e., subscript “1" denoting runoff compartment, and subscript “2" denoting surficial soil compartment), let the total (dissolved, particulate, and gaseous phase) chemical concentration in the surficial soil column layer of any local watershed subarea i be denoted as $C_{2,i}$. ($C_{2,i}$ is equivalent to C_T in the GSCM description.) From Section F-2.2 (GSCM), the governing differential equation for the surface soil layer of subarea i is

$$\frac{\partial C_{2,i}}{\partial t} = D_E \frac{\partial^2 C_{2,i}}{\partial z^2} - V_E \frac{\partial C_{2,i}}{\partial z} - \Sigma k_j C_{2,i} + ss_i \qquad \text{(F-3-38)}$$

where k_j represents first-order rate constant due to process j not including runoff/erosion processes, i.e., biological decay and hydrolysis and wind/mechanical action. The last term, ss_i, is a source/sink term representing the net effect of runoff and erosion processes on $C_{2,i}$ as illustrated in Figure F-3-3. This term is given by

$$ss_i = \frac{vs_i Fp_{1,i} C_{1,i} - vr_i Fp_{2,i} Er_i C_{2,i} - vd_i\left(\frac{Fd_{2,i}}{\Phi_2} C_{2,i} - \frac{Fd_{1,i}}{\Phi_{1,i}} C_{1,i}\right) - vb_i Fp_2 C_{2,i}}{dz} \qquad \text{(F-3-39)}$$

where vs_i, vr_i, vb_i, and vd_i denote, respectively, the settling, resuspension, burial/erosion and diffusive exchange velocities for subarea i as described in the Runoff Compartment model. Thus, the terms comprising ss_i are, respectively, a source of chemical due to settling from the overlying runoff water, a sink of chemical due to resuspension, and a source or sink (depending on the relative values of $C_{1,i}$ and $C_{2,i}$) due to chemical diffusion from/to the runoff.

(The burial/erosion mechanism introduces a minor mass balance error into the model. The module for surface soil/runoff water fate and transport [Section F-3.4.1] is based on a conceptual module originally developed for use in a stream/sediment application [e.g., Thomann and Mueller, 1987] where the sediment compartment location relative to a reference point below the surface can move vertically ["float"] as burial and erosion occur. In that moving frame of reference, burial/erosion of contaminant does not introduce a mass balance error because, with respect to the modeled sediment, this sink/source of contaminant is **exogenous** to the modeled system, i.e., it is coming from/going to outside of the modeled system. There is internal [endogenous] mass balance consistency within the modeled system. However, the frame of reference is not allowed to float, but is fixed by the elevation of the lower boundary, e.g. top of the vadose zone. Thus, if sorbed chemical is eroded from the surface cell, that surface cell, which is vertically fixed, must have a "source" that is internal to the modeled soil column to compensate for this sink or its internal mass balance is not maintained. The magnitude of this mass balance error is equal to the mass of eroded soil from the surface over the duration of the simulation times its average sorbed chemical concentration. In most cases, this error as a percentage of the total chemical mass in the modeled LAU will be quite small, and that has been confirmed in multiple executions of the module. Conceptually at least, the GSCM could be designed so that, after each runoff event, the surficial soil compartment could decrease or increase in size to accommodate the event's erosion/burial magnitude, while maintaining a fixed vertical reference.

Grouping coefficients of $C_{1,i}$ and $C_{2,i}$, Equation F-3-39 can be rewritten as

$$ss_i = a_i C_{1,i} - b_i C_{2,i} - k_{bu,i} C_{2,i} \quad \text{(F-3-40a)}$$

where

$$a_i = \frac{vs_i Fp_{1,i} + vd_i \dfrac{Fd_{1,i}}{\Phi_{1,i}}}{dz} \quad \text{(F-3-40b)}$$

$$b_i = \frac{vr_i Fp_{2,i} Er_i + vd_i \dfrac{Fd_{2,i}}{\Phi_2}}{dz} \quad \text{(F-3-40c)}$$

$$k_{bu,i} = \frac{vb_i \; Fp_{2,i}}{dz} \quad \text{(F-3-40d)}$$

and $k_{bu,i}$ is the first-order rate constant (1/T) associated with the burial/erosion process.

Using Equation F-3-40, Equation F-3-38 can be rewritten as

$$\frac{\partial C_{2,i}}{\partial t} = D_E \frac{\partial^2 C_{2,i}}{\partial z^2} - V_E \frac{\partial C_{2,i}}{\partial z} - \Sigma k_j C_{2,i} + a_i C_{1,i} - b_i C_{2,i} - k_{bu,i} C_{2,i} \quad \text{(F-3-41)}$$

From Equation F-3-41, it can be seen that $C_{2,i}$ is a function of $C_{1,i}$. Similarly, from Equation F-3-30 of the Runoff Compartment Module, it can be seen that $C_{1,i}$ is a function of $C_{2,i}$. Thus, $C_{2,i}$ and $C_{1,i}$ are jointly determined at any time t by simultaneous solution of their two respective equations.

$C_{2,i}$ at time t can be determined by substitution for $C_{1,i}$. From the Runoff Compartment module (Equation F-3-30). $C_{1,i}$ can be expressed as

$$C_{1,i} = \frac{Q'_{i-1} C_{1,i-1}}{d_{2,i}} + \frac{d_{1,i}}{d_{2,i}} C_{2,i} \quad \text{(F-3-42a)}$$

where

$$d_{1,i} = vr_i A_i Fp_{2,i} Er_i + vd_i A_i \frac{Fd_{2,i}}{\Phi_2} \quad \text{(F-3-42b)}$$

Substituting for $C_{1,i}$ from Equation F-3-42 into Equation F-3-41, the differential equation for $C_{2,i}$ is now

$$d_{2,i} \; = \; Q'_i + vs_i A_i Fp_{1,i} + vd_i A_i \frac{Fd_{1,i}}{\Phi_{1,i}} \qquad \text{(F-3-42c)}$$

expressed implicitly as a function of $C_{1,i}$ as

$$\frac{\partial C_{2,i}}{\partial t} \; = \; D_E \frac{\partial^2 C_{2,i}}{\partial z^2} \; - \; V_E \frac{\partial C_{2,i}}{\partial z} \; - \; (\Sigma k_j \; + \; b_i \; + \; k_{bu,i} \; - \; \frac{a_i d_{1,i}}{d_{2,i}}) C_{2,i} \; + \; \frac{a_i Q'_{i-1} C_{1,i-1}}{d_{2,i}} \qquad \text{(F-3-43)}$$

Once $C_{2,i}$ at time t is determined by solution of Equation F-3-43, the associated value for $C_{1,i}$ can be found from Equation F-3-42, thus completing the simultaneous solution. (The value for
$C_{1,i-1}$, i.e., the runoff concentration in the immediately upslope subarea, will have been determined previously during the simultaneous solution for the i-1 subarea at time t.)

To implement the simultaneous solution, Equation F-3-43 can be simplified to

$$\frac{\partial C_{2,i}}{\partial t} \; = \; D_E \frac{\partial^2 C_{2,i}}{\partial z^2} \; - \; V_E \frac{\partial C_{2,i}}{\partial z} \; - \; k_i' C_{2,i} \; + \; ld_{i-1} \qquad \text{(F-3-44a)}$$

where

$$k'_i \; = \; \Sigma k_j \; + \; k_{ev,i} \; + \; k_{bu,i} \qquad \text{(F-3-44b)}$$

$$k_{ev,i} \; = \; b_i \; - \; a_i \; \frac{d_{1,i}}{d_{2,i}} \qquad \text{(F-3-44c)}$$

$$ld_{i-1} \; = \; \frac{a_i}{d_{2,i}} \; Q'_{i-1} \; C_{1,i-1} \qquad \text{(F-3-44d)}$$

$k_{ev,i}$ is the storm event (or runoff and erosion) first-order loss rate, k'_i is the lumped first-order loss rate which includes the effects of abiotic hydrolysis (j=hy), aerobic biodegradation (j=ae), and wind/mechanical activity (j=wd), in addition to runoff and erosion. k_{hy} and k_{ae} are inputs to the module
and k_{wd} is calculated using the methodologies detailed in Appendix F-A. The last term, ld_{i-1} is the run-on load from upslope subareas in g/m^3/d.

Recall that in the GSCM, the governing equation is broken up into three component equations—diffusion, convection, and first-order losses (Equations F-2-13 through F-2-15), each solved individually on a grid. In the subsurface layers, the solution technique described in Section 2 is applied directly. However, for the surface soil column layer, the first two-component equations remain the same, while the third is revised to:

$$\frac{\partial C_{2,i}}{\partial t} = - k' C_{2,i} + ld_{i-1} \qquad \text{(F-3-45)}$$

which has the following analytical solution for $C_{2,i} = C^0_{2,i}$ at t = 0:

$$C_{2,i} = \begin{cases} C^0_{2,i} \exp(-k'_i t) + ld_{i-1}\left[\frac{1 - \exp(-k'_i t)}{k'_i}\right] & k'_i > 0 \\ C^0_{2,i} + ld_{i-1} t & k'_i = 0 \end{cases} \qquad \text{(F-3-46)}$$

To track mass losses, the total mass added to the soil column in subarea i in any time period zero to t due to settling from runoff water, $M_{add,i}$ (M/L^2), is evaluated using

$$M_{add,i} = ld_{i-1} t \; dz \qquad \text{(F-3-47)}$$

A mass balance on the soil column in time t gives:

$$\Delta M_i = M_{add,i} - M_{loss,i} \qquad \text{(F-3-48)}$$

where ΔM_i (M/L2) is the change in mass in the soil column in subarea i as given by (($C_{2,i}$ - $C°_{2,i}$)*dz) and $M_{loss,i}$ (M/L^2) is the total mass lost from the subarea i soil column in any time

$$M_{loss,i} = [C^0_{2,i}(1 - \exp(-k'_i t)) + ld_{i-1}(\frac{k'_i t + \exp(-k'_i t) - 1}{k'_i})]dz \qquad \text{(F-3-49)}$$

period zero to t. By substituting Equation F-3-46 for $C_{2,i}$ and Equation F-3-47 for $M_{add,i}$ and rearranging, the following equation for $M_{loss,i}$ was derived for k'_i>0. For k'_i = 0, $M_{loss,i}$ = 0.

The total mass lost in any time period zero to t from subarea i soil column can be attributed to specific first-order loss processes, j, $M_i(t)$ (M/L^2) using

$$M_{j,i} = M_{loss,i} \frac{k_j}{k'_i} \qquad \text{(F-3-50)}$$

where

j = hy for hydrolysis,
j = ae for aerobic degradation,

$$\overline{C}_{1,i} = \frac{Q'_{i-1}\overline{C}_{1,i-1}}{d_{2,i}} + \frac{d_{1,i}}{d_{2,i}}\overline{C}_{2,i} \quad \text{(F-3-51)}$$

j = wd for losses due to wind/mechanical activity,
j = ev for runoff/erosion events, and
j = bu for burial/erosion.

Equation F-3-42a provides the contaminant concentration in the runoff water at time t.

$$\overline{C}_{2,i} = \frac{C^0_{2,i} + C_{2,i}}{2} \quad \text{(F-3-52)}$$

The average contaminant concentration in the runoff water ($\overline{C}_{1,i}$) over time 0 to t is determined using:

where $\overline{C}_{2,i}$ is the time-weighted average contaminant concentration in the soil compartment over the same time period. Given the short time step (i.e., 1 day) used in the integration of the Local Watershed/Soil Column Module, $\overline{C}_{2,i}$ is approximated using:

where the 0 superscript denotes concentration at the beginning of the day.

F-3.5 Implementation

F-3.5.1 Overview

An overview of the algorithm implementing the combined Local Watershed/Soil Column Modules is provided in Figure F-3-4a and b. Some additional differences from the GSCM general algorithm (Section F-2.4.1) are noted. In the GSCM, it is assumed that infiltration is constant and convection events occur at regular intervals throughout the entire simulation. (With a convection event, soil column concentrations are propagated downward and M_{lcha} is incremented.) In the Local Watershed/Soil Column Modules, the infiltration rate (I) is allowed to vary from year to year. As a

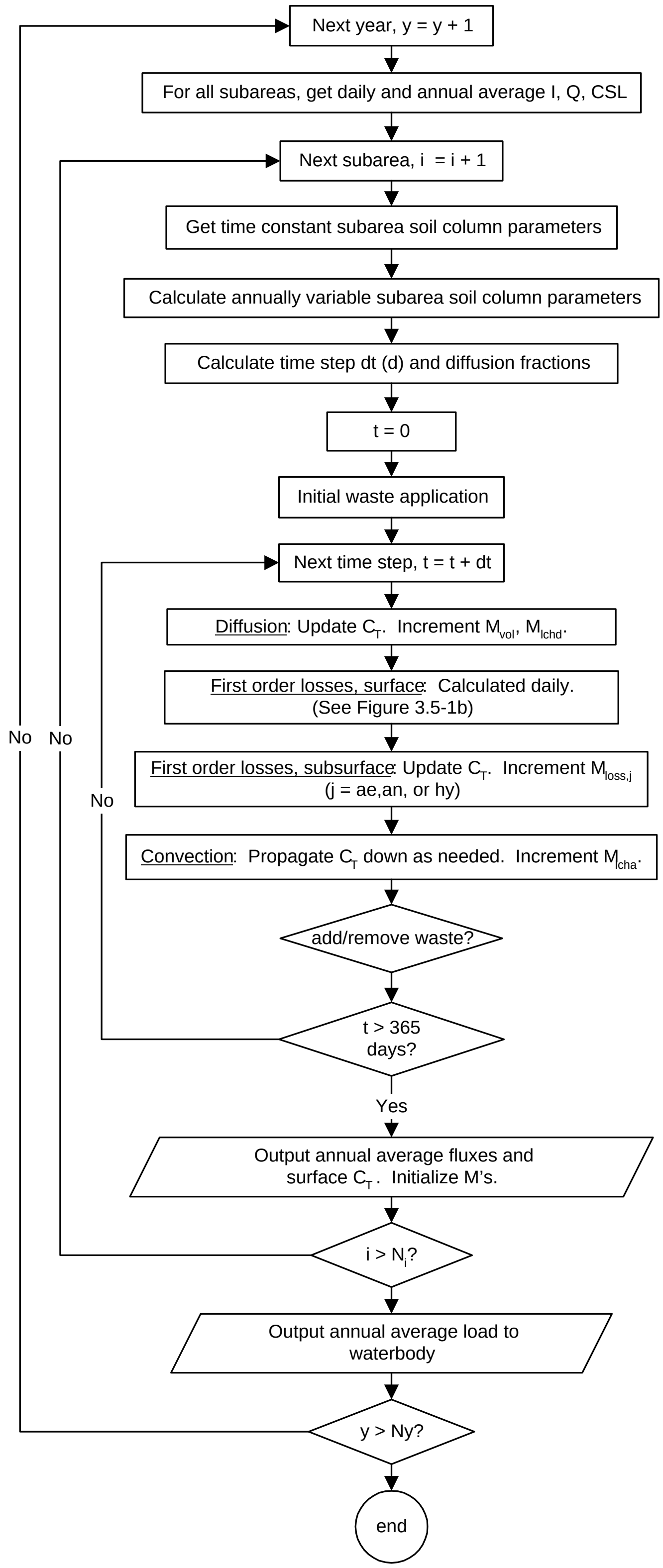

Figure F-3-4a. Overview of algorithm for combined local watershed/soil column module.

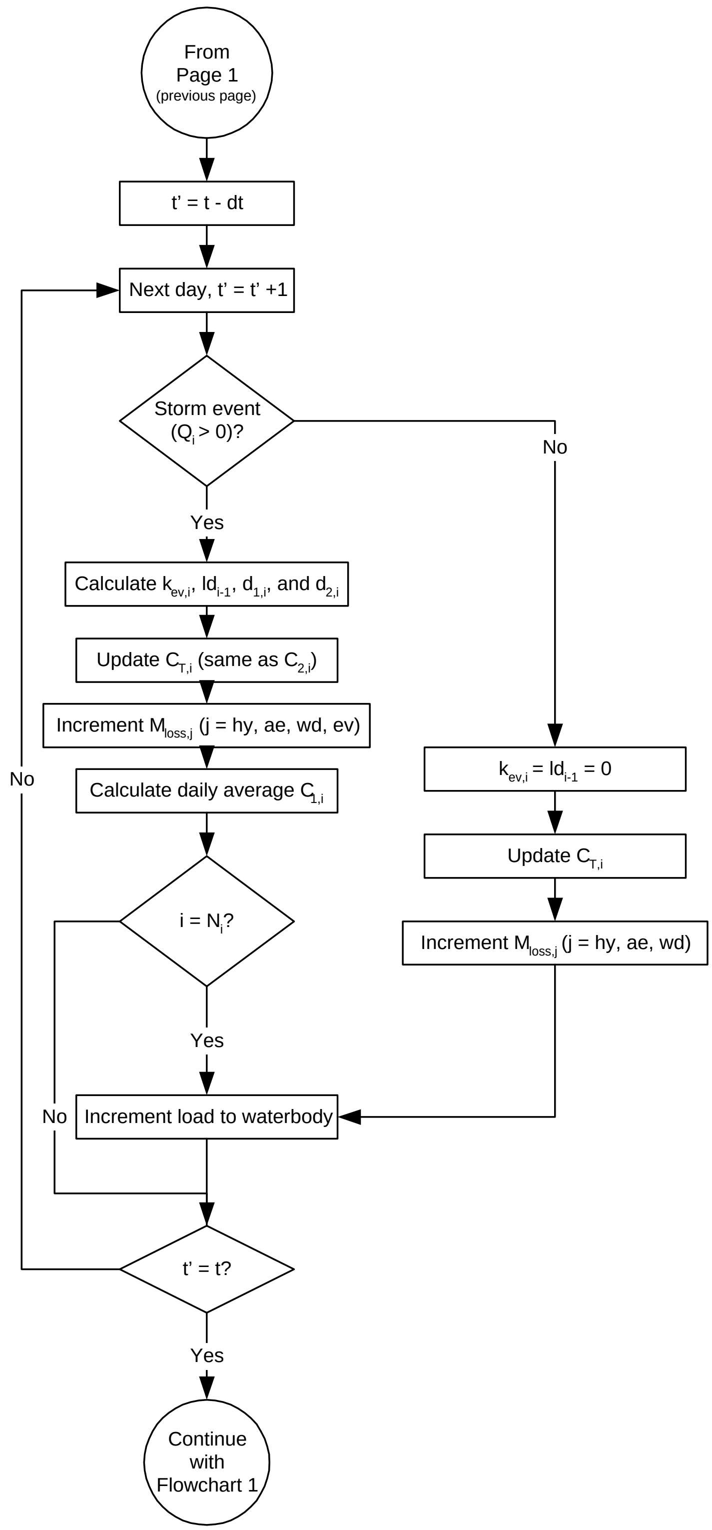

Figure F-3-4b. Detail on calculation of first-order losses in surface layer.

result, convection events do not occur at regular intervals. To determine the appropriate time to initiate a convection event, at the end of every time step a variable (fadv) tracking the fraction of mass in the bottom soil column layer that would have convected is incremented by ($dt \cdot V_E/dz$). If fadv is sufficiently close to 1, a convection event is initiated and fadv is reset to zero. At the end of the simulation (year = NyrMax), if fadv is greater than zero.

M_{lcha} is incremented by fadv times dz times C_T in the lowest layer and C_T in the lowest layer is adjusted accordingly. Leachate flux for the final year is then calculated using Equation F-2-29.

F-3.5.2 Simulation-Stopping Criterion

For a given local watershed, i, the simulation is stopped in each successive subarea when the amount of contaminant mass in local watershed i and all upslope subareas j (j < i) is determined to be insignificant. "Insignificance" is defined by the input parameter TermFrac, and this simulation criterion is implemented as follows:

1. During the years before the end of the operating life of the LAU, the year-end cumulative subarea contaminant mass in each subarea is determined. Here, cumulative subarea mass ($samass_i$) refers to the sum of the contaminant mass in subarea i and all upslope subareas j (j < i). The maximum cumulative subarea contaminant mass (max_samass_i) is stored for each subarea.

2. After LAU operation ceases, the year-end cumulative subarea contaminant mass in each subarea is compared to the stored maximum for that subarea. The simulation in subarea i is stopped when

$$samass_i \leq TermFrac * maxsamass_i$$

   where "TermFrac" is the user-specified fraction ranging from 0 to 1.0 (unless the NyrMax parameter is reached first, at which point the simulation is automatically stopped). The year the simulation ceases in each local watershed and subarea is stored in an internal two-dimensional array dimensioned on local watershed and subarea.

(Note: As of this writing, computer memory requirements have resulted in an inability to make full use of the above-described TermFrac stopping critierion for highly persistent chemicals. Time series outputs are kept in random access memory [RAM] for postprocessing. When the length of the time series becomes excessive with respect to array sizes and available RAM, memory-cacheing occurs with a concomitant drastic slowdown in run time. To mitigate this problem, it was determined that the length of the time series would be determined by the TermFrac criterion, as described above, or 200 years, whichever comes first.)

F-3.5.3 Leachate Flux Processing

Preliminary module runs indicated that there are many cases where the convective transfer step will occur less than once per year, sometimes even less than once in the entire simulation period. In these cases the leachate flux will be nonzero in the years when a convection event occurs and zero in years when it did not. This is a limitation of the solution technique. In reality, leaching occurs more or less continuously over the time between the modeled convection events. To mitigate this limitation, a leachate flux postprocessing algorithm was developed. The entire simulation ($0 < j \leq NyrMax$) is split into three time periods, where j is used here as the year index:

1. LAU operating years ($0 \leq j \leq y_{op}$)
2. Non-operating years ($y_{op} < j \leq LeachFluxNY$
3. No leachate flux years ($LeachFluxNY < j \leq NyrMax$)

where LeachFLuxNY is the last year there is a positive leachate flux. The processed leachate fluxes (J_{lchp}, g/m^2/d) in time periods 1 and 2 are calculated from J_{lch} in each year, j, using:

$$J_{lchp,j} = \frac{I_j}{\bar{I}\ (b - a + 1)} \sum_{j=a}^{j=b} J_{lch,j} \tag{F-3-53}$$

where, in time period 1, a = 0 and b = y_{op}. In time period 2, a = y_{op} and b = LeachFluxNY. The first term in Equation (F-3-53) is an infiltration-based weight where I_j is the annual average infiltration rate in year j and $\bar{I}$ is the average infiltration rate between years a and b. In time period 3, J_{lchp} is zero.

With use of Equation F-3-53 to estimate the leachate flux, mass is conserved. That is, the total mass lost due to leaching over the course of the simulation is the same using the processed and unprocessed leachate fluxes. However, with the processed leachate flux, a smoother function of leachate flux over time is provided.

F-3.5.4 End-of-Simulation Mass Balance Check

At the end of the simulation, a system-wide mass balance check is performed in the code. The system, in the Local Watershed/Soil Column Modules, includes the LAU subarea and all other subarea "soil columns." The mass balance error (fMerr) is computed as a fraction of the total contaminant mass added to the system from the mass balance equation

$$fMerr = 1 - (fMrem + fMlost) \tag{F-3-54}$$

where fMrem is the fraction of total contaminant mass added that remains in the system at the end of the simulation. fMlost is the fraction of the contaminant mass added that was estimated to have been lost from the system by the end of the simulation. fMlost is the sum of the variables listed and defined in Table 3-2.

Time series outputs are reported as follows:

- *Outputs to Air Module***.** All annnual time series outputs to ISCST3 are reported up to and including the last year that there is nonzero VE or CE. Thus, the annual time series outputs to the air model are all the same length.

Table F-3-2. Variables Summarizing Contaminant Mass Losses

Variable	Definition: Fraction of the total mass added lost due to:
fMvol_wmu	Volatilization from the LAU
fMlch_wmu	Leaching from the LAU
fMwnd_wmu	Wind/mechanical action on the LAU surface
fMdeg_wmu	Abiotic and biodegradation within the LAU
fMrmv_wmu[a]	Removal from the LAU
fMvol_sa	Volatilization from the non-LAU subarea soil columns
fMlch_sa	Leaching from the non-LAU subarea soil columns
fMdeg_sa	Abiotic and biodegradation in the non-LAU subarea soil columns
fMswl	Runoff/erosion from the most downslope subarea
fMbur[b]	Burial/erosion in all subareas (see k_{bu} in Equation 3-44d)

[a] Applies only to the WP, which is removed and refreshed regularly. See Section 3.7 for details.
[b] fMbur is the only variable listed that can be negative (indicating a mass gain). This results from the inclusion of a burial/erosion term in linking the runoff and soil compartments. See Figure 3-3 and the discussion of the meaning of the burial/erosion term in Section 3.4.2.

- *Outputs to the Groundwater Model*. The annual time series of LeachFlux for each local watershed is reported up to and including the last year that there is anonzero LeachFlux in any local watershed. This results in the same reported LeachFlux time series length for all local watersheds. After this, all LeachFlux values for all local watersheds will be zero and are not reported. AnnInfil is reported from year one to the last year that meteorological data are available.

F-3.6 Output Summary

Table F-3-3 summarizes the outputs of the combined Local Watershed/Soil Column Module.

- *Outputs to Surface Water*. The annual time series of SWLoadChem are reported up to and including the last year that there is nonzero SWLoadChem in any local

Table F-3-3. Output Summary for the LAU Model

Variable Name[a]			
Documentation	**Code**	**Definition**	**Units**
I	AnnInfil	Leachate infiltration rate (annual avg., WMU subarea(s) only)	m/d
J_{vol}	VE	Volatile emission rate	$g/m^2/d$
	VEYR	Year associated with output	Year
	VENY	Number of years in outputs	Unitless
CE30	CE	Constituent mass emission rate-PM30	$g/m^2/d$
	CEYR	Year associated with output	Year
	CENY	Number of years in outputs	Unitless
E30	PE30	Eroded solids mass emission rate-PM30	$g/m^2/d$
	PE30YR	Year associated with output	Year
	PE30NY	Number of years in outputs	Unitless
pmf	PMF	Particulate emission particle size distribution	Mass frac.
	PMFYR	Year associated with output	Year
	PMFNY	Number of years in outputs	Unitless
Q	Runoff	Runoff flow to waterbody	m3/d
J_{lch}	LeachFlux	Leachate contaminant flux	$g/m^2/d$
	LeachFluxYR	Year associated with output	Year
LeachFluxNY	LeachFluxNY	Number of years in outputs	Unitless
	SWLoadChem	Chemical load to waterbody	g/d
	SWLoadChemYr	Year associated with output	year
	SWLoadChemNY	Number of years in outputs	Unitless
CSL	SWLoadSolid	Total suspended solids load to waterbody	g/d
C1	SWConcTot	Total chemical concentration in surface water runoff	mg/L
	SWConcTotYR	Year associated with output	Year
	SWConcTotNY	Number of years in outputs	Unitless
C_T	CTss	Soil concentration in surface soil layer	µg/g
	CTssYR	Year associated with output	Year
	CTssNY	Number of years in outputs	Unitless

(continued)

Table 3-3. (continued)

Variable Name[a]			
Documentation	**Code**	**Definition**	**Units**
C_T	CTda	Depth-weighted average soil concentration (from zava to zavb)	µg/g
	CTdaYR	Year associated with output	Year
	CTdaNY	Number of years in outputs	Unitless
	SrcSoil	Flag for soil presence (true)	Logical
	SrcOvl	Flag for overland flow presence (true)	Logical
	SrcLeachMet	Flag for leachate presence when leachate is met-driven (true)	Logical
	SrcLeachSrc	Flag for leachate presence when leachate is not met-driven (false)	Logical
	SrcVE	Flag for volatile emissions presence (true)	Logical
	SrcCE	Flag for chemical sorbed to particulates emissions presence (true)	Logical
	SrcH2O	Flag for surface water presence for eco-exposure (false)	Logical
	NyrMet	Number of years in the available met record	Unitless

[a]Where the variable name is used in the code but not in the documentation, the first column is left blank.

watershed. This results in the same reported SWLoadChem time series length for all local watersheds. SWLoadSolid and Runoff are reported for all local watersheds up to the last year that meteorological data are available.

Outputs to Fate and Transport Model. The annual time series of CTda is reported to the the last year of nonzero CTda in each local watershed and subarea. Thus, the length of the reported time series for CTda in each local watershed and subarea may differ. The same is true for CTss.

F-3.7 Land Application Unit

F-3.7.1 Introduction

Section F-3.4 presented the Local Watershed/Soil Column Module. This section discusses LAU-specific issues in implementation. Figure F-3-5 illustrates the LAU in the local watershed conceptual module.

F-3.7.2 Additional Assumptions

- Waste is applied to the soil surface periodically at even intervals (e.g., quarterly) and then tilled or mixed into the top layer of soil to a depth of z_{till} (m).
- Till zone ($z = 0$ to z_{till}) is completely mixed upon each application of waste to soil.
- The modeled soil column consists of one homogeneous zone, the till zone, consisting of a soil/waste mixture. The till zone properties ($\rho_{b,till}$, $foc_{till,}$) can be estimated as the depth-weighted average of the soil ($\rho_{b,s}$, foc_s) and waste properties ($\rho_{b,w}$, foc_w) according to the depth of soil (d_s, m) and waste (d_w, m) in the till zone. To illustrate, an example using ρ_b is presented below.

$$\rho_{b,till} = \rho_{b,s} \frac{d_s}{z_{till}} + \rho_{b,w} \frac{d_w}{z_{till}} \tag{F-3-55}$$

$$d_s = z_{till} - d_w \tag{F-3-56}$$

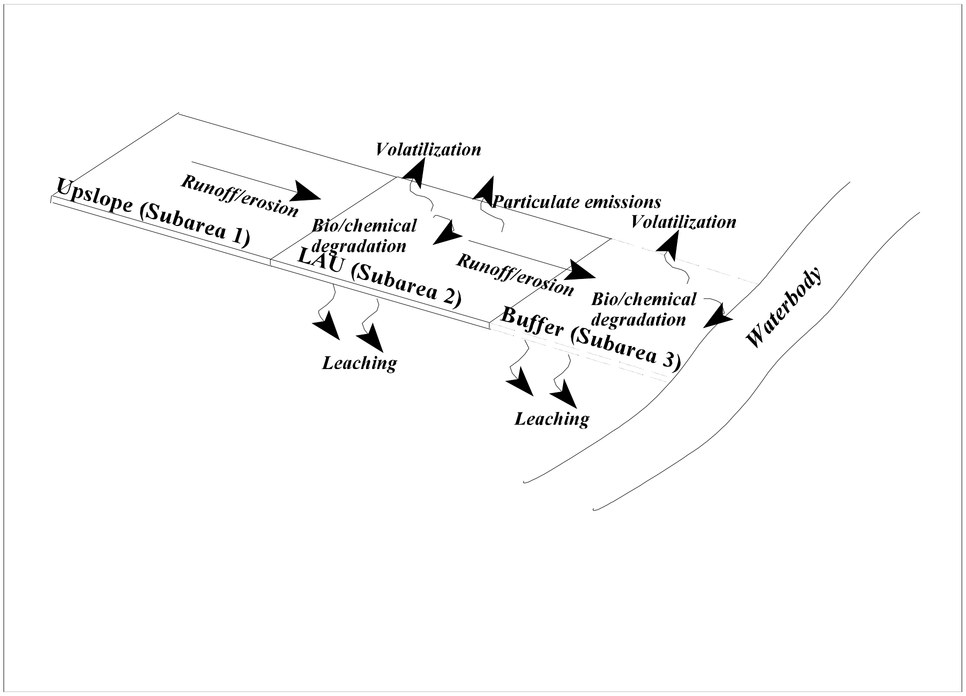

Figure F-3-5. Illustration of LAU in local watershed.

where W is the wet waste mass loading for a single application, determined as

$$d_w = \frac{W}{\rho_{b,w}} \qquad \text{(F-3-57)}$$

where R_{appl} is the wet waste application rate (Mg/m^2-y), sd is the weight percent solids in the waste, N_{appl} is the number of waste applications per year, ρb,s (g/cm^3) is the dry bulk density of the soil estimated from η_s using Equation (F-3-63), and $\rho_{b,w}$ (g/cm^3) is the dry bulk density.

$$W = \frac{R_{appl} \cdot sd/100}{N_{appl}} \qquad \text{(F-3-58)}$$

- The water added to the LAU contained in the wet waste increases the annual average infiltration rate (I) by:

$$+ \frac{R_{appl}\ (1 - sd/100)}{365\,\rho_{H_2O}} \qquad \text{(F-3-59)}$$

- The contaminant mass is concentrated in the solids portion of the waste and is re-partitioned among the solid, aqueous, and gas phases in the soil column.

- The waste added to the till zone does not significantly affect the hydraulic properties of the till zone. Thus, the hydraulic properties of the soil (K_{sat}, SM_b) are used in Equation 2-11 to determine the water content if the till zone. Although

$$\eta = 1 - \frac{\rho_b}{2.65} \qquad \text{(F-3-60)}$$

the waste may affect the hydraulic properties of the till zone, there is no way of determining this effect theoretically.

- Total porosity of the till zone (η_{till}) is estimated using the following relationship for porous media (Freeze and Cherry, 1979):

- Waste applications do not result in significant buildup of the soil surface, nor does erosion significantly degrade the soil surface (i.e., the distance from the site surface
(z = 0) to a fixed point below the surface is constant). As a result, there is no naturally occurring limit to the modeled C_T other than the limit for NAPLs. In other words, the modeled contaminant concentration in the till zone could exceed

the contaminant concentration in the waste. Indeed, this is physically possible for highly immobile constituents if the waste matrix is organic and decomposes, leaving behind the constituent to concentrate over multiple applications.

- The land application unit is operated for y_{op} years.

- The first-order chemical and biological loss processes in the till zone include aerobic biodegradation (k_{ae}, 1/d) and hydrolysis (k_{hy}, 1/d).

- The first-order loss rate due to wind erosion and other surface disturbances (k_{wd}, 1/d) is applied to the surface layer of the till zone only and is calculated each year as an annual average with consideration of losses from an active LAU due to wind erosion, vehicular activity on the surface of the LAU, and tilling operations. The particulate emission loss rate from an inactive LAU includes wind erosion only. Appendix F-A outlines the estimation procedures for k_{wd}.

- The annual average infiltration rate (I, m/d) is determined using the method described in Section F-3.2.4 (note that I is the same as IN in Section F-3.2.4) with consideration of the properties of the till zone only.

- As described in Section F-3.4, the topmost soil column layer in the GSCM developed for the LAU serves as the soil compartment in the watershed/soil column algorithm (see Figure F-3-3). For the purposes of applying the watershed/ soil column algorithm, it is assumed that the appropriate depth for the soil column surface layer (dz) is 0.01 m. In the LAU module, dz = 0.01 m is used for the entire till zone.

F-3.7.3 Initial Conditions

The simulation starts immediately following the first application of waste, at which time the till zone is well-mixed. Initial conditions are

$$C_T\Big|_{z,t=0} = \frac{W \cdot C'_{T,w} \cdot f_{wmu}}{z_{till}} \qquad \text{(F-3-61)}$$

where $C'_{T,w}$ is the initial total contaminant concentration in the dry waste, calculated by dividing the total mass-based concentration in the wet waste (input by the user as CTPwaste in the LAU code) by sd/100.

During the operating lifetime of the LAU ($t \leq 365y_{op}$), with each application of waste the

$$C_T\Big|_{z,t=j \cdot t_{bet}} = \frac{W \cdot C'_{T,w} \cdot f_{wmu}}{z_{till}} + \overline{C}_T^{\,z}(z_{till}, j \cdot t_{bet}) \qquad \text{(F-3-62)}$$

initial condition in the till zone is reset to account for the contaminant mass added as well as any contaminant mass remaining in the till zone from previous applications.

$$t_{bet} = \frac{365}{N_{appl}} \qquad \text{(F-3-63)}$$

where j is the waste application counter index = 1,2,3..., $\bar{C}_T^z$ (z,t) (g/m^3) is the depth-weighted average total contaminant concentration at time t averaged over a depth of z, and t_{bet} is the time between applications:

F-4.0 References

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Appendix F-A

Symbols, Units, and Definitions

Appendix F-A

Symbols, Units, and Definitions

(Symbols listed in Tables in Appendix F-C, Particulate Emission Equations are not repeated here.)

Table F-A-1. Symbols, Units, and Definitions

Symbol	Units	Definition
η_j	---	total porosity where j is a subscript indicating waste, w; waste/soil mixture in the till zone, till; and soil, s.
η	---	total porosity
θ_a	---	soil volumetric air content
$\theta_{a,j}$	---	soil volumetric air content where j is a subscript indicating waste, w; waste/soil mixture in the till zone, till; and soil, s.
θ_w	---	soil volumetric water content
$\theta_{w,j}$	---	soil volumetric water content where j is a subscript indicating waste, w; waste/soil mixture in the till zone, till; and soil, s.
ρ_b	g/cm^3	soil dry bulk density. Same as m2. (Note: $g/cm^3 = Mg/m^3$)
$\rho_{b,j}$	g/cm^3	dry bulk density where j is a subscript indicating waste, w; waste/soil mixture in the till zone, till; and soil, s.
$\rho_{b,w}^{wet}$	g/cm^3	wet bulk density of LAU waste
A	m^2	area of WMU
a_i	1/d	calculated parameter (equation 3.4.2-3b) for subarea i
bcm	---	lower coil column boundary condition multiplier

(continued)

Table F-A-1. (continued)

Symbol	Units	Definition
b_i	1/d	calculated parameter (equation 3.4.2-3c) for subarea i
C'_T	µg/g	total mass-based contaminant concentration in dry soil
$C'_{T,W}$	µg/g	total mass-based contaminant concentration in incoming dry waste
$C_{2,i}$	g/m^3	contaminant concentration in surface soil grid space in subarea i (equivalent to C_T)
C_G	g/m^3	contaminant concentration in gaseous phase in soil
C_L	g/m^3	contaminant concentration in aqueous phase in soil
C_L^{sol}	g/m^3	contaminant aqueous solubility
CN	unitless	SCS runoff module Curve Number parameter
C_S	µg/g	contaminant concentration in adsorbed phase in soil
$CSL_{i,t}$	kg	cumulative soil load leaving subarea i, day t
C_T	g/m^3	total volume-based contaminant concentration in soil
C_{T0}	g/m^3	initial total volume-based contaminant concentration in soil
$d_{1,i}$	m^3/d	calculated parameter (equation 3.4.2-5b) for subarea i
$d_{2,i}$	m^3/d	calculated parameter (equation 3.4.2-5c) for subarea i
D_a	cm^2/s	diffusivity in air
D_E	m^2/d	effective diffusivity in soil
$D_{E,a}$	m^2/d	effective diffusivity in soil air
$D_{E,w}$	m^2/d	effective diffusivity in soil water
Df	---	fraction of original mass in soil column grid space that diffuses past a boundary in time, t.
Df_0	---	fraction of original mass in soil column grid space that remains after time, t.
DRZ	cm	depth of the root zone
d_s	m	thickness of soil in unmixed LAU till zone
dt	d	length of time step in GSCM solution algorithm
d_w	m	thickness of waste in unmixed LAU till zone

(continued)

Table F-A-1. (continued)

Symbol	Units	Definition
D_w	cm^2/s	diffusivity in water
dz	m	soil column grid size in GSCM solution algorithm
ER_i	unitless	erosion chemical enrichment ratio for subarea i
$ET_{i,t}$	cm/day	evapotranspiration from root zone on day t for subarea i
FC_i	cm	soil moisture field capacity for subarea i
foc	---	organic carbon fraction in soil
foc_j	---	organic carbon fraction where j is a subscript indicating waste, w; waste/soil mixture in the till zone, till; and soil, s.
h	m	height of wastepile
H'	---	dimensionless Henry's Law constant
I	m/d	average annual water infiltration rate
$IN_{i,t}$	cm/day	daily infiltration for subarea i, day t
J_{lch}	$g/m^2/d$	annual average leachate flux at lower soil column boundary
J_{vol}	$g/m^2/d$	annual average volatilization flux at upper soil column boundary
k	1/d	total first-order loss rate
$k_{bu,i}$	m/d	first order rate constant due to burial/erosion for subarea i
K_d	cm^3/g	soil-water partition coefficient
k_j	1/d	annual average first order loss rate due to process j, where j indicates hydrolysis, h; aerobic biodegradation, ae; anaerobic biodegradation, an; storm events in subarea i, ev,i; and wind/mechanical activity, wd.
K_{oc}	cm^3/g	equilibrium partition coefficient normalized to organic carbon
K_{sat}	cm/hr	saturated hydraulic conductivity
K_{TL}	---	equilibrium distribution coefficient between the total (g/m^3) and aqueous phase (g/m^3) contaminant concentrations in soil
L	Mg/yr	bulk waste mass loading rate into WMU
ld_{i-1}	$g/m^3/d$	run-on load to subarea i from subarea i-1
L'	Mg/yr	bulk waste loading rate adjusted for mass losses due to unloading

(continued)

Table F-A-1. (continued)

Symbol	Units	Definition
$m1_i$	g/m3	suspended solids concentration in runoff water, subarea i
m	g/m2	total amount of material from soil column grid space that has passed a boundary at time, t
M_{col1}	g/m^2	total mass in soil column at start of year
M_{col2}	g/m^2	total mass in soil column at end of year
M_i	g/m^2	annual contaminant mass loss due to process i, where i is a subscript indicating: ■ total diffusive loss at the surface, 0; ■ gas phase diffusive losses (volatilization) at the surface, vol; ■ aqueous phase leaching due to diffusion, lchd; ■ aqueous phase leaching due to advection, lcha; ■ first order loss process j where j is as defined in k_j.
M_{add}	g/m^2	annual mass added to soil column
M_{rem}	g/m^2	annual mass removed from soil column
N_{appl}	1/y	number of LAU applications per year
N_{dz}	---	total number of grid spaces of depth dz in soil column
N_{ly}	---	assumed number of waste layers in LF cell
PET_i	cm/day	potential evapotranspiration for day t
P_t	cm	total precipitation on day t
$Q_{i,t}$	m3/day	runoff flow volume (water only) leaving subarea i, day t
$Q'_{i,t}$	m3/day	total runoff flow volume (including solids) leaving subarea i, day t
R_{appl}	Mg/m^2-y	LAU waste application rate
Sd	unitless	sediment delivery ratio for subarea/watershed i
$RO_{i,t}$	cm	stormwater runoff depth leaving subarea i, day t
sd	w/w, %	weight percent of solids in raw waste applied to LAU
SM_b	---	unitless soil-specific exponent in equation (2.3-1)
$SM_{i,t}$	cm	soil moisture in root zone at end of day t for subarea i
t	d	time since start of simulation

(continued)

Table F-A-1. (continued)

Symbol	Units	Definition
t_{bet}	d	time between WP refresh or LAU waste application
vb_i	m/d	burial/erosion velocity for subarea i
vd_i	m/d	diffusive exchange velocity between runoff and surficial soil
vr_i	m/d	stormwater runoff resuspension velocity for subarea i
$\bar{C}_T^z$	g/m^3	depth-weighted average C_T at time, t
V_E	m/d	effective solute velocity in soil
W	Mg/m^2	average mass of waste added per LAU application
WP_i	cm	soil moisture wilting point for subarea i
y_{op}	yr	last year of operation of LAU or WP
z	m	distance down from soil surface
z_{sc}	m	total depth of soil column
z_{till}	m	distance from soil surface to bottom of LAU till (mixing) zone

Appendix F-B

Determination H′, D_a, and D_w for Organic Compounds

Appendix F-B

Determination H′, D_a, and D_w for Organic Compounds and Outputs

F-B.1 Introduction

For organic compounds, the dimensionless Henry's law coefficent (H′) and air and water diffusivities (D_a and D_w, cm^2/s, respectively) are calculated as a function of system temperature given user-input reference values and temperatures. H′ is determined from the dimensionless Henry's Law Coefficient (H'^r) at temperature $T^r_{H'}$ (K). D_a and D_w are determined from air (D_a^r) and water (D_w^r) diffusivities (cm^2/s) at temperature t^r_D (°C). The methodologies used are described in this Appendix. Here, the convention is used where T is temperature in Kelvin and t is temperature in degrees centigrade.

F-B.2 Air Diffusivity (D_a)

The reference air diffusivity (D_a^r) is adjusted using the following equation which was derived from the Fuller, Schettler, and Giddings (FSG) Method for estimating air diffusivities of organic compounds in Lyman et al. (1990, Eq. 17-12):

$$D_a = D_a^r \left[\frac{T}{T_D^r} \right]^{1.75} \qquad \text{(F-B.2-1)}$$

In the module, D_a is converted from cm^2/s to m^2/d by multiplying by 8.64.

F-B.3 Water Diffusivity (D_w)

The reference water diffusivity (D_w^r) is adjusted using the following equation which was derived from the Hayduk and Laudie Method for estimating water diffusivities of organic compounds in Lyman et al. (1990, Eq, 17-24):

$$D_w = \frac{\eta_w(t_D^r)}{\eta_w(t)} D_w^r \qquad \text{(F-B.3-1)}$$

where η_w (cp) is the viscosity of water as a function of temperature, t, in degrees centigrade, t^r is the temperature for which D_w^r was specified. Values for η_w are provided in the program and were obtained from Lyman at al. (1990, Table 17-7) for t=0 to 30°C in one degree increments. In the module, D_w is converted from cm^2/s to m^2/d by multiplying by 8.64.

F-B.4 Dimensionless Henry's Law Coefficient (H′)

The algorithm used to adjust the dimensionless Henry's law coefficient, H′, as a function of temperature, T, is based on the Claussius-Clayperon equation and consideration of temperature effects on solubility (Dzombak et al., 1993) and is presented below:

$$H' = H'^r \cdot \exp\left[\frac{\Delta H_V(T_{H'}^r)}{R\ T_{H'}^r} - \frac{\Delta H_V(T)}{R\ T}\right] \qquad \text{(F-B.4-1)}$$

where H'^r is the dimensionless Henry's law coefficient at reference temperature $T_{H'}^r$ (K), R is the gas constant (1.9872 cal/mol-K), and $\Delta H_v(T)$ (cal/mol) is the molar heat of vaporization as a function of temperature T (K). $\Delta H_v(T)$ is estimated using Eq. 13-21 and Table 13-7 in Lyman et al. (1990):

$$\Delta H_V = \Delta H_{VB} \left[\frac{1 - T/T_c}{1 - T_b/T_c}\right]^n \qquad \text{(F-B.4-2a)}$$

where

$$n = \begin{cases} 0.30 & \dfrac{T_b}{T_c} < 0.57 \\ 0.74\left(\dfrac{T_b}{T_c}\right) - 0.116 & 0.57 \le \dfrac{T_b}{T_c} \le 0.71 \\ 0.41 & \dfrac{T_b}{T_c} > 0.71 \end{cases} \qquad \text{(F-B.4-2b)}$$

where T_c (K) is the critical temperature and T_b(K) is the boiling point of the compound of interest

$$\Delta H_{VB} = \frac{2.303\ B\ R\ T_b^2\ (z_g - z_l)}{(t_b + C)^2} \qquad \text{(F-B.4-3a)}$$

ΔH_{VB} (cal/mol) is the molar heat of vaporization at the normal boiling point and is estimated using the method of Haggenmacher (Lyman et al., 1990, Section 13-5):

where

$$z_g - z_l = \sqrt{1 - \frac{1/P_c}{(T_b/T_c)^3}} \qquad \text{(F-B.4-3b)}$$

where T_c (K) is the critical temperature, P_c (atm) is the critical pressure, B (˚C or K) and C (˚C). are Antoine's constants. Antoine's constants have been calculated for many compounds, especially hydrocarbons, and are tabulated in the literature (e.g., Reid et al., 1977). Some caution is required in specifying values for the Antoine's constants, because in some tabulations, the conversion factor to natural log (2.303) is included in the value of B. To check, if the value for methane is 405.42 (˚C or K) use the values for B directly. If it is about 930 (˚C or K), divide all values given for B by 2.303. Also, if Antoine's constants are presented in the literature in K, B should not be changed and C should be converted to ˚C by adding 273.2. Note that this is not the usual way to convert from K to ˚C, but is necessary to maintain the constancy of the term B/(t+C) in Antoine's relationship since temeperature,t, is assumed to be in ˚C.

In the code, if T_c is unavailable, T_c is estimated as 1.5Tb (Lyman et al., 1990, p. 14-13). If P_c is unavailable, but B and C are available, (z_g-z_l) is approximated as one (Lyman et al., 1990, Table 14-6). If B and C are unavailable, Trouton's rule is used to estimate ΔH_{VB} (Lyman et al. (1990):

$$\Delta H_{VB} = 21 \frac{cal}{mole - K} T_b \qquad \text{(F-B.4-4)}$$

F-B.5 References

Dzombak, D. A., Fang, H., and Roy, S. B. (1993). ASDC: A microcomputer-based program for air stripper design and costing (CE Report No. 92-204). Department of Civil Engineering, Carnegie Mellon University, Pittsburgh, PA.

Lyman, W. J., Reehl, W. F., and Rosenblatt, D. H. (1990). Handbook of Chemical Property Estimation Methods . Washington, DC: American Chemical Society.

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Appendix F-C

Particulate Emission Equations

Appendix F-C

Particulate Emission Equations

F-C.1 Introduction

The nonwastewater source modules have been designed to provide estimates of the annual average, area-normalized emission rate of contaminant mass adsorbed to particulate matter less than 30 μm in diameter, CE30 (g of contaminant/m^2/d), as well as annual average particle size distribution information in the form of the mass fractions of the total particulate emissions in four aerodynamic particle size categories—30 to 15 μm, 15 to 10 μm, 10 to 2.5 μm, and <2.5 μm.

A variety of release mechanisms are considered. The inventory of release mechanisms considered is different for each WMU, but includes, in general, wind erosion, vehicular activity, unloading operations, tilling, and spreading/compacting operations. The mechanisms considered for each WMU are summarized in Table F-C-1.

This appendix describes the algorithms and assumptions used to estimate annually for each mechanism of release:

- $E30_i$ (g of particulates $\leq$ 30 μm in diameter/m^2/d), the annual average PM_{30} emission rate due to release mechanism i, where mechanisms of release considered for each WMU are summarized in Table F-C-1

- Particle size range mass fractions, the mass fractions of $E30_i$ in the aerodynamic particle size categories identified above.

For each WMU:

- $\Sigma E30_i$ (g/m_2/d), the total annual average PM_{30} emission rate due to all release mechanisms

- Annual average particle size range mass fractions of the total annual average PM_{30} emission rate

Table F-C-1. Summary of Mechanisms of Release of Particulate Emissions for Each WMU

Mechanism of Release	$E30_i$ Subscript	WMU Type[a,b]						Algorithm Reference
		LAU		LF cell[c]		WP		
		Active	Inact.	Active	Inact.[d]	Active	Inact.	
Wind erosion from open area	wd	X	X	X	X			Cowherd et al. (1985)
Wind erosion from wastepile	wp					X	X	U.S. EPA (1985)
Vehicular activity	ve	X		X		X		U.S. EPA (1995)
Unloading	un			X		X		U.S. EPA (1995)
Spreading/compacting or tilling	sc	X		X		X		U.S. EPA (1985)

[a] X = Mechanism of release is considered in modeling the WMU.
[b] Active = Operating WMU.
Inact. = Inactive WMU where no additional contaminant mass is being added.
[c] For a description of how results for whole LF are obtained from LF cell results, see Section 4.5.
[d] Inactive (full) and uncovered landfill cell. Assume no emissions from a covered LF cell.

- CE30 ($g/m^2/d$), the annual average emission rate of contaminant as PM_{30}
- Annual average first-order loss rate from the soil surface due to contaminant mass losses caused by particulate emissions, k_{wd} (1/d).

F-C.2 Particulate Emission Rate ($E30_i$) Algorithms and Particle Size Range Mass Fractions

F-C.2.1 Wind Erosion from Open Fields ($E30_{wd}$)

The algorithm for the estimation of PM_{30} emissions due to wind erosion from an open field is based on the procedure developed by Cowherd et al. (1985). It was adapted for implementation in a computer code and is presented in detail here. $E30_{wd}$ is estimated in the LAU and LF source emission modules. The user-specified input parameters are summarized in Table F-C-2.

To account for the fact that active and inactive WMUs can differ in the degree of vegetation (veg´), surface roughness height (z'_0), and frequency of disturbances per month (fd´), different values are assigned to these parameters in the equations presented below according to whether the WMU is active or inactive. The value assignments are summarized in Table F-C-3 where veg, z_0, and fd are user input values.

Table F-C-2. Input Parameter Units and Definitions for $E30_{wd}$

Symbol	Units	Definition
asdm	mm	Mode of the aggregate size distribution
Lc	---	Ratio of the silhouette area of roughness elements too large to be included in sieving to total base area
veg	---	Fraction of surface covered with vegetation (inactive WMU)
z_0	cm	Surface roughness height (inactive WMU)
S	w/w, %	Silt content of surface material
U^+	m/s	Observed or probable fastest mile of wind between disturbances
PE	---	Thornthwaite Precipitation Evaporation Index
u	m/s	Mean annual windspeed
p	d/yr	Mean number of days per year with ≥0.01 in precipitation
fd	1/mo	Frequency of disturbance per month where a disturbance is defined as an action that exposes fresh surface material (inactive WMU)

Table F-C-3. Active/Inactive WMU Assignments for veg′, z'_0, fd′

Symbol	Units	Active WMU	Inactive WMU
veg′	---	0.0	veg
z'_0	cm	1.0	z_0
fd′	1/mo	fd	0.0

Step 1: Calculate U_{*t}

Calculate the threshold friction velocity, U_{*t} (m/s), the threshold windspeed for the onset of wind erosion:

$$U_{*t} = 0.650 \cdot cf \cdot (asdm)^{0.425} \qquad \text{(F-C-1a)}$$

where

$$cf = \begin{cases} 1.0 & Lc < 2x10^{-4} \\ 1.05 + 50.18Lc - 647.89Lc^2 + 6863.50Lc^3 & 2x10^{-4} \le Lc \le 1x10^{-1} \end{cases} \quad \text{(F-C-1b)}$$

Table F-C-2 provides definitions of asdm and Lc. Lc is measured by inspection of a representative 1-m^2 transect of the site surface. Lc can range from zero to 0.1. High Lc ($\geq 2x10^{-4}$) increases the threshold friction velocity, which results in a relatively low or zero particulate emission rate due to wind erosion. Low Lc ($<2x10^{-4}$) is indicative of a bare surface with homogeneous finely divided material (e.g., an agricultural field). Such surfaces have a relatively low threshold friction velocity and increased particulate emissions. Equations (F-C-1a) and (F-C-1b) were derived from Cowherd et al. (1985, Figures 3-4 and 3-5).

Step 2: Calculate U_t

$$U_t = \frac{U_{*t}}{0.4} \ln\left(\frac{700}{z'_0}\right) \qquad z'_0 < 700 \qquad \text{(F-C-2)}$$

U_t (m/s) is the threshold wind velocity at a height of 7.0 m (7.0 m is the typical weather station anemometer height). It is calculated using Cowherd et al. (1985, Equation, 4-3, with z = 700 cm):

where z'_0 is the roughness height in cm. Values for z'_0 for various surface conditions are provided in Cowherd et al. (1985, Figure 3-6).

Step 3: Calculate $E30_{wd}$

$E30_{wd}$ is the annual average emission rate of particulate matter less than 30 µm in diameter per unit area of the contaminated surface. Note that the methodology developed in Cowherd et al. (1985) was developed for estimation of emission rate of particulate matter less than 10 µm (or $E10_{wd}$). $E30_{wd}$ can be approximated from $E10_{wd}$ with knowledge of the ratio between PM_{30} and PM_{10} for wind erosion. Cowherd (1998) advises that a good first approximation of this ratio is provided by the particle size multiplier information presented in U.S. EPA (1995) for wind erosion from open fields where PM_{30}/PM_{10} is equal to 2. Therefore, a factor of 2 has been incorporated into Cowherd et al.'s (1985) equations for $E10_{wd}$ to allow estimation of $E30_{wd}$.

For sites with limited erosion potential ($U_{*t} > 0.75$ m/s)

The following equation was derived by using Cowherd et al. (1985, Equations 4-1 to 4-3), applying a factor of 2 as discussed above and converting units to g/m^2/d :

Data for mean annual U^+ and PE for locations throughout the United States can be found in climatic atlases (e.g., U.S. Department of Commerce, 1968) and Cowherd et al. (1985, Figure 4-2), respectively. Cowherd et al. (1985) advise that, in the worst case, fd should be assumed to be 30 per month.

<u>For sites with unlimited erosion potential ($U_{*t} \leq 0.75$ m/s)</u>

When U_{*t} is less than 0.75 m/s, the site is considered to have unlimited erosion potential

$$E30_{wd} = \begin{cases} \dfrac{11.12(U^+ - U_t)(1 - veg')fd'}{(PE/50)^2} \cdot \dfrac{24}{10^3} & U^+ \geq U_t \\ 0 & U^+ < U_t \end{cases} \qquad \text{(F-C-3)}$$

and $E30_{wd}$ is calculated using Cowherd et al. (1985, Equation 4-4) with a factor of 2 applied as discussed above.

$$E30_{wd} = 0.072 \; (1 - veg') \left(\frac{u}{U_t}\right)^3 g(x) \cdot 24 \; \frac{h}{d} \qquad \text{(F-C-4a)}$$

where

$$x = 0.886 \; \frac{U_t}{u} \qquad \text{(F-C-4b)}$$

$$g(x) = \begin{cases} 1.91 & 0 \leq x < 0.5 \\ 2.2 - 0.6x & 0.5 \leq x \leq 1.0 \\ 2.9 - 1.3x & 1.0 < x \leq 2.0 \\ 0.18\,(8x^3 + 12x)\exp(-x^2) & x > 2.0 \end{cases} \qquad \text{(F-C-4c)}$$

where g(x) was derived from Cowherd et al. (1985, Figure 4-3). Data for u for locations throughout the United States can be found in climatic atlases (e.g., U.S. Department of Commerce, 1968).

Step 4: Apply Particle Size Range Mass Fractions

Particle size range mass fractions allow estimation of the fraction of the PM_{30} emitted that is in specific size fractions. As mentioned above, Cowherd (1998) suggests using the particle size multipliers provided for wind erosion from industrial fields in U.S. EPA (1995). The U.S. EPA (1995) distribution was adapted to get the fraction of the emissions in the designated size categories as presented in Table F-C-4.

Table F-C-4. Aerodynamic Particle Size Range Mass Fractions for $E30_{wd}$ and $E30_{wp}$

30 μm -15 μm	15 μm -10 μm	10 μm -2.5 μm	≤2.5 μm
0.4	0.10	0.3	0.2

F-C2.2 Vehicular Activity ($E30_{ve}$)

To estimate $E30_{ve}$ (g/m²/d), the quantity of particulate emissions from vehicular travel on the surface of the WMU, the following equation was used:

$$E30_{ve} = 1.36\left(\frac{S}{12}\right)\left(\frac{vs}{48}\right)\left(\frac{vw}{2.7}\right)^{0.7}\left(\frac{nw}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)\cdot nv\cdot\left(1-eff_{dust}\right)\cdot\frac{mt}{A} \quad \text{(F-C-5)}$$

where parameter definitions are provided in Table F-C-5. Equation F-C-5 was derived from an empirical equation presented in U.S. EPA (1995; Equation 1, p. 13.2.2-1) for the kilograms of size-specific particulate emissions emitted per vehicle kilometer traveled on unpaved roads. (In this application, the EPA parameter "fraction of waste on unpaved roads" is one since travel is on the surface of the WMU.) The first six terms of Equation F-C-5 are equivalent to the U.S. EPA (1995) equation after application of the 0.80 particle size multiplier for PM_{30}. EPA's equation has been adapted here to provide emissions normalized to the contaminated surface area and to account for the control of emissions with a dust control efficiency factor of eff_{dust}.

The particle size multipliers for $E30_{ve}$ are presented in Table F-C-6. These have been adapted for the size categories of interest from the particle size multiplier information presented in U.S. EPA (1995).

Table F-C-5. Parameter Units and Definitions for $E30_{ve}$

Symbol	Units	Definition
S	w/w,%	Silt content of roadway (4.3-20)[a, b]
vs	km/h	Mean vehicle speed (21-64)
vw	Mg	Mean vehicle weight (2.7-142)
nw	—	Mean number of wheels per vehicle (4-13)

Symbol	Units	Definition
nv	1/d	Mean annual number of vehicles per day
eff_{dust}	—	Dust suppression control efficiency
A	m^2	Contaminated surface area
mt	m	Meters traveled per vehicle (nv) on contaminated surface
p	d/y	Mean number of days per year with ≥0.01 in precipitation

[a] Silt is defined as particles less than 75 µm in diameter. Silt content is determined by the percent of loose dry surface material that passes through a 200-mesh screen using the ASTM-C-136 method (U.S. EPA, 1985).

[b] Values in parentheses are the ranges of source conditions that were tested in developing the U.S. EPA (1995, Equation 1, p. 13.2.1-1).

Table F-C-6. Aerodynamic Particle Size Range Mass Fractions for $E30_{ve}$

30 µm -15 µm	15 µm -10 µm	10 µm -2.5 µm	≤2.5 µm
0.38	0.17	0.33	0.12

F-C.2.3 Unloading Operations ($E30_{un}$)

The equation for estimating $E30_{un}$ ($g/m^2/d$), the PM_{30} emission rate due to unloading operations at wastepiles and landfills, was adapted from U.S. EPA. (1995, Equation 1, p. 13.2.4-3). The EPA equation was adapted by multiplying it by the average annual loading rate (L, Mg/yr), normalizing the emissions for the contaminated surface area, and applying the particle size multiplier for <30 µm.

$$E30_{un} = (0.0012) \cdot \frac{\left(\frac{u}{2.2}\right)^{1.3}}{\left(\frac{mcW}{2}\right)^{1.4}} \cdot \frac{L}{A} \cdot \frac{10^3\,\mathrm{g}}{\mathrm{kg}} \, \frac{\mathrm{yr}}{365\mathrm{d}} \qquad \text{(F-C-6)}$$

Parameter definitions are provided in Table F-C-7. The particle size range mass fractions were developed from information provided in U.S. EPA (1995) and are presented in Table F-C-8.

Table F-C-7. Parameter Units and Definitions for $E30_{un}$

Symbol	Units	Definition
u	m/s	Mean annual wind speed (0.6-6.7)
mcW	volume %	Waste moisture content (0.25-4.8)
L	Mg/yr	Annual average waste loading rate

Note: Values in parentheses are the ranges of source conditions that were tested in developing the U.S. EPA (1995) equation.

Table F-C-8. Aerodynamic Particle Size Range Mass Fractions for $E30_{un}$

30 µm -15 µm	15 µm -10 µm	10 µm -2.5 µm	≤2.5 µm
0.35	0.18	0.32	0.15

F-C.2.4 Spreading/Compacting or Tilling Operations ($E30_{sc}$)

The equation for estimating $E30_{sc}$ ($g/m^2/d$), the rate of PM_{30} emissions due to spreading and compacting or tilling operations, was adapted from an equation in U.S. EPA (1985, Equation 1, p. 11.2.2-1) that was developed for estimating emissions due to agricultural tilling in units of kilogram of particulate emissions per hectare per tilling (or spreading/ compacting) event. The first two terms in Equation F-C-7 represent the EPA equation with the particle size multiplier for <30 µm applied.

$$E30_{sc} = (1.77)\ S^{0.6} \cdot N_{op} \cdot \frac{10^3\ g}{kg} \cdot \frac{ha}{10^4\ m^2} \qquad \text{(F-C-7)}$$

Parameter definitions are provided in Table F-C-9. The particle size range mass fractions were developed from information provided in U.S. EPA (1985) and are presented in Table F-C-10.

F-C.3 Particle Size Range Mass Fractions for Total PM_{30} Emission Rate

Particle size range mass fractions characterizing the total annual average PM_{30} emission rate ($E30_i$ summed over all applicable mechanisms) is determined annually by applying the mechanism-specific mass fractions to the $E30_i$ estimates to obtain size-specific emission rate

Table F-C-9. Parameter Units and Definitions for $E30_{sc}$

Symbol	Units	Definition
S	w/w, %	Silt content of surface material (1.7-88)[a, b]
N_{op}[c]	1/d	Number of tilling (or spreading and compacting) operations per day
fcult	---	Number of cultivations per application

[a] Silt is defined as particles less than 75 µm in diameter. Silt content is determined by the percent of loose dry surface material that passes through a 200-mesh screen using the ASTM-C-136 method (U.S. EPA, 1985).
[b] Values in parentheses are the ranges of source conditions that were tested in developing the U.S. EPA (1985) equation.
[c] For the LAU, Nop = (Nappl/365 x fcult).

Table F-C-10. Aerodynamic Particle Size Range Mass Fractions for $E30_{sc}$

30 µm -15 µm	15 µm -10 µm	10 µm -2.5 µm	≤2.5 µm
0.24	0.12	0.34	0.30

estimates $E_{i,j}$ (g/m^2/d) where subscript j identifies the particle size range (j= 1 indicates 30-15 µm; 2, 15-10 µm; 3, 10-2.5 µm; and 4, <2.5 µm). The total particle size range mass fraction, pmf_j, is calculated as:

$$pmf_j = \frac{\sum_i E_{i,j}}{\sum_i E30_i} \quad \text{(F-C-8)}$$

F-C.4 Annual Average Constituent Emission Rate (CE30) Equations

The amount of mass lost due to wind and mechanical disturbances, $M_{loss,wd}$ (g/m^2), estimated using Equation F-2-24 and accumulated throughout the simulated year is used to estimate CE30 (g/m^2/d), the annual average, area-normalized emission rate of contaminant mass adsorbed to particulate matter less than 30 µm in diameter.

$$CE30 = \frac{M_{loss,wd}}{365} \quad \text{(F-C-9)}$$

Equation F-C-10 is directly applicable to the LAU during both the inactive and active years, the WP during the inactive years, and the inactive (full) LF cell. For the first year of the

LF cell and the active years of the WP, the raw waste losses due to particulate emissions during unloading waste are added to the CE30 estimate. The increment is equal to

$$+\ E30un \cdot C'_{T,W} \cdot fwmu \cdot 10^{-6} \frac{g}{\mu g} \qquad \text{(F-C-10)}$$

F-C.5 Estimation of First Order Loss Rate (k_{wd})

$$\frac{\partial C_T}{\partial t} = -k_{wd} C_T \qquad \text{(F-C-11)}$$

An equation for k_{wd} was derived by performing a mass balance on the surface layer of the "soil" column to a depth of dz (the depth of the surface soil column cell) and considering losses due to wind and mechanical activity only:

where:

$$k_{wd} = \frac{1}{dz} \cdot \frac{K_d}{K_{TL}} \cdot \frac{g}{10^6 \mu g} \cdot \Sigma_i E30_i \qquad i \neq un \qquad \text{(F-C-12)}$$

The processes indicated by subscript i that are included for each WMU are summarized in Table F-C-1. Only processes acting on the surface layer are included in the summation of $E30_i$. Therefore, the unloading of raw waste (i=un) is excluded.

F-C.6 References

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Appendix D

Modifications to LAU Source Partition Model Programs

Appendix F-D

Modifications to LAU Source Partition Model Programs

Several coding modifications were made to the LAU source model to enable it to be used for this analysis. Those modifications are summarized below.

F-D.1 LAU Model for Crop Agricultural Field

F-D.1.1 Temperature Correction

The temperature correction routines were revised so that they were performed internal to the program. Routines for internal temperature corrections had been developed and these internal routines were re-instated for the sewage sludge application. These routines are: chemical diffusivity in air (Da), chemical diffusivity in water (Dw), and Henry's law constant (H). The correction routine for Da was derived from the FSG Method (Lyman, 1990, Ch. 17, eq. 17-12), and the routine for Dw was derived from Equation 17-24 (Hayduk and Laudie) in Lyman et al. (1990). The temperature correction for H used estimates of the heat of vaporization from Lyman et al. (1990, eq. 13-21). The Haggenmacher method (Lyman et al., 1990, Sect. 13-5) is used to get the heat of vaporization at the boiling point. Temperature corrections for partitioning (Kd, Koc), hydrolysis, and solubility were not included in the sewage sludge source models.

The temperature correction routines introduced several new input variables to the model: Antoine's constants B and C, the boiling temperature of the chemical, and the critical temperature and pressure for the chemical. Changes were made to the program executables and the data dictionary files to read these data into the program.

F-D.1.2 AP42 Changes to Vehicular Activity Particulate Emissions

One of the particulate emissions equations was modified to reflect a 1998 update by EPA (URL: www.epa.gov/ttn/chief/ap42/ch13) to the equation previously used the LAU. The equation that was updated is presented as equation F-C-6 in this appendix. That equation predicts the daily flux of particulate emissions of 30 um of less particles resulting from vehicular traffic on the surface of the LAU, i.e. variable "E30ve". The updated equation is

E30ve = 2.819(S/12)^0.8(vw/3)^0.5((365-p)/365)nv(1-effdust)(mt/A)

where the variables and units are as described in F-C-9.

F-D.2 LAU Model for Pasture Agricultural Field

F-D.2.1 Temperature Correction

Code changes to enable internal temperature corrections were identical to those described above for the crop agricultural field.

F-D.2.2 AP42 Changes to Vehicular Activity Particulate Emissions

Code changes to update the vehicular activity particulate emissions calculations were identical to those described above for the crop agricultural field.

F-D.2.3 Changes to Include Waste Lying on Soil Surface

The most significant change to the LAU Module to configure it for the pasture agricultural field was a set of modifications that together reflect the conceptual scenario that sludge applied to the pasture is not tilled into the soil, but rather spread on the soil surface and mixed with the top 2 cm of soil through natural means. The code changes to effect this scenario performed the following steps:

1. The modeled depth of the "soil column" (variable zZ1WMU) was increased by this depth. The new "soil column" then consisted of the actual soil underneath the spread sludge (0.2 m) plus the depth of the sludge layer lying on top.

2. A sludge application now reflects an updating of the above-soil-surface model layers, rather than a "tilling" into the soil depth.

F-D.2.4 Shortcoming of the LAU Pasture Model

It is noted here that a shortcoming of the LAU model used to simulate the pasture scenario is that the modeled "soil column" now consists of two zones with nonhomogeneous physical properties – the sludge zone lying of top of the soil, and the underlying soil zone. The LAU model was not designed to accommodate different zones; indeed, the single zone soil column's properties (percent silt, bulk density, and fraction organic carbon) are estimated as a weighted average of the soil properties and the waste properties, because they are mixed together. Although the pasture's complete soil column in fact consists of these two different zones, the properties of the sludge (assumed to resemble silt) were used for the entire soil column in the simulation due to this model limitation. Thus, to the extent that the underlying soil is different from silt, some error is introduced into the results by this simplifying assumption. Despite this limitation, the LAU model was considered the most appropriate model to be used for the pasture simulation.

Appendix G

Air Dispersion and Deposition Modeling Input Files

Appendix G

Air Dispersion and Deposition Modeling Input Files

Using PCRAMMET

PCRAMMET is a preprocessor program that integrates surface and upper air meteorological data into an input file for ISCST3. PCRAMMET calculates hourly stability values from surface observations, interpolates hourly mixing height values from twice-daily upper air data, and calculates parameters for wet and dry deposition/depletion calculations. PCRAMMET output can be selected as unformatted or ASCII format (U.S. EPA, 1995c). ISCST3 requires that meteorological data be in ASCII format when multiple-year meteorological data are used.

PCRAMMET input files were set up in an automated fashion. In addition to the surface and upper air data, PCRAMMET requires the input of the following meteorological parameters (U.S. EPA, 1995c):

- Minimum Monin-Obukhov length (m)
- Anemometer height (m)
- Roughness length (m), surface meteorological station
- Roughness length (m), area around facility
- Noontime albedo
- Bowen ratio
- Anthropogenic heat flux (W/m^2)
- Fraction net radiation absorbed by the ground.

Anemometer height was collected from the local climatic data summaries (NOAA, 1983). When anemometer height was not available, the station was assigned the most common anemometer height from the other stations. This value was 6.1 m.

Land use information is required for determining a number of PCRAMMET inputs. To obtain this information, a GIS was used to determine the land use within a 3-km radius around each meteorological station by using GIRAS spatial data with Anderson land use codes (Anderson et al., 1976). Table G-1 shows how the Anderson land use codes were related to PCRAMMET land use codes.

A weighted average, based on the land use percentages for a 3-km radius around each meteorological station, was used to estimate the Bowen ratio, minimum Monin-Obukhov length, the noontime albedo, the roughness height at the meteorological station, and the fraction of net radiation absorbed by the ground.

- The Bowen ratio is a measure of the amount of moisture at the surface around a meteorological station. The wetness of a location was determined based on the annual average precipitation amount. The range of values is provided in Table G-2 as a function of land use type, season, and moisture condition. For this analysis, the annual average values were applied.

- The minimum Monin-Obukhov length, a measure of the atmospheric stability at a meteorological station, was correlated with the land use classification, as shown in Table G-3.

- Noontime albedo values also were correlated with land use around a meteorological station, as shown in Table G-4.

- The surface roughness length is a measure of the height of obstacles to the wind flow. It is not equal to the physical dimensions of the obstacles but is generally proportional to them. Surface roughness length data are shown in Table G-5, along with their corresponding land use. The roughness height was assumed to be the same at the meteorological station and at the LAU site in order to avoid creating a separate meteorological input file for every facility modeled.

- During daytime hours, the heat flux into the ground is parameterized as a fraction of the net radiation incident on the ground. This fraction varies based on land use. A value of 0.15 was used for rural locations. Suburban and urban locations were given values of 0.22 and 0.27, respectively (U.S. EPA, 1995c).

Anthropogenic heat flux for a meteorological station can usually be neglected in areas outside of highly urbanized locations; however, in areas with high population densities or energy use, such as an industrial facility, this flux may not always be negligible (U.S. EPA, 1995c). For this analysis, anthropogenic heat flux was assumed to be zero for all meteorological stations because little information was available to assume any anthropogenic heat flux value for most locations.

Table G-1. Relation Between Anderson Land Use Codes and PCRAMMET Land Use Codes

Anderson Code and Description[a]		RAMMET Type and Description[b]	
51	Streams and canals	1	Water surface
52	Lakes	1	Water surface
53	Reservoirs	1	Water surface
54	Bays and estuaries	1	Water surface
41	Deciduous forest land	2	Deciduous forest
61	Forested wetland	2	Deciduous forest
42	Evergreen forest land	3	Conifuerous forest
43	Mixed forest land	4	Mixed forest
62	Nonforested wetland	5	Swamp (nonforested)
84	Wet tundra	5	Swamp (nonforested)
21	Cropland and pasture	6	Agricultural
22	Orchards-groves-vineyards-nurseries-ornamental	6	Agricultural
23	Confined feeding operations	6	Agricultural
24	Other agricultural land	6	Agricultural
31	Herbaceous rangeland	7	Rangeland (grassland)
32	Shrub and brush rangeland	7	Rangeland (grassland)
33	Mixed rangeland	7	Rangeland (grassland)
11	Residential	9	Urban
12	Commercial and services	9	Urban
13	Industrial	9	Urban
14	Transportation-communication-utilities	9	Urban
15	Industrial and commercial complexes	9	Urban
16	Mixed urban or built-up land	9	Urban
17	Other urban or built-up land	9	Urban
71	Dry salt flats	10	Desert shrubland
72	Beaches	10	Desert shrubland

(continued)

Table G-1. (continued)

Anderson Code and Description[a]		RAMMET Type and Description[b]	
73	Sandy areas not beaches	10	Desert shrubland
74	Bare exposed rock	10	Desert shrubland
75	Strip mines-quarries-gravel pits	10	Desert shrubland
76	Transitional areas	10	Desert shrubland
81	Shrub and brush tundra	10	Desert shrubland
82	Herbaceous tundra	10	Desert shrubland
83	Bare ground	10	Desert shrubland
85	Mixed tundra	10	Desert shrubland
91	Perennial snowfields	10	Desert shrubland
92	Glaciers	10	Desert shrubland

[a] Anderson codes from Anderson et al. (1976).
[b] RAMMET codes from U.S. EPA (1995c).

Table G-2. Daytime Bowen Ratio by Land Use and Season

	Spring			Summer			Autumn			Winter			Annual Average		
Land Use Type	**Dry**	**Wet**	**Avg.**	**Dry**	**Wet**	**Avg.**	**Dry**	**Wet**	**Avg.**	**Dry**	**Wet**	**Avg.**	**Dry**	**Wet**	**Avg.**
Water surface	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	2.0	0.3	1.5	0.575	0.15	0.45
Deciduous forest	1.5	0.3	0.7	0.6	0.2	0.3	2.0	0.4	1.0	2.0	0.5	1.5	1.53	0.35	0.875
Coniferous forest	1.5	0.3	0.7	0.6	0.2	0.3	1.5	0.3	0.8	2.0	0.3	1.5	1.4	0.275	0.825
Swamp	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	2.0	0.5	1.5	0.65	0.2	0.45
Cultivated land (agricultural)	1.0	0.2	0.3	1.5	0.3	0.5	2.0	0.4	0.7	2.0	0.5	1.5	1.63	0.35	0.75
Grassland	1.0	0.3	0.4	2.0	0.4	0.8	2.0	0.5	1.0	2.0	0.5	1.5	1.75	0.425	0.825
Urban	2.0	0.5	1.0	4.0	1.0	2.0	4.0	1.0	2.0	2.0	0.5	1.5	3.0	0.75	1.6
Desert shrub land	5.0	1.0	3.0	6.0	5.0	4.0	10.0	2.0	6.0	10.0	2.0	6.0	7.75	2.5	4.75

Source: U.S. EPA, 1995c. Averages computed for this effort.

Table G-3. Minimum Monin-Obukhov Length (Stable Conditions)

Urban Land Use Classification	Length (m)
Agriculture (open)	2
Residential	25
Compact residential/industrial	50
Commercial (19-40 story buildings)	100
(> 40 story buildings)	150

Source: U.S. EPA, 1995c.

Table G-4. Albedo Values of Natural Ground Covers for Land Use Types and Seasons

Land Use Type	Spring	Summer	Autumn	Winter	Annual Average
Water surface	0.12	0.1	0.14	0.2	0.14
Deciduous forest	0.12	0.12	0.12	0.5	0.22
Coniferous forest	0.12	0.12	0.12	0.35	0.18
Swamp	0.12	0.14	0.16	0.3	0.18
Cultivated land (agricultural)	0.14	0.2	0.18	0.6	0.28
Grassland	0.18	0.18	0.20	0.6	0.29
Urban	0.14	0.16	0.18	0.35	0.21
Desert shrub land	0.3	0.28	0.28	0.45	0.33

Source: U.S. EPA, 1995c. Average values computed for this analysis.

Table G-5. Surface Roughness Length for Land Use Types and Seasons (meters)

Land Use Type	Spring	Summer	Autumn	Winter	Annual Average
Water surface	0.0001	0.0001	0.0001	0.0001	0.0001
Deciduous forest	1.0	1.3	0.8	0.5	0.9
Coniferous forest	1.3	1.3	1.3	1.3	1.3
Swamp	0.2	0.2	0.2	0.05	0.16
Cultivated land (agricultural)	0.03	0.2	0.05	0.01	0.07
Grassland	0.05	0.2	0.01	0.001	0.04
Urban	1.0	1.0	1.0	1.0	1.0
Desert shrubland	0.3	0.3	0.3	0.15	0.26

Source: U.S. EPA, 1995c. Average values computed for this analysis.

```
CO STARTING
   TITLEONE  Albuquerque
   TITLETWO  464.3 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  23050.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -1174.35   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    1174.35  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    1174.35  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -1174.35  11  234.87  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  23050.REC
RE FINISHED

ME STARTING
ME INPUTFIL  23050H.MET
ME ANEMHGHT  7 METERS
ME SURFDATA  23050  1985
ME UAIRDATA  23050  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 23050_1C.PLP
   PLOTFILE  ANNUAL 2 23050_1P.PLP
   PLOTFILE  ANNUAL ALL 23050.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Asheville
   TITLETWO  55.4 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  03812.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -236.75   -236.75    0.00
SO LOCATION 1P     AREA    0   -236.75    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    236.75  473.49   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    236.75  473.49   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -236.75  11  47.35  -236.75  11  47.35
RE GRIDCART  ONSITE END
RE INCLUDED  03812.REC
RE FINISHED

ME STARTING
ME INPUTFIL  03812H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  03812  1985
ME UAIRDATA  13723  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 03812_1C.PLP
   PLOTFILE  ANNUAL 2 03812_1P.PLP
   PLOTFILE  ANNUAL ALL 03812.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Atlanta
   TITLETWO  105.9 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13874.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -327.32   -327.32    0.00
SO LOCATION 1P     AREA    0   -327.32    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    327.32  654.65   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    327.32  654.65   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -327.32  11  65.46  -327.32  11  65.46
RE GRIDCART  ONSITE END
RE INCLUDED  13874.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13874H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  13874  1986
ME UAIRDATA  13873  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13874_1C.PLP
   PLOTFILE  ANNUAL 2 13874_1P.PLP
   PLOTFILE  ANNUAL ALL 13874.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Billings
   TITLETWO  1241.7 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24033.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -3140.63   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    3140.63  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    3140.63  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -3140.63  11  628.13  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  24033.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24033H.MET
ME ANEMHGHT  7.6 METERS
ME SURFDATA  24033  1986
ME UAIRDATA  24143  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24033_1C.PLP
   PLOTFILE  ANNUAL 2 24033_1P.PLP
   PLOTFILE  ANNUAL ALL 24033.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Bismarck
   TITLETWO  923.8 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24011.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -2336.56   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    2336.56  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    2336.56  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -2336.56  11  467.31  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  24011.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24011H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  24011  1984
ME UAIRDATA  24011  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24011_1C.PLP
   PLOTFILE  ANNUAL 2 24011_1P.PLP
   PLOTFILE  ANNUAL ALL 24011.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Boise
   TITLETWO  194.4 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24131.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -491.7   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    491.7  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    491.7  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -491.7  11  98.34  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  24131.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24131H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  24131  1978
ME UAIRDATA  24131  1978
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24131_1C.PLP
   PLOTFILE  ANNUAL 2 24131_1P.PLP
   PLOTFILE  ANNUAL ALL 24131.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Boulder
   TITLETWO  738 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  94018.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -1866.62   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    1866.62  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    1866.62  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -1866.62  11  373.32  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  94018.REC
RE FINISHED

ME STARTING
ME INPUTFIL  94018H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  94018  1986
ME UAIRDATA  23062  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 94018_1C.PLP
   PLOTFILE  ANNUAL 2 94018_1P.PLP
   PLOTFILE  ANNUAL ALL 94018.PLP
OU FINISHED
```

```
CO STARTING
  TITLEONE  Burlington
  TITLETWO  159.2 ACRES
  MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
  AVERTIME  ANNUAL
  SAVEFILE  14742.SAP
  POLLUTID  PART
  TERRHGTS  FLAT
  ERRORFIL  ERRORS.OUT
  RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -402.66   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    402.66  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    402.66  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -402.66  11  80.53  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  14742.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14742H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  14742  1985
ME UAIRDATA  14735  1985
ME FINISHED

OU STARTING
  RECTABLE  ALLAVE FIRST
  MAXTABLE  ALLAVE  10
  PLOTFILE  ANNUAL 1 14742_1C.PLP
  PLOTFILE  ANNUAL 2 14742_1P.PLP
  PLOTFILE  ANNUAL ALL 14742.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Casper
   TITLETWO  829.6 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24089.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -2098.3   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    2098.3  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    2098.3  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -2098.3  11  419.66  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  24089.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24089H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  24089  1985
ME UAIRDATA  24021  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24089_1C.PLP
   PLOTFILE  ANNUAL 2 24089_1P.PLP
   PLOTFILE  ANNUAL ALL 24089.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Charleston
   TITLETWO  80.4 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13880.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -285.21   -285.21    0.00
SO LOCATION 1P     AREA    0   -285.21    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    285.21  570.41   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    285.21  570.41   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -285.21  11  57.04  -285.21  11  57.04
RE GRIDCART  ONSITE END
RE INCLUDED  13880.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13880H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  13880  1984
ME UAIRDATA  13880  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13880_1C.PLP
   PLOTFILE  ANNUAL 2 13880_1P.PLP
   PLOTFILE  ANNUAL ALL 13880.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Chicago
   TITLETWO  177.6 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  94846.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -449.2   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    449.2  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    449.2  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -449.2  11  89.84  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  94846.REC
RE FINISHED

ME STARTING
ME INPUTFIL  94846H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  94846  1984
ME UAIRDATA  14842  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 94846_1C.PLP
   PLOTFILE  ANNUAL 2 94846_1P.PLP
   PLOTFILE  ANNUAL ALL 94846.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Cleveland
   TITLETWO  109.2 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14820.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -332.38   -332.38    0.00
SO LOCATION 1P     AREA    0   -332.38    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    332.38  664.77   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    332.38  664.77   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -332.38  11  66.48  -332.38  11  66.48
RE GRIDCART  ONSITE END
RE INCLUDED  14820.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14820H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  14820  1985
ME UAIRDATA  14733  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14820_1C.PLP
   PLOTFILE  ANNUAL 2 14820_1P.PLP
   PLOTFILE  ANNUAL ALL 14820.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Fresno
   TITLETWO  46.8 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  93193.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -217.6   -217.6    0.00
SO LOCATION 1P     AREA    0   -217.6    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    217.6  435.19   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    217.6  435.19   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -217.6  11  43.52  -217.6  11  43.52
RE GRIDCART  ONSITE END
RE INCLUDED  93193.REC
RE FINISHED

ME STARTING
ME INPUTFIL  93193H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  93193  1985
ME UAIRDATA  23230  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 93193_1C.PLP
   PLOTFILE  ANNUAL 2 93193_1P.PLP
   PLOTFILE  ANNUAL ALL 93193.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Harrisburg
   TITLETWO  102.8 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14751.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -322.5   -322.5    0.00
SO LOCATION 1P     AREA    0   -322.5    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    322.5  644.99   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    322.5  644.99   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -322.5  11  64.5  -322.5  11  64.5
RE GRIDCART  ONSITE END
RE INCLUDED  14751.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14751H.MET
ME ANEMHGHT  6.7 METERS
ME SURFDATA  14751  1985
ME UAIRDATA  93734  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14751_1C.PLP
   PLOTFILE  ANNUAL 2 14751_1P.PLP
   PLOTFILE  ANNUAL ALL 14751.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Hartford
   TITLETWO  50 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14740.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -224.91   -224.91    0.00
SO LOCATION 1P     AREA    0   -224.91    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    224.91  449.83   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    224.91  449.83   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -224.91  11  44.98  -224.91  11  44.98
RE GRIDCART  ONSITE END
RE INCLUDED  14740.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14740H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  14740  1985
ME UAIRDATA  14735  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14740_1C.PLP
   PLOTFILE  ANNUAL 2 14740_1P.PLP
   PLOTFILE  ANNUAL ALL 14740.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Houston
   TITLETWO  123.5 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  12960.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -353.48   -353.48    0.00
SO LOCATION 1P     AREA    0   -353.48    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    353.48  706.96   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    353.48  706.96   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -353.48  11  70.7  -353.48  11  70.7
RE GRIDCART  ONSITE END
RE INCLUDED  12960.REC
RE FINISHED

ME STARTING
ME INPUTFIL  12960H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  12960  1985
ME UAIRDATA  3937  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 12960_1C.PLP
   PLOTFILE  ANNUAL 2 12960_1P.PLP
   PLOTFILE  ANNUAL ALL 12960.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Huntington
   TITLETWO  86.7 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  03860.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -296.17   -296.17    0.00
SO LOCATION 1P     AREA    0   -296.17    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    296.17  592.34   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    296.17  592.34   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -296.17  11  59.23  -296.17  11  59.23
RE GRIDCART  ONSITE END
RE INCLUDED  03860.REC
RE FINISHED

ME STARTING
ME INPUTFIL  03860H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  03860  1984
ME UAIRDATA  3860  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 03860_1C.PLP
   PLOTFILE  ANNUAL 2 03860_1P.PLP
   PLOTFILE  ANNUAL ALL 03860.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Las Vegas
   TITLETWO  97.6 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  23169.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -314.24   -314.24    0.00
SO LOCATION 1P     AREA    0   -314.24    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    314.24  628.47   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    314.24  628.47   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -314.24  11  62.85  -314.24  11  62.85
RE GRIDCART  ONSITE END
RE INCLUDED  23169.REC
RE FINISHED

ME STARTING
ME INPUTFIL  23169H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  23169  1986
ME UAIRDATA  3160  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 23169_1C.PLP
   PLOTFILE  ANNUAL 2 23169_1P.PLP
   PLOTFILE  ANNUAL ALL 23169.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Lincoln
   TITLETWO  282.2 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14935.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -713.77   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    713.77  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    713.77  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -713.77  11  142.75  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  14935.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14935H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  14935  1986
ME UAIRDATA  94918  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14935_1C.PLP
   PLOTFILE  ANNUAL 2 14935_1P.PLP
   PLOTFILE  ANNUAL ALL 14935.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Little Rock
   TITLETWO  159.1 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13963.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -402.41   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    402.41  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    402.41  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -402.41  11  80.48  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  13963.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13963H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  13963  1984
ME UAIRDATA  13963  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13963_1C.PLP
   PLOTFILE  ANNUAL 2 13963_1P.PLP
   PLOTFILE  ANNUAL ALL 13963.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Los Angeles
   TITLETWO  24.2 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  23174.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -156.47   -156.47    0.00
SO LOCATION 1P     AREA    0   -156.47    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    156.47  312.94   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    156.47  312.94   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -156.47  11  31.29  -156.47  11  31.29
RE GRIDCART  ONSITE END
RE INCLUDED  23174.REC
RE FINISHED

ME STARTING
ME INPUTFIL  23174H.MET
ME ANEMHGHT  9.1 METERS
ME SURFDATA  23174  1985
ME UAIRDATA  23230  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 23174_1C.PLP
   PLOTFILE  ANNUAL 2 23174_1P.PLP
   PLOTFILE  ANNUAL ALL 23174.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Meridian
   TITLETWO  123 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13865.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -352.76   -352.76    0.00
SO LOCATION 1P     AREA    0   -352.76    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    352.76  705.52   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    352.76  705.52   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -352.76  11  70.55  -352.76  11  70.55
RE GRIDCART  ONSITE END
RE INCLUDED  13865.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13865H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  13865  1986
ME UAIRDATA  3940  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13865_1C.PLP
   PLOTFILE  ANNUAL 2 13865_1P.PLP
   PLOTFILE  ANNUAL ALL 13865.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Miami
   TITLETWO  39.6 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  12839.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -200.16   -200.16    0.00
SO LOCATION 1P     AREA    0   -200.16    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    200.16  400.32   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    200.16  400.32   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -200.16  11  40.03  -200.16  11  40.03
RE GRIDCART  ONSITE END
RE INCLUDED  12839.REC
RE FINISHED

ME STARTING
ME INPUTFIL  12839H.MET
ME ANEMHGHT  7 METERS
ME SURFDATA  12839  1972
ME UAIRDATA  12839  1972
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 12839_1C.PLP
   PLOTFILE  ANNUAL 2 12839_1P.PLP
   PLOTFILE  ANNUAL ALL 12839.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Minneapolis
   TITLETWO  208.6 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14922.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -527.61   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    527.61  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    527.61  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -527.61  11  105.52  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  14922.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14922H.MET
ME ANEMHGHT  6.4 METERS
ME SURFDATA  14922  1986
ME UAIRDATA  14926  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14922_1C.PLP
   PLOTFILE  ANNUAL 2 14922_1P.PLP
   PLOTFILE  ANNUAL ALL 14922.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Muskegon
   TITLETWO  117.1 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14840.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -344.2   -344.2    0.00
SO LOCATION 1P     AREA    0   -344.2    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    344.2  688.4   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    344.2  688.4   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -344.2  11  68.84  -344.2  11  68.84
RE GRIDCART  ONSITE END
RE INCLUDED  14840.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14840H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  14840  1977
ME UAIRDATA  14826  1977
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14840_1C.PLP
   PLOTFILE  ANNUAL 2 14840_1P.PLP
   PLOTFILE  ANNUAL ALL 14840.PLP
OU FINISHED

CO STARTING
```

```
   TITLEONE  Nashville
   TITLETWO  94.4 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13897.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -309.04   -309.04    0.00
SO LOCATION 1P     AREA    0   -309.04    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    309.04  618.08   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    309.04  618.08   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -309.04  11  61.81  -309.04  11  61.81
RE GRIDCART  ONSITE END
RE INCLUDED  13897.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13897H.MET
ME ANEMHGHT  7.6 METERS
ME SURFDATA  13897  1984
ME UAIRDATA  13897  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13897_1C.PLP
   PLOTFILE  ANNUAL 2 13897_1P.PLP
   PLOTFILE  ANNUAL ALL 13897.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  New Orleans
   TITLETWO  90.9 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  12916.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -303.26   -303.26    0.00
SO LOCATION 1P     AREA    0   -303.26    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    303.26  606.52   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    303.26  606.52   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -303.26  11  60.65  -303.26  11  60.65
RE GRIDCART  ONSITE END
RE INCLUDED  12916.REC
RE FINISHED

ME STARTING
ME INPUTFIL  12916H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  12916  1985
ME UAIRDATA  3937  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 12916_1C.PLP
   PLOTFILE  ANNUAL 2 12916_1P.PLP
   PLOTFILE  ANNUAL ALL 12916.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Norfolk
   TITLETWO  97.5 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13737.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -314.07   -314.07    0.00
SO LOCATION 1P     AREA    0   -314.07    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    314.07  628.15   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    314.07  628.15   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -314.07  11  62.81  -314.07  11  62.81
RE GRIDCART  ONSITE END
RE INCLUDED  13737.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13737H.MET
ME ANEMHGHT  10.1 METERS
ME SURFDATA  13737  1986
ME UAIRDATA  93739  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13737_1C.PLP
   PLOTFILE  ANNUAL 2 13737_1P.PLP
   PLOTFILE  ANNUAL ALL 13737.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Philadelphia
   TITLETWO  39 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13739.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -198.64   -198.64    0.00
SO LOCATION 1P     AREA    0   -198.64    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    198.64  397.28   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    198.64  397.28   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -198.64  11  39.73  -198.64  11  39.73
RE GRIDCART  ONSITE END
RE INCLUDED  13739.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13739H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  13739  1981
ME UAIRDATA  93734  1981
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13739_1C.PLP
   PLOTFILE  ANNUAL 2 13739_1P.PLP
   PLOTFILE  ANNUAL ALL 13739.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Phoenix
   TITLETWO  339.7 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  23183.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -859.2   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    859.2  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    859.2  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -859.2  11  171.84  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  23183.REC
RE FINISHED

ME STARTING
ME INPUTFIL  23183H.MET
ME ANEMHGHT  10.1 METERS
ME SURFDATA  23183  1986
ME UAIRDATA  23160  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 23183_1C.PLP
   PLOTFILE  ANNUAL 2 23183_1P.PLP
   PLOTFILE  ANNUAL ALL 23183.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Portland
   TITLETWO  98.2 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14764.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -315.2   -315.2    0.00
SO LOCATION 1P     AREA    0   -315.2    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    315.2  630.4   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    315.2  630.4   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -315.2  11  63.04  -315.2  11  63.04
RE GRIDCART  ONSITE END
RE INCLUDED  14764.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14764H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  14764  1985
ME UAIRDATA  14764  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14764_1C.PLP
   PLOTFILE  ANNUAL 2 14764_1P.PLP
   PLOTFILE  ANNUAL ALL 14764.PLP
OU FINISHED

CO STARTING
```

```
  TITLEONE  Raleigh-Durham
  TITLETWO  85.4 ACRES
  MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
  AVERTIME  ANNUAL
  SAVEFILE  13722.SAP
  POLLUTID  PART
  TERRHGTS  FLAT
  ERRORFIL  ERRORS.OUT
  RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -293.94   -293.94    0.00
SO LOCATION 1P     AREA    0   -293.94    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    293.94  587.88   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    293.94  587.88   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -293.94  11  58.79  -293.94  11  58.79
RE GRIDCART  ONSITE END
RE INCLUDED  13722.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13722H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  13722  1986
ME UAIRDATA  13723  1986
ME FINISHED

OU STARTING
  RECTABLE  ALLAVE FIRST
  MAXTABLE  ALLAVE  10
  PLOTFILE  ANNUAL 1 13722_1C.PLP
  PLOTFILE  ANNUAL 2 13722_1P.PLP
  PLOTFILE  ANNUAL ALL 13722.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Salem
   TITLETWO  44.6 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24232.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -212.42   -212.42    0.00
SO LOCATION 1P     AREA    0   -212.42    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    212.42  424.84   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    212.42  424.84   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -212.42  11  42.48  -212.42  11  42.48
RE GRIDCART  ONSITE END
RE INCLUDED  24232.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24232H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  24232  1986
ME UAIRDATA  24232  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24232_1C.PLP
   PLOTFILE  ANNUAL 2 24232_1P.PLP
   PLOTFILE  ANNUAL ALL 24232.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Salt Lake City
   TITLETWO  143.5 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24127.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -381.03   -381.03    0.00
SO LOCATION 1P     AREA    0   -381.03    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    381.03  762.05   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    381.03  762.05   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -381.03  11  76.21  -381.03  11  76.21
RE GRIDCART  ONSITE END
RE INCLUDED  24127.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24127H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  24127  1986
ME UAIRDATA  24127  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24127_1C.PLP
   PLOTFILE  ANNUAL 2 24127_1P.PLP
   PLOTFILE  ANNUAL ALL 24127.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  San Francisco
   TITLETWO  39.8 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  23234.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -200.66   -200.66    0.00
SO LOCATION 1P     AREA    0   -200.66    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    200.66  401.33   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    200.66  401.33   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -200.66  11  40.13  -200.66  11  40.13
RE GRIDCART  ONSITE END
RE INCLUDED  23234.REC
RE FINISHED

ME STARTING
ME INPUTFIL  23234H.MET
ME ANEMHGHT  10.1 METERS
ME SURFDATA  23234  1985
ME UAIRDATA  23230  1985
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 23234_1C.PLP
   PLOTFILE  ANNUAL 2 23234_1P.PLP
   PLOTFILE  ANNUAL ALL 23234.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Seattle
   TITLETWO  40.1 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24233.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -201.42   -201.42    0.00
SO LOCATION 1P     AREA    0   -201.42    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    201.42  402.84   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1      0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    201.42  402.84   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1      0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -201.42  11  40.28  -201.42  11  40.28
RE GRIDCART  ONSITE END
RE INCLUDED  24233.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24233H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  24233  1986
ME UAIRDATA  94240  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24233_1C.PLP
   PLOTFILE  ANNUAL 2 24233_1P.PLP
   PLOTFILE  ANNUAL ALL 24233.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Shreveport
   TITLETWO  110.9 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13957.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -334.96   -334.96    0.00
SO LOCATION 1P     AREA    0   -334.96    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    334.96  669.92   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1      0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    334.96  669.92   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1      0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -334.96  11  66.99  -334.96  11  66.99
RE GRIDCART  ONSITE END
RE INCLUDED  13957.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13957H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  13957  1986
ME UAIRDATA  3951  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13957_1C.PLP
   PLOTFILE  ANNUAL 2 13957_1P.PLP
   PLOTFILE  ANNUAL ALL 13957.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Tampa
   TITLETWO  67 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  12842.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -260.36   -260.36    0.00
SO LOCATION 1P     AREA    0   -260.36    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    260.36  520.71   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    260.36  520.71   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -260.36  11  52.07  -260.36  11  52.07
RE GRIDCART  ONSITE END
RE INCLUDED  12842.REC
RE FINISHED

ME STARTING
ME INPUTFIL  12842H.MET
ME ANEMHGHT  6.7 METERS
ME SURFDATA  12842  1986
ME UAIRDATA  12842  1986
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 12842_1C.PLP
   PLOTFILE  ANNUAL 2 12842_1P.PLP
   PLOTFILE  ANNUAL ALL 12842.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Tulsa
   TITLETWO  184 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  13968.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -465.39   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    465.39  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C      1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    465.39  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P      1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -465.39  11  93.08  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  13968.REC
RE FINISHED

ME STARTING
ME INPUTFIL  13968H.MET
ME ANEMHGHT  7 METERS
ME SURFDATA  13968  1984
ME UAIRDATA  13967  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 13968_1C.PLP
   PLOTFILE  ANNUAL 2 13968_1P.PLP
   PLOTFILE  ANNUAL ALL 13968.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Williamsport
   TITLETWO  127.1 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  14778.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -358.59   -358.59    0.00
SO LOCATION 1P     AREA    0   -358.59    0.00

**          SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    358.59  717.19   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1      0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    358.59  717.19   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1      0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -358.59  11  71.72  -358.59  11  71.72
RE GRIDCART  ONSITE END
RE INCLUDED  14778.REC
RE FINISHED

ME STARTING
ME INPUTFIL  14778H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  14778  1979
ME UAIRDATA  94823  1979
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 14778_1C.PLP
   PLOTFILE  ANNUAL 2 14778_1P.PLP
   PLOTFILE  ANNUAL ALL 14778.PLP
OU FINISHED
```

```
CO STARTING
   TITLEONE  Winnemucca
   TITLETWO  162.3 ACRES
   MODELOPT  TOXICS RURAL CONC DDEP WDEP DRYDPLT WETDPLT
   AVERTIME  ANNUAL
   SAVEFILE  24128.SAP
   POLLUTID  PART
   TERRHGTS  FLAT
   ERRORFIL  ERRORS.OUT
   RUNORNOT  RUN
CO FINISHED

SO STARTING

SO LOCATION 1C     AREA    -410.5   -400    0.00
SO LOCATION 1P     AREA    0   -400    0.00

**         SRCID    QS       HS     XINIT   YINIT   ROTATE   SZINIT

SO SRCPARAM 1C    1.0E-3      0.0    410.5  800   0.0
SO PARTDIAM 1C    22.5     12.5     6.3     1.3
SO MASSFRAX 1C     0.4      0.1     0.3     0.2
SO PARTDENS 1C       1        1       1       1
SO PARTSLIQ 1C    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1C    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCPARAM 1P    1.0E-3      0.0    410.5  800   0.0
SO PARTDIAM 1P    22.5     12.5     6.3     1.3
SO MASSFRAX 1P     0.4      0.1     0.3     0.2
SO PARTDENS 1P       1        1       1       1
SO PARTSLIQ 1P    6.7E-4  6.7E-4  4.5E-4  6.0E-5
SO PARTSICE 1P    2.2E-4  2.2E-4  1.5E-4  2.0E-5

SO SRCGROUP 1 1C
SO SRCGROUP 2 1P
SO SRCGROUP ALL

SO FINISHED

RE STARTING
RE GRIDCART  ONSITE STA
RE GRIDCART  ONSITE XYINC   -410.5  11  82.1  -400  11  80
RE GRIDCART  ONSITE END
RE INCLUDED  24128.REC
RE FINISHED

ME STARTING
ME INPUTFIL  24128H.MET
ME ANEMHGHT  6.1 METERS
ME SURFDATA  24128  1984
ME UAIRDATA  24128  1984
ME FINISHED

OU STARTING
   RECTABLE  ALLAVE FIRST
   MAXTABLE  ALLAVE  10
   PLOTFILE  ANNUAL 1 24128_1C.PLP
   PLOTFILE  ANNUAL 2 24128_1P.PLP
   PLOTFILE  ANNUAL ALL 24128.PLP
OU FINISHED
```

Appendix H

Direct and Indirect Exposure Equations

Table H-1.1. ADDmat - Average Daily Dose of Dioxin (2,3,7,8-TCDD) Consumed by Mother (mg/kg-d)

ADDmat

$$ADDmat = ADDoral + ADDinhal$$

$$ADDinhal = \frac{Risk_{inhal} \times AT}{ED_i \times CSFInhal}$$

$$ADDoral = \frac{Risk_{oral} \times AT}{ED \times CSFOral}$$

Name	**Description**	**Location**
ADDinhal	Average daily dose due to inhalation (mg/kg-d)	Calculated
ADDoral	Average daily dose due to oral ingestion (mg/kg-d)	Calculated
AT	Averaging time (yr)	See Appendix J
CSFInhal	Inhalation cancer slope factor (mg/kg/d)-1	See Section 2
CSFOral	Oral cancer slope factor (mg/kg/d)-1	See Section 2
ED	Exposure duration for oral ingestion (yr)	See Appendix J
EDi	Exposure duration for inhalation (yr)	See Appendix J
Risk_Inhal	Cancer risk due to inhalation (unitless)	Calculated in Table H-3.16
Risk_Oral	Cancer risk due to oral ingestion (unitless)	Calculated in Table H-3.17

Source: Back calculated from risk values.

Table H-1.2. Cmilkfat - Concentration of Dioxin (2,3,7,8-TCDD) in Maternal Milk Fat (mg/kg)

Cmilkfat

$$Cmilkfat = \frac{ADDmat \times f_{am} \times f_f}{\frac{0.693}{t_{halfb}} \times f_{fm}}$$

Name	**Description**	**Location**
0.693	Constant LN(2) (unitless)	
ADDmat	Average daily dose of dioxin (2,3,7,8-TCDD) consumed by mother (mg/kg-d)	Calculated in Table H-1.1
f_am	Fraction of ingested contaminant absorbed by mother (unitless)	See Appendix J
f_f	Proportion of contaminant stored in maternal fat (unitless)	See Appendix J
f_fm	Fraction of mother's weight that is fat (unitless)	See Appendix J
t_halfb	Biological half-life of contaminant in lactating women (d)	See Appendix J

Source: Based on U.S. EPA, 1998.

Table H-1.3. IngBM - Infant Breast Milk Exposure Calculated for Dioxin (2,3,7,8-TCDD) (mg/kg-day)

IngBM

$$IngBM = \frac{(C_{milkfat} \times f_{mbm} + C_{aqueous} \times (1 - f_{mbm})) \times f_{ai} \times CR_{bm} \times 0.001}{BW_{infant}}$$

Name	**Description**	**Location**
0.001	Units conversion factor (kg/mL)	
BW_infant	Body weight of infant (kg)	See Appendix J
C_aqueous	Concentration in aqueous phase of maternal milk (mg/kg)	See Appendix J
Cmilkfat	Concentration of contaminant in maternal milk fat (mg/kg)	Calculated in Table H-1.2
CR_bm	Ingestion rate of breast milk (mL/d)	See Appendix J
f_ai	Fraction of ingested contaminant absorbed by the infant (unitless)	See Appendix J
f_mbm	Fraction of fat in maternal breastmilk (unitless)	See Appendix J

Source: Based on U.S. EPA, 1998.

Table H-2.1. Cair - Total (Vapor + Particulate) Air Concentration (mg/m3)

Cair

$$Cair = Q \times (F_v \times Cyv + (1 - F_v) \times Cyp) \times 0.001$$

Name	**Description**	**Location**
0.001	Conversion factor (mg/ug)	
Cyp	Normalized particulate air concentration (ug-s-m2/g-m3)	See Appendix G
Cyv	Normalized vapor phase air concentration (ug-s-m2/g-m3)	See Appendix G
Fv	Fraction of air concentration in vapor phase (unitless)	See Appendix D
Q	Emission rate from source (g/s-m2)	Calculated by Source Model

Source: U.S. EPA, 1998.

Table H-2.2. Csed - Concentration of Dioxin on Sediment Settling to Bottom (mg/kg)

Csed

$$Csed = Cssed \times \frac{foc_{bs}}{foc_{sw}}$$

Name	**Description**	**Location**
Cssed	Concentration of dioxin on suspended sediment (mg/kg)	Calculated in Table H-2.6
foc_bs	Fraction of organic carbon in bottom sediment (unitless)	See Appendix I
foc_sw	Fraction of organic carbon in suspended sediment (unitless)	See Appendix I

Source: U.S. EPA, 2000.

Table H-2.3. Csoil_1F - Average Soil Concentration Over Time Period of Exposure, T2<=Td (mg/kg)

Csoil_1F

$$Csoil_{1F} = \frac{(Csoil_{t2} + Csoil_{t1})}{2}$$

Name	**Description**	**Location**
Csoil_t1	Soil concentration at first year of exposure, T1(mg/kg)	Calculated in Table H-2.5
Csoil_t2	Soil concentration at last year of exposure, T2 (mg/kg)	Calculated in Table H-2.5

Source: Equation was used to estimate the average concentration over the exposure duration.

Table H-2.4. Csoil_2F - Average Soil Concentration OverTime Period of Exposure, T2>Td (mg/kg)

Csoil_2F

$$Csoil_{td2} = \frac{(Csoil_{t2} + Csoil_{td})}{2}$$

$$Csoil_{td1} = \frac{(Csoil_{td} + Csoil_{t1})}{2}$$

$$Csoil_{2F} = Csoil_{td1} \times \frac{(Td - T1)}{ED} + Csoil_{td2} \times \frac{(T2 - Td)}{ED}$$

Name	Description	Location
Csoil_t1	Soil concentration at first year of exposure, T1 (mg/kg)	Calculated in Table H-2.5
Csoil_t2	Soil concentration at last year of exposure, T2 (mg/kg)	Calculated in Table H-2.5
Csoil_td	Soil concentration at last year of deposition, Td (mg/kg)	Calculated in Table H-2.5
Csoil_td1	Average soil concentration from the first year of exposure to the last year of deposition (mg/kg)	Calculated in Table H-2.5
Csoil_td2	Average soil concentration from last year of deposition to the last year of exposure (mg/kg)	Calculated in Table H-2.5
ED	Exposure duration (yr)	See Appendix J
T1	The time at which exposure begins (yr)	See Appendix E
T2	The time at which exposure ends, T1 + ED (yr)	Calculated
Td	The length of time the unit is operational (yr)	See Appendix E

Source: Equations were used to calculate the average concentration over the period of exposure while biosolids were applied and the average concentration after biosolids application ceased. These two concentrations were then time-weighted to determine the average concentration over the exposure duration.

Table H-2.5. Csoil_t - Soil Concentration at Time, T (mg/kg)

Csoil_t

$$Csoil_t = Csoil_i + \frac{Dep + Load}{SoilR + K_s \times Mass} \times 1 - e^{\left(-\frac{SoilR}{Mass} + K_s\right) \times T}$$

Name	Description	Location
Csoil_i	Initial soil concentration (mg/kg)	Calculated
Dep	Deposition term for soil (mg/yr)	Calculated in Table H-2.9
K_s	Soil loss constant (1/yr)	Calculated
Load	Mass of contaminant loaded to soil (mg/yr)	Calculated in Table H-2.18
Mass	Mass of soil (kg)	Calculated in Table H-2.21
SoilR	Mass of soil removed from site (kg/yr)	Calculated in Table H-2.23
T	The time for which the soil concentration is being calculated (yr)	

Source: Equation was based on the equation in U.S. EPA, 2000 with values for deposition load added into the equation.

Note: Depending on the value of T this equation is used to calculate Csoil_t1, Csoil_t2 or Csoil_td. The Value for T is determined in either Csoil_1F or Csoil_2F.

Table H-2.6. Cssed - Concentration of Dioxin on Suspended Sediment (mg/kg)

Cssed

$$Cssed = \frac{Lt}{\frac{Vfx}{Kd_{sw}} + (Fs \times ERw) + \frac{foc_{bs}}{foc_{sw}} \times (1 - Fs) \times ERw}$$

Name	Description	Location
ERw	Total watershed annual soil erosion (kg/yr)	Calculated in Table H-2.12
foc_bs	Fraction of organic carbon in bottom sediment (unitless)	See Appendix I
foc_sw	Fraction of organic carbon in suspended sediment (unitless)	See Appendix I
Fs	Fraction of annual erosion remaining as suspended material (unitless)	Calculated in Table H-2.13
Kd_sw	Soil-water partition coefficient in suspended sediment (L/kg)	Calculated in Table H-2.15
Lt	Loading term for dioxin in waterbody (mg/yr)	Calculated in Table H-2.20
Vfx	Waterbody annual flow mixing volume (L/yr)	Calculated in Table H-2.24

Source: U.S. EPA, 2000.

Table H-2.7. Cvapor - Vapor Air Concentration - Could be Farm, Waterbody or Watershed (mg/m3)

Cvapor

$$Cvapor = Q \times F_v \times Cyv \times 0.001$$

Name	Description	Location
0.001	Conversion factor (mg/ug)	
Cyv	Normalized vapor phase air concentration (ug-s-m2/g-m3)	See Appendix G
Fv	Fraction of air concentration in vapor phase (unitless)	See Appendix D
Q	Emission rate from source (g/s-m2)	Calculated by Source Model

Source: U.S. EPA, 1998.

Table H-2.8. Cw - Concentration of Dioxin in the Waterbody (mg/kg)

Cw

$$Cw = TSS \times Cssed \times 1000000$$

Name	**Description**	**Location**
Cssed	Concentration of dioxin on suspended sediment (mg/kg)	Calculated in Table H-2.6
TSS	Total suspended solids (mg/L)	See Appendix I

Source: Best professional judgement

Table H-2.9. Dep - Deposition Term for Soil (mg/yr)

Dep

$$Dydv = 0.31536 \times Cyv \times Vdv$$

$$Dep = 1000 \times Q \times Area \times (F_v \times (Dydv + Dywv) + (1 - F_v) \times (Dydp + Dywp))$$

Name	**Description**	**Location**
0.31536	Unit conversion factor (m-g-s/cm-ug-yr)	
1000	Units conversion (mg/g)	
Area	Area of deposition (m2)	See Appendix E
Cyv	Normalized vapor phase air concentration (ug-s-m2/g-m3)	See Appendix G
Dydp	Normalized annual average dry deposition from particle phase (s-m2/m2-yr)	See Appendix G
Dydv	Normalized annual dry deposition from vapor phase (s-m2/m2-yr)	Calculated
Dywp	Normalized annual average wet deposition from particle phase(s-m2/m2-yr)	See Appendix G
Dywv	Normalized annual average wet deposition from vapor phase (s-m2/m2-yr)	See Appendix G
Fv	Fraction of air concentration in vapor phase (unitless)	See Appendix D
Q	Emission rate from source (g/s-m2)	Calculated by Source Model
Vdv	Dry deposition velocity (cm/s)	See Appendix D

Source: U.S. EPA, 1998.

Table H-2.10. Di - Deposition Term for Impervious Surfaces (g/m2-yr)

Di

$$Dydv = 0.31536 \times Cyv \times Vdv$$

$$Di = Q \times (F_v \times (Dydv + Dywv) + (1 - F_v) \times (Dydp + Dywp))$$

Name	Description	Location
0.31536	Unit conversion factor (m-g-s/cm-ug-yr)	
Cyv	Normalized vapor phase air concentration (ug-s-m2/g-m3)	See Appendix G
Dydp	Normalized annual average dry deposition from particle phase (s-m2/m2-yr)	See Appendix G
Dydv	Normalized annual dry deposition from vapor phase (s-m2/m2-yr)	Calculated
Dywp	Normalized annual average wet deposition from particle phase(s-m2/m2-yr)	See Appendix G
Dywv	Normalized annual average wet deposition from vapor phase (s-m2/m2-yr)	See Appendix G
Fv	Fraction of air concentration in vapor phase (unitless)	See Appendix D
Q	Emission rate from source (g/s-m2)	Calculated by Source Model
Vdv	Dry deposition velocity (cm/s)	See Appendix D

Source: U.S. EPA, 1998.

Table H-2.11. Dw - Deposition Term for Water (g/m2-yr)

Dw

$$Dw = Q \times ((F_v \times Dywv) + ((1 - F_v) \times (Dydp + Dywp)))$$

Name	Description	Location
Dydp	Normalized annual average dry deposition from particle phase (s-m2/m2-yr)	See Appendix G
Dywp	Normalized annual average wet deposition from particle phase(s-m2/m2-yr)	See Appendix G
Dywv	Normalized annual average wet deposition from vapor phase (s-m2/m2-yr)	See Appendix G
Fv	Fraction of air concentration in vapor phase (unitless)	See Appendix D
Q	Emission rate from source (g/s-m2)	Calculated by Source Model

Source: U.S. EPA, 1998.

Table H-2.12. ERw - Total Watershed Annual Soil Erosion (kg/yr)

ERw

$$ERw = (Area_{RWS} \times X_e \times SD_{RWS}) + (Area_{LWS} \times X_e \times SD_{LWS})$$

Name	Description	Location
Area_LWS	Area of the local watershed (m2)	See Appendix E
Area_RWS	Area of the regional watershed (m2)	See Appendix E
SD_LWS	Sediment delivery ratio from local watershed (unitless)	Calculated in Table H-2.22
SD_RWS	Sediment delivery ratio from regional watershed (unitless)	Calculated in Table H-2.22
Xe	Universal Soil Loss Equation (kg/m2-yr)	Calculated in Table H-2.25

Table H-2.13. Fs - Fraction of Annual Erosion Remaining as Suspended Material (unitless)

Fs
$$Fs = \left(Tss \times \frac{Vfx}{ERw} \right) \times 1E-06$$

Name	Description	Location
1E-06	Conversion factor (kg/mg)	
ERw	Total watershed annual soil erosion (kg/yr)	Calculated in Table H-2.12
TSS	Total suspended solids (mg/L)	See Appendix I
Vfx	Waterbody annual flow mixing volume (L/yr)	Calculated in Table H-2.24

Source: U.S. EPA, 2000.

Table H-2.14. KdSoil - Soil-Water Partition Coefficient (mL/g)

KdSoil

$$KdSoil = Koc \times foc$$

Name	Description	Location
foc	Fraction organic carbon (unitless)	See Appendix I
Koc	Organic carbon partition coefficient (ml/g)	See Appendix D

Source: U.S. EPA, 1998.

Table H-2.15. Kdsw - Soil-Water Partition Coefficient for Suspended Sediment (mL/g)

Kdsw

$$Kdsw = Koc \times foc$$

Name	**Description**	**Location**
foc	Fraction organic carbon (unitless)	See Appendix I
Koc	Organic carbon partition coefficient (ml/g)	See Appendix D

Source: U.S. EPA, 1998.

Table H-2.16. Ldep - Total (Wet and Dry) Particle and Wet Vapor Phase Deposition Load to Waterbody (g/yr)

Ldep

$$Ldep = D_W \times Waw$$

Name	Description	Location
Dw	Deposition term for water (g/m2-yr)	Calculated in Table H-2.11
Waw	Area of the waterbody (m2)	Calculated

Source: U.S. EPA, 1998.

Table H-2.17. Le - Erosion Load to Waterbody (g/yr)

Le

$$Wai = Wat \times \frac{PI}{100}$$

$$L_e = X_e \times (Wat - Wai) \times SD \times ER \times Csoil \times 0.001$$

Name	Description	Location
0.001	Conversion factor (g/mg)	
100	Conversion factor from percent to a fraction (unitless)	
Csoil	Concentration of contaminant in soil (mg/kg)	Calculated in Tables H-2.3, H-2.4
ER	Soil enrichment ratio (unitless)	See Appendix C
PI	Percent impervious (percent)	See Appendix E
SD	Sediment delivery ratio (unitless)	Calculated in Table H-2.22
Wai	Impervious watershed area (m2)	Calculated
Wat	Total watershed area (m2)	See Appendix E
Xe	Universal Soil Loss Equation (kg/m2-yr)	Calculated in Table H-2.25

Source: U.S. EPA, 2000.

Table H-2.18. Loss - Loss Term from Soil (mg/yr)

Loss

$$Loss = (Lri + Le) \times 1000$$

Name	Description	Location
1000	Conversion factor (1000 mg/g)	
Le	Erosion loss from soil (g/yr)	Calculated in Table H-2.17
Lri	Impervious runoff load from soil (g/yr)	Calculated in Table H-2.19

Source: Equivalent of the term "load" in other equations.

Table H-2.19. Lri - Impervious Runoff Load from Soil (g/yr)

Lri
$$Wai = Wat \times \frac{PI}{100}$$ $$Lri = D_i \times Wai$$

Name	**Description**	**Location**
100	Conversion factor from percent to a fraction (unitless)	
Di	Deposition term for impervious surfaces (g/m2-yr)	Calculated in Table H-2.10
PI	Percent impervious (percent)	See Appendix E
Wai	Impervious watershed area (m2)	Calculated
Wat	Total watershed area (m2)	See Appendix E

Source: U.S. EPA, 1998.

Table H-2.20. Lt - Loading Term for Dioxin in Waterbody (mg/yr)

Lt

$$Lt = Load_{LWS} + Load_{RWS} + (Ldep \times 1000)$$

Name	Description	Location
1000	Conversion factor (mg/g)	
Ldep	Total (wet and dry) particle and wet vapor phase deposition load to waterbody (g/yr)	Calculated in Table H-2.16
Load_LWS	Total loading from local watershed (mg/yr)	Calculated in Table H-2.18
Load_RWS	Total loading from regional watershed (mg/yr)	Calculated in Table H-2.18

Source: U.S. EPA, 2000.

Table H-2.21. Mass - Mass of Soil (kg)

Mass

$$Wai = Wat \times \frac{PI}{100}$$

$$Mass = (Wat - Wai) \times Z \times BD \times 10$$

Name	Description	Location
10	Conversion factor (cm2/m2)(kg/g)	
100	Conversion factor from percent to a fraction (unitless)	
BD	Soil bulk density (g/cm3)	See Appendix E
PI	Percent impervious (percent)	See Appendix E
Wai	Impervious watershed area (m2)	Calculated
Wat	Total area receiving deposition (m2)	See Appendix E
Z	Mixing depth of the soil (cm)	See Appendix I

Table H-2.22. SedDelivery - Sediment Delivery Ratio (unitless)

SedDelivery

$$AreaSM = \frac{Area}{2590000}$$

$$SD = A \times (AreaSM)^{-B}$$

Name	**Description**	**Location**
2590000	Conversion factor (m2/sq miles)	
A	A = 1.2 if the area ranges from 10 to 100 square miles (unitless)	
	Empirical intercept coefficient related to the size of the area (unitless)	
	A = 2.1 if the area is less than or equal to 0.1 square miles (unitless)	
	A = 1.9 if the area ranges from 0.1 to 1 square miles (unitless)	
	A = 1.4 if the area ranges from 1 to 10 square miles (unitless)	
	A = 0.6 for all other cases (unitless)	
Area	Area receiving pollutant deposition (m2)	See Appendix E
AreaSM	Area receiving pollutant deposition, area / 2590000 (sq miles)	Calculated
B	Empirical slope coefficient related to the power of the drainage area (unitless), (B = 0.125)	

Source: U.S. EPA, 1998.

Table H-2.23. SoilR - Mass of Soil Removed from Exposure Site (kg/yr)

SoilR

$$Wai = Wat \times \frac{PI}{100}$$

$$SoilR = X_e \times (Wat - Wai) \times SD \times ER$$

Name	**Description**	**Location**
100	Conversion factor from percent to a fraction (unitless)	
ER	Soil enrichment ratio (unitless)	See Appendix C
PI	Percent impervious (percent)	See Appendix E
SD	Sediment delivery ratio (unitless)	Calculated in Table H-2.22
Wai	Impervious watershed area (m2)	Calculated
Wat	Total watershed area (m2)	See Appendix E
Xe	Universal Soil Loss Equation (kg/m2-yr)	Calculated in Table H-2.25

Source: U.S. EPA, 2000.

Table H-2.24. Vfx - Waterbody Annual Flow Mixing Volume (L/yr)

Vfx

$$Baseflow = a \times Waw^{b}$$

$$Vfx = (Runoff_{RWS} + Runoff_{LWS} + Baseflow) \times 365 \times 1000$$

Name	**Description**	**Location**
1000	Conversion factor (L/m3)	
365	Conversion factor (days/yr)	
a	Parameter from regression analysis, based on HUC region (m/d)	
b	Parameter from regression analysis, based on HUC region (unitless)	
Baseflow	30Q2 Flow rate (m3/d)	Calculated
Runoff_LWS	Runoff from local watershed (m3/day)	Calculated by Source Model
Runoff_RWS	Runoff from regional watershed (m3/day)	Calculated by Source Model
Waw	Area of the waterbody (m2)	Calculated

Source: Baseflow - U.S. EPA, 1999.

Table H-2.25. Xe - Universal Soil Loss Equation (kg/m2-yr)

Xe

$$X_e = R \times K \times LS \times C \times P \times \frac{907.18}{4047}$$

Name	Description	Location
4047	Conversion factor (m2/acres)	
907.18	Conversion factor (kg/short tons)	
C	USLE cover management factor (unitless)	See Appendix C
K	USLE soil erodibility factor (short tons/acre)	See Appendix E
LS	USLE length-slope factor (unitless)	See Appendix E
P	USLE supporting practice factor (unitless)	See Appendix C
R	USLE rainfall/erosivity factor (1/yr)	See Appendix E

Source: U.S. EPA, 1998.

Table H-3.1. Abeef - Concentration in Beef Due to Plant and Soil Ingestion (mg/kg - WW)

Abeef

$$Abeef = C_{fat} \times 0.2$$

$$C_{fat} = (BCF_{cattle} \times FF) \times (DF_{beef_{soil}} \times B_s \times Csoil + DF_{beef_{forage}} \times P_{forage} + DF_{beef_{feed}} \times P_{feed})$$

Name	Description	Location
0.2	Fraction of fat in beef (unitless)	
B_s	Bioavailability of contaminant on the soil vehicle relative to the vegetative vehicle (unitless)	See Appendix I
BCF_cattle	Bioconcentration ratio of contaminant as determined from cattle vegetative intake (pasture grass or feed) (unitless)	See Appendix D
C_fat	Concentration of dioxin (2,3,7,8-TCDD) in beef fat (mg/kg)	Calculated
Csoil	Average contaminant soil concentration (mg/kg)	Calculated in Tables H-2.3, H-2.4
DF_beef_feed	Fraction of cattle diet that is feed (unitless)	See Appendix I
DF_beef_forage	Fraction of cattle diet that is pasture grass (unitless)	See Appendix I
DF_beef_soil	Fraction of cattle diet that is soil (unitless)	See Appendix I
FF	Feedlot factor for beef fat calculation (<=1 for beef fat and =1 for milk fat) (unitless)	See Appendix I
P_feed	Average concentration of contaminant in feed (mg/kg)	Calculated
P_forage	Average concentration of contaminant on pasture grass (mg/kg)	Calculated

Source: U.S. EPA, 2000.

Note: Fries and Paustenbach used the same bioconcentration for beef fat and milk fat.The dioxin reassessment provides a range of fat content from 18-22%. The value used above is the mean of 20%.

Table H-3.2. Aeggs - Concentration in Eggs Due to Grain Uptake from Chickens (mg/kg - WW)

Aeggs

$$Aeggs = C_{fat} \times 0.1$$

$$C_{fat} = BCF_{egg} \times (DF_{poultry_{soil}} \times B_s \times Csoil + DF_{poultry_{forage}} \times P_{forage} + DF_{poultry_{feed}} \times P_{feed})$$

Name	**Description**	**Location**
0.1	Fraction of fat in eggs (unitless)	
B_s	Bioavailability of contaminant on the soil vehicle relative to the vegetative vehicle (unitless)	See Appendix I
BCF_egg	Bioconcentration ratio of contaminant developed for chicken vegetative intake (unitless)	See Appendix D
C_fat	Concentration of dioxin (2,3,7,8-TCDD) in egg fat (mg/kg)	Calculated
Csoil	Average contaminant soil concentration (mg/kg)	Calculated in Tables H-2.3, H-2.4
DF_poultry_feed	Fraction of chicken diet that is feed (unitless)	See Appendix I
DF_poultry_forage	Fraction of chicken diet that is incidental vegetation while free ranging (unitless)	See Appendix I
DF_poultry_soil	Fraction of chicken diet that is soil (unitless)	See Appendix I
P_feed	Average concentration of contaminant in feed (mg/kg)	Calculated
P_forage	Average concentration of contaminant on free range vegetation (mg/kg)	Calculated

Source: U.S. EPA, 2000.

Table H-3.3. Amilk - Concentration in Milk Due to Plant and Soil Ingestion (mg/kg - WW)

Amilk

$$Amilk = C_{fat} \times 0.04$$

$$C_{fat} = (BCF_{cattle} \times FF) \times (DF_{dairy_{soil}} \times B_s \times Csoil + DF_{dairy_{forage}} \times P_{forage} + DF_{dairy_{feed}} \times P_{feed})$$

Name	**Description**	**Location**
0.04	Fraction of fat in milk (unitless)	
B_s	Bioavailability of contaminant on the soil vehicle relative to the vegetative vehicle (unitless)	See Appendix I
BCF_cattle	Bioconcentration ratio of contaminant as determined from cattle vegetative intake (pasture grass or feed) (unitless)	See Appendix D
C_fat	Concentration of dioxin (2,3,7,8-TCDD) in milk fat (mg/kg)	Calculated
Csoil	Average contaminant soil concentration (mg/kg)	Calculated in Tables H-2.3, H-2.4
DF_dairy_feed	Fraction of cattle diet that is feed (unitless)	See Appendix I
DF_dairy_forage	Fraction of cattle diet that is pasture grass (unitless)	See Appendix I
DF_dairy_soil	Fraction of cattle diet that is soil (unitless)	See Appendix I
FF	Feedlot factor for beef fat calculation (<=1 for beef fat and =1 for milk fat) (unitless)	See Appendix I
P_feed	Average concentration of contaminant in feed (mg/kg)	Calculated
P_forage	Average concentration of contaminant on pasture grass (mg/kg)	Calculated

Source: U.S. EPA, 2000.

Table H-3.4. Apoultry - Concentration in Poultry Meat Due to Grain Uptake from Chickens (mg/kg - WW)

Apoultry

$$Apoultry = C_{fat} \times 0.1$$

$$C_{fat} = BCF_{poultry} \times (DF_{poultry_{soil}} \times B_s \times Csoil + DF_{poultry_{forage}} \times P_{forage} + DF_{poultry_{feed}} \times P_{feed})$$

Name	**Description**	**Location**
0.1	Fraction of fat in poultry (unitless)	
B_s	Bioavailability of contaminant on the soil vehicle relative to the vegetative vehicle (unitless)	See Appendix I
BCF_poultry	Bioconcentration ratio of contaminant developed for chicken vegetative intake (unitless)	See Appendix D
C_fat	Concentration of dioxin (2,3,7,8-TCDD) in chicken fat (mg/kg)	Calculated
Csoil	Average contaminant soil concentration (mg/kg)	Calculated in Tables H-2.3, H-2.4
DF_poultry_feed	Fraction of chicken diet that is feed (unitless)	See Appendix I
DF_poultry_forage	Fraction of chicken diet that is incidental vegetation while free ranging (unitless)	See Appendix I
DF_poultry_soil	Fraction of chicken diet that is soil (unitless)	See Appendix I
P_feed	Average concentration of contaminant in feed (mg/kg)	Calculated
P_forage	Average concentration of contaminant on free range vegetation (mg/kg)	Calculated

Source: U.S. EPA, 2000.

Table H-3.5. Cfish - Concentration in Fish (mg/kg)

Cfish

$$Cfish = Cfish_{lipid} \times LF$$

$$Cfish_{lipid} = BASF \times Csed$$

Name	Description	Location
BSAF	Biota sediment accumulation factor (unitless)	See Appendix D
Cfish_lipid	Concentration of contaminant in fish lipid (mg/kg)	Calculated
Csed	Concentration in sediment settling to bottom (mg/kg)	Calculated in Table H-2.2
LF	Lipid fraction (unitless)	See Appendix I

Source: U.S. EPA, 1998.

Table H-3.6. Dp - Deposition Term for Plants (mg/m2-yr)

Dp

$$D_p = 1000 \times Q \times (1 - F_v) \times (Dydp + (F_w \times Dywp))$$

Name	**Description**	**Location**
1000	Conversion factor (mg/g)	
Dydp	Normalized annual average dry deposition from particle phase (s-m2/m2-yr)	See Appendix G
Dywp	Normalized annual average wet deposition from particle phase(s-m2/m2-yr)	See Appendix G
Fv	Fraction of air concentration in vapor phase (unitless)	See Appendix D
Fw	Fraction of wet deposition adhering to plant surface (unitless)	See Appendix D
Q	Emission rate from source (g/s-m2)	Calculated by Source Model

Source: U.S. EPA, 1997.

Table H-3.7. Iag - Daily Intake of Contaminant from Consumption of Above-Ground Produce (mg/kg BW/d)

Iag

$$Iag = I_{exfruit} + I_{exveg}$$

$$I_{exveg} = \frac{CR_{exveg}}{1000} \times F_{exveg} \times P_{exveg} \times (1 - L_{exveg})$$

$$I_{exfruit} = \frac{CR_{exfruit}}{1000} \times F_{exfruit} \times P_{exfruit} \times (1 - L_{exfruit})$$

Name	Description	Location
1000	Unit conversion (g/kg)	
CR_exfruit	Daily human consumption rate of exposed fruit (g WW/kg BW/day)	See Appendix J
CR_exveg	Daily human consumption rate of exposed vegetables (g WW/kg BW/day)	See Appendix J
F_exfruit	Fraction of exposed fruit grown in contaminated soil (unitless)	See Appendix J
F_exveg	Fraction of exposed vegetables grown in contaminated soil (unitless)	See Appendix J
I_exfruit	Daily intake of contaminant from consumption of exposed fruit (mg/kg BW/d)	Calculated
I_exveg	Daily intake of contaminant from consumption of exposed vegetables (mg/kg BW/d)	Calculated
L_exfruit	Food preparation loss for exposed fruit (unitless)	See Appendix J
L_exveg	Food preparation loss for exposed vegetables (unitless)	See Appendix J
P_exfruit	Exposed fruit concentration (mg/kg)	Calculated
P_exveg	Exposed vegetable concentration (mg/kg)	Calculated

Source: U.S. EPA, 1998.

Table H-3.8. Ianimal - Daily Intake of Contaminant from Ingestion of ith Animal Tissue Group (mg/kg BW/d)

Ianimal

$$I_{animal} = A_i \times F_i \times L_i \times \frac{CR_i}{1000}$$

Name	Description	Location
1000	Unit conversion (g/kg)	
Ai	Concentration of contaminant in ith animal tissue group (mg/kg WW)	Calculated in Tables H-3.1, H-3.2, H-3.3, H-3.4
CRi	Daily human consumption rate of ith animal tissue group (g WW/kg BW/day)	See Appendix J
Fi	Fraction of animal tissue that is contaminated (unitless)	See Appendix J
Li	Contaminant loss factor (unitless)	See Appendix J

Source: U.S. EPA, 1998.

Table H-3.9. Ibg - Daily Intake of Contaminant from Consumption of Below-Ground Produce (mg/kg-d)

Ibg

$$I_{bg} = \frac{CR_{bg}}{1000} \times Pr_{bg} \times F_{bg} \times (1 - L_{bg})$$

Name	**Description**	**Location**
1000	Unit conversion (g/kg)	
CR_bg	Daily human consumption rate of below ground vegetables (g WW/kg BW/day)	See Appendix J
F_bg	Fraction of below ground vegetables grown in contaminated soil (unitless)	See Appendix J
L_bg	Food preparation loss for root vegetables (unitless)	See Appendix J
Prbg	Below ground vegetable concentration in whole weight (mg/kg WW)	Calculated in Table H-3.13

Source: U.S. EPA, 1998.

Table H-3.10. Ifish - Daily Intake of Contaminant from Consumption of Fish (mg/kg-d)

Ifish

$$Ifish = \frac{Cfish \times CR_{fish} \times F_{fish}}{BW \times 1000}$$

$$Cfish = (F_{T3} \times C_{fishT3F}) + (F_{T4} \times C_{fishT4F})$$

Name	**Description**	**Location**
1000	Unit conversion (g/kg)	
BW	Body weight (kg)	See Appendix J
C_fishT3F	Concentration of contaminant in T3 fish (mg/kg)	Calculated
C_fishT4F	Concentration of contaminant in T4 fish (mg/kg)	Calculated
Cfish	Concentration of contaminant in fish (mg/kg)	Calculated in Table H-3.5
CRf	Consumption rate of fish (g WW/day)	See Appendix J
F_fish	Fraction of fish intake from contaminated source (unitless)	See Appendix J
F_T3	Fraction of trophic level 3 intake, 0.36 (unitless)	
F_T4	Fraction of trophic level 4 intake, 0.64 (unitless)	

Source: U.S. EPA, 1998.

Table H-3.11. Isoil - Daily Intake of Contaminant from Incidental Ingestion of Soil (mg/kg-d)

Isoil

$$I_{soil} = \frac{C_{soil} \times CR_s \times F_{soil}}{BW}$$

Name	**Description**	**Location**
BW	Body weight (kg)	See Appendix J
CRs	Soil ingestion rate (kg/day)	See Appendix J
Csoil	Concentration of contaminant in soil (mg/kg)	Calculated in Tables H-2.3, H-2.4
Fsoil	Fraction of contaminated soil that is ingested (unitless)	See Appendix J

Source: U.S. EPA, 1998.

Table H-3.12. Pd - Vegetative Concentration Due to Direct Deposition (mg/kg - DW)

Pd
$$Pd = \frac{(Dp \times Rp)}{(Yp \times KpPar)}$$

Name	**Description**	**Location**
Dp	Deposition term for plants (mg/m2-yr)	Calculated in Table H-3.6
KpPar	Plant surface loss coefficient, particulate (1/yr)	See Appendix D
Rp	Interception fraction - above-ground vegetables (fraction)	See Appendix I
Yp	Crop yield (kg DW/m2)	See Appendix I

Source: U.S. EPA, 2000.

Table H-3.14. Pr - Above-ground vegetation concentration due to root uptake (mg/kg - DW)

Pr

$$Pr = Csoil \times Br$$

Name	Description	Location
Br	Soil-to-plant bioconcentration factor (ug/g DW plant / ug/g soil)	
Csoil	Soil concentration due to deposition to soil (mg/kg)	Calculated

Source: U.S. EPA, 1998. In this analysis Br was set to 0.

Table H-3.13. Prbg - Concentration in Below-Ground Vegetation Due to Root Uptake (mg/kg - WW)

Prbg

$$Pr_{bg} = \frac{C_{soil} \times RCF \times VG_{bg}}{Kd}$$

Name	**Description**	**Location**
Csoil	Concentration of contaminant in soil (mg/kg)	Calculated in Tables H-2.3, H-2.4
RCF	Root concentration factor (ug/g - WW plant) / (ug/mL soil water)	See Appendix D
VGbg	Empirical correction factor for below ground vegetables (unitless)	See Appendix I

Source: U.S. EPA, 1998.

Table H-3.15. Pv - Vegetative Concentration Due to Air-to-Plant Transfer
(mg/kg - DW)

Pv

$$Pv = \frac{C_{vapor} \times Bv \; x \; VG_{ag} \times 1000}{1200}$$

Name	**Description**	**Location**
1000	Conversion factor (g/kg)	
1200	Rho_air is the density of air (g/m3)	
Bv	Air-to-plant biotransfer factor (ug/g DW plant / ug/g air)	See Appendix D
Cvapor	Concentration of vapor (mg/m3)	Calculated in Table H-2.7
VGag	Empirical correction factor for above ground vegetables (unitless)	See Appendix I

Source: U.S. EPA, 1998.

Table H-3.16. Pveg - Total Concentration in Above-Ground Vegetation (mg/kg - WW or DW)

Pveg

$$Pveg_{WW} = (Pd_{veg} + Pv_{veg} + Pr_{veg}) \times \frac{(100 - MAF)}{100}$$

$$Pveg_{DW} = (Pd_{veg} + Pv_{veg} + Pr_{veg})$$

Name	**Description**	**Location**
MAF	Plant tissue-specific moisture adjustment factor to convert DW concentration into WW (percent)	
Pd_veg	Vegetative concentration due to direct deposition (mg/kg - DW)	Calculated in Table H-3.12
Pr	Above-ground vegetation concentration due to root uptake, zero for dioxins (mg/kg - DW)	Calculated in Table H-3.13
Pv_veg	Vegetative concentration due to air-to-plant transfer (mg/kg - DW)	Calculated in Table H-3.14

Source: U.S. EPA, 1998.

Note: For exposed vegetataion MAF is 92, for exposed fruit MAF is 85, and for protected fruit MAF is 90. Dry weight is used for forage and feed. Wet weight is used for exposed vegetataion, exposed fruit, and protected fruit

Table H-3.17. Risk_Air - Risk Due to Inhalation (unitless)

Risk_Air

$$Risk_{Air} = TEF \times \frac{(C_{air} \times B_{ri} \times ED_i \times EF_i \times CSFInhal)}{(AT \times 365 \times BW)}$$

Name	Description	Location
365	Conversion factor (days/yr)	
AT	Averaging time (yr)	See Appendix J
Bri	Breathing rate (m3/d)	See Appendix J
BW	Body weight (kg)	See Appendix J
Cair	Concentration of contaminant in air (mg/m3)	Calculated in Table H-2.1
CSFInhal	Inhalation cancer slope factor (mg/kg/d)-1	See Section 2
EDi	Exposure duration for inhalation (yr)	See Appendix J
EFi	Exposure frequency (d/yr)	See Appendix J
TEF	Toxicity equivalency factor (unitless)	See Appendix D

Note: For adults with an ED greater than 50, AT is the ED plus 20. For children with an ED greater than 70, AT is the ED. Otherwise the AT is set to 70 years.

Table H-3.18. Risk_Oral - Risk Due to Ingestion (unitless)

Risk_Oral

$$Risk_{Oral} = TEF \times \frac{(I \times ED \times EF \times CSFOral)}{(AT \times 365)}$$

Name	Description	Location
365	Conversion factor (days/yr)	
AT	Averaging time (yr)	See Appendix J
CSFOral	Oral cancer slope factor (mg/kg/d)-1	See Section 2
ED	Exposure duration for oral ingestion (yr)	See Appendix J
EF	Exposure frequency (d/yr)	See Appendix J
TEF	Toxicity equivalency factor (unitless)	See Appendix D

Note: For adults with an ED greater than 50, AT is the ED plus 20. For children with an ED greater than 70, AT is the ED. Otherwise the AT is set to 70 years.

Appendix I

Variables for Aboveground Fate and Transport

Table I-1. Waterbody and Soil Parameters with Constant Values

Parameter Code	Parameter Description	Value
foc_bs	Fraction organic carbon for bed sediments (unitless)	0.04
foc_sw	Fraction organic carbon for suspended sediments (unitless)	0.075
bsc	Bed sediment concentration (kg/L)	1
bsp	Bed sediment porosity (cm^3/cm^3)	0.6
db	Depth of upper benthic layer (m)	0.03
dw	Depth of water column (m)	0.18
dz	Waterbody depth (m)	0.21
G	Gas phase transfer coefficient (m/yr)	36500
U	Velocity of the stream (m/s)	0.5
TSS	Total suspended solids in water column (mg/L)	10
Zt	Mixing depth of soil - tilled (cm) - pasture	20 2
Zu	Mixing depth of soil - untilled (cm)	1

Source: U.S. EPA (Environmental Protection Agency). 1998. *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions. Update to EPA/600/6-90/003 Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. EPA 600/R-98/137. Washington, DC: U.S. Government Printing Office.

Table I-2. Biota Parameters for Farm Food Chain Algorithms

Parameter Code	Parameter Description	Parameter Type	Value
Rp	Interception fraction (unitless)	Exposed fruit Exposed vegetables Forage Feed	0.48 0.48 0.35 0.62
VG	Empirical correction factor (unitless)	Exposed fruit Exposed vegetables Belowground roots Forage Feed	0.01 0.01 0.25 1.00 0.50
Yp	Crop yield (kg DW/m^2)	Exposed fruit Exposed vegetables Forage Feed	1.17 1.17 0.15 0.63
DF_beef	Fraction of diet from contaminated source for beef cattle (unitless)	Soil Forage Feed	0.04 0.48 0.48
DF_dairy	Fraction of diet from contaminated source for dairy cattle (unitless)	Soil Forage Feed	0.02 0.08 0.90
DF_poultry	Fraction of diet from contaminated source for poultry (unitless)	Soil Forage Feed	0.10 0.05 0
LF	Lipid fraction for fish (unitless)	Trophic Level 3 Trophic Level 4	0.0182 0.031
FF	Fraction of diet from feed lot for cattle (unitless)		1.00
Bs	Bioavailability for soil (unitless)		0.65

Source: U.S. EPA (Environmental Protection Agency). 2000. *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds. Volume 4: Site-Specific Assessment Procedures*. Draft. Exposure Assessment and Risk Characterization Group, Office of Research and Development, Washington, DC. September.

Appendix J

Human Exposure Factors

Appendix J

Human Exposure Factors

Exposure factors are data that quantify human behavior patterns (e.g., ingestion rates of beef and fruit) and characteristics (e.g., body weight) that affect their exposure to environmental contaminants. These data can be used to construct realistic assumptions concerning an individual's exposure to and subsequent intake of a contaminant in the environment. The exposure factors data also enable the U.S. Environmental Protection Agency (EPA) to differentiate the exposures of individuals who have different lifestyles (e.g., a resident vs. a farmer and a child vs. an adult). The derivation and values used for the human exposure factors in this risk assessment are described here and the exposure factors selected for the probabilistic and deterministic analyses are presented.

J.1 Exposure Parameters Used in Probabilistic Analysis

J.1.1 Introduction

The general methodology for collecting human exposure data for the probabilistic analysis relied on the *Exposure Factors Handbook* (U.S. EPA, 1997a), which was used in one of three ways:

1. When *Exposure Factors Handbook* (EFH) percentile data were adequate (most input variables), maximum likelihood estimation was used to fit selected parametric models (gamma, lognormal, Weibull, and generalized gamma) to the EFH data. The chi-square measure of goodness of fit was then used to choose the best distribution. Parameter uncertainty information (e.g., for averages, standard deviations) also was derived using the asymptotic normality of the maximum likelihood estimate or a regression approach.

2. For a few variable conditions when percentile data were not adequate for statistical model fitting, models were selected on the basis of results for other age cohorts or, if no comparable information was available, by assuming lognormal as a default distribution and reasonable coefficients of variation (CVs).

3. Other variables for which data were not adequate for either 1 or 2 above were fixed at EFH-recommended mean values or according to established EPA policy.

Table J-1 summarizes all of the parameters used in the probabilistic analysis. Both fixed variables and the values used to define distributed data are provided.

J.1.2 Exposure Parameter Distribution Methodology

Exposure parameter distributions were developed for use in the Monte Carlo analysis. For most variables for which distributions were developed, exposure factor data from the EFH were analyzed to fit selected parametric models (i.e., gamma, lognormal, Weibull). Steps in the development of distributions included preparing data, fitting models, assessing fit, and preparing parameters to characterize distributional uncertainty in the model inputs.

For many exposure factors, EFH data include sample sizes and estimates of the following parameters for specific receptor types and age groups: mean, standard deviation, standard error, and percentiles corresponding to a subset of the following probabilities–0.01, 0.02, 0.05, 0.10, 0.15, 0.25, 0.50, 0.75, 0.85, 0.90, 0.95, 0.98, and 0.99. These percentile data were used as a basis for fitting distributions where available. Although in no case are all of these percentiles actually provided for a single factor, seven or more are typically present in the EFH data. Therefore, using the percentiles is a fuller use of the available information than simply fitting data based on the method of moments (e.g., selecting models that agree with the data mean and standard deviation). For some factors, certain percentiles were not used in the fitting process because sample sizes were too small to justify their use. Percentiles were used only if at least one data point was in the tail of the distribution. If the EFH data repeated a value across several adjacent percentiles, only one value (the most central or closest to the median) was used in most cases (e.g., if both the 98th and 99th percentiles had the same value, only the 98th value was used).

The EFH does not use standardized age cohorts across exposure factors. Different exposure factors have data reported for different age categories. Therefore, to obtain the percentiles for fitting the four standardized age cohorts (i.e., ages 1 to 5, 6 to 11, 12 to 19, and more than 20), each EFH cohort-specific value for a given exposure factor was assigned to one of these four cohorts. When multiple EFH cohorts fit into a single cohort, the EFH percentiles were averaged within each cohort (e.g., data on 1- to 2- and 3- to 5-year-olds were averaged for the 1- to 5-year old cohort). If sample sizes were available, weighted averages were used, with weights proportional to sample sizes. If sample sizes were not available, equal weights were assumed (i.e., the percentiles were simply averaged).

Because the EFH data are always positive and almost always skewed to the right (i.e., have a long right tail), three two-parameter probability models commonly used to characterize such data (gamma, lognormal, and Weibull) were selected. In addition, a three-parameter model (generalized gamma) was used that unifies them[1] and allows for a likelihood ratio test of the fit of the two-parameter models. However, only the two-parameter models were selected for use in the analysis because the three-parameter generalized gamma model did not significantly improve the goodness of fit over the two-parameter models. This simple setup constitutes a considerable improvement over the common practice of using a lognormal model in which adequate EFH data were available to support maximum likelihood estimation. However, in a few cases (e.g.,

[1] Gamma, Weibull, and lognormal distributions are all special cases of the generalized gamma distribution.

Table J-1. Summary of Exposure Parameters used in Probabilistic Analysis

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Averaging time for carcinogens	yr	Constant	7.00E+01					U.S. EPA (1989) (RAGS)
Body weight (adult)	kg	Lognormal		7.12E+01	1.33E+01	1.50E+01	3.00E+02	U.S. EPA (1997a); Tbl 7-2, 7-4, 7-5
Body weight (child 1)	kg	Lognormal		1.55E+01	2.05E+00	4.00E+00	5.00E+01	U.S. EPA (1997b); Tbl 7-3, 7-6, 7-7
Body weight (child 2)	kg	Lognormal		3.07E+01	5.96E+00	6.00E+00	2.00E+02	U.S. EPA (1997a); Tbl 7-3, 7-6, 7-7
Body weight (child 3)	kg	Lognormal		5.82E+01	1.02E+01	1.30E+01	3.00E+02	U.S. EPA (1997a); Tbl 7-3, 7-6, 7-7
Body weight (infant)	kg	Gamma		5.42E+01	1.70E-01	2.00E+00	2.60E+01	U.S. EPA (1997a); Tbl 7-3, 7-6, 7-7
Consumption rate: beef (adult farmer)	g WW/kg-d	Lognormal		2.50E+00	2.69E+00	0.00E+00	2.30E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: beef (child 1 farmer)	g WW/kg-d	Lognormal		3.88E+00	4.71E+00	0.00E+00	3.60E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: beef (child 2 farmer)	g WW/kg-d	Lognormal		3.88E+00	4.71E+00	0.00E+00	3.60E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: beef (child 3 farmer)	g WW/kg-d	Gamma		2.47E+00	7.10E-01	0.00E+00	1.00E+01	U.S. EPA (1997b); Tbl 13-36
Consumption rate: breast milk (infant)	mL/d	Triangle		6.88E+02	6.88E+02	0.00E+00	1.38E+03	U.S. EPA (1997b); Tbl 14-16
Consumption rate: egg (adult farmer)	g WW/kg-d	Gamma		1.64E+00	4.88E-01	0.00E+00	1.30E+01	U.S. EPA (1997b); Tbl 11-7, 13-43; USDA (1997)
Consumption rate: egg (child 1 farmer)	g WW/kg-d	Gamma		1.88E+00	8.39E-01	0.00E+00	1.00E+01	U.S. EPA (1997b); Tbl 11-7, 13-43; USDA (1997)
Consumption rate: egg (child 2 farmer)	g WW/kg-d	Gamma		1.88E+00	4.93E-01	0.00E+00	6.00E+00	U.S. EPA (1997b); Tbl 11-7, 13-43; USDA (1997)
Consumption rate: egg (child 3 farmer)	g WW/kg-d	Gamma		1.88E+00	3.34E-01	0.00E+00	4.00E+00	U.S. EPA (1997b); Tbl 11-7, 13-43; USDA (1997)
Consumption rate: exposed fruit (adult farmer)	g WW/kg-d	Lognormal		2.36E+00	3.33E+00	0.00E+00	3.10E+01	U.S. EPA (1997b); Tbl 13-61

(continued)

Table J-1. (continued)

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Consumption rate: exposed fruit (child 1 farmer)	g WW/kg-d	Gamma		1.43E+00	1.58E+00	0.00E+00	1.60E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (child 2 farmer)	g WW/kg-d	Lognormal		2.78E+00	5.12E+00	0.00E+00	3.60E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (child 3 farmer)	g WW/kg-d	Lognormal		1.54E+00	2.44E+00	0.00E+00	1.80E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (adult home gardener)	g WW/kg-d	Lognormal		1.57E+00	2.30E+00	0.00E+00	2.60E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (child 1 home gardener)	g WW/kg-d	Gamma		1.43E+00	1.58E+00	0.00E+00	1.60E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (child 2 home gardener)	g WW/kg-d	Lognormal		2.78E+00	5.12E+00	0.00E+00	3.60E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed fruit (child 3 home gardener)	g WW/kg-d	Lognormal		1.54E+00	2.44E+00	0.00E+00	1.80E+01	U.S. EPA (1997b); Tbl 13-61
Consumption rate: exposed vegetables (adult farmer)	g WW/kg-d	Lognormal		2.38E+00	3.50E+00	0.00E+00	2.60E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 1 farmer)	g WW/kg-d	Gamma		9.70E-01	2.62E+00	0.00E+00	2.10E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 2 farmer)	g WW/kg-d	Lognormal		1.64E+00	3.95E+00	0.00E+00	2.70E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 3 farmer)	g WW/kg-d	Gamma		9.10E-01	1.19E+00	0.00E+00	1.10E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (adult home gardener)	g WW/kg-d	Weibull		8.90E-01	1.48E+00	0.00E+00	2.10E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 1 home gardener)	g WW/kg-d	Gamma		9.70E-01	2.62E+00	0.00E+00	2.10E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 2 home gardener)	g WW/kg-d	Lognormal		1.64E+00	3.95E+00	0.00E+00	2.70E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: exposed vegetables (child 3 home gardener)	g WW/kg-d	Gamma		9.10E-01	1.19E+00	0.00E+00	1.10E+01	U.S. EPA (1997b); Tbl 13-63
Consumption rate: fish (adult)	g/d	Lognormal		6.48E+00	1.99E+01	0.00E+00	1.50E+03	U.S. EPA (1997b); Tbl 10-64

(continued)

Table J-1. (continued)

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Consumption rate: milk (adult farmer)	g WW/kg-d	Gamma		1.38E+00	1.19E+01	0.00E+00	1.16E+02	U.S. EPA (1997b); Tbl 13-28; CSFII (1997)
Consumption rate: milk (child 1 farmer)	g WW/kg-d	Gamma		9.61E-01	6.18E+01	0.00E+00	4.82E+02	U.S. EPA (1997b); Tbl 11-2, 13-28; USDA (1997)
Consumption rate: milk (child 2 farmer)	g WW/kg-d	Gamma		9.61E-01	3.14E+01	0.00E+00	2.45E+02	U.S. EPA (1997b); Tbl 11-2, 13-28; USDA (1997)
Consumption rate: milk (child 3 farmer)	g WW/kg-d	Gamma		9.61E-01	1.39E+01	0.00E+00	1.09E+02	U.S. EPA (1997b); Tbl 11-2, 13-28; USDA (1997)
Consumption rate: poultry (adult farmer)	g WW/kg-d	Gamma		1.38E+00	1.16E+00	0.00E+00	1.10E+01	U.S. EPA (1997b); Tbl 11-5, 13-55; USDA (1997)
Consumption rate: poultry (child 1 farmer)	g WW/kg-d	Gamma		1.69E+00	1.92E+00	0.00E+00	2.10E+01	U.S. EPA (1997b); Tbl 11-5, 13-55; USDA (1997)
Consumption rate: poultry (child 2 farmer)	g WW/kg-d	Gamma		1.69E+00	1.21E+00	0.00E+00	1.40E+01	U.S. EPA (1997b); Tbl 11-5, 13-55; USDA (1997)
Consumption rate: poultry (child 3 farmer)	g WW/kg-d	Gamma		1.69E+00	8.70E-01	0.00E+00	1.00E+01	U.S. EPA (1997b); Tbl 11-5, 13-55; USDA (1997)
Consumption rate: root vegetables (adult farmer)	g WW/kg-d	Lognormal		1.45E+00	2.06E+00	0.00E+00	1.50E+01	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (child 1 farmer)	g WW/kg-d	Lognormal		2.31E+00	6.05E+00	0.00E+00	4.10E+01	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (child 2 farmer)	g WW/kg-d	Weibull		6.80E-01	1.06E+00	0.00E+00	1.50E+01	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (child 3 farmer)	g WW/kg-d	Weibull		8.40E-01	9.10E-01	0.00E+00	9.00E+00	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (adult home gardener)	g WW/kg-d	Weibull		8.70E-01	1.07E+00	0.00E+00	1.50E+01	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (child 1 home gardener)	g WW/kg-d	Lognormal		2.31E+00	6.05E+00	0.00E+00	4.10E+01	U.S. EPA (1997b); Tbl 13-65

(continued)

Table J-1. (continued)

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Consumption rate: root vegetables (child 2 home gardener)	g WW/kg-d	Weibull		6.80E-01	1.06E+00	0.00E+00	1.50E+01	U.S. EPA (1997b); Tbl 13-65
Consumption rate: root vegetables (child 3 home gardener)	g WW/kg-d	Weibull		8.40E-01	9.10E-01	0.00E+00	9.00E+00	U.S. EPA (1997b); Tbl 13-65
Exposure duration (adult resident)	yr	Weibull		1.34E+00	1.74E+01	1.00E+00	1.00E+02	U.S. EPA (1999) (ACS)
Exposure duration (child resident, child farmer)	yr	Weibull		1.32E+00	7.06E+00	1.00E+00	1.00E+02	U.S. EPA (1999) (ACS)
Exposure duration (adult farmer)	yr	Gamma		6.07E-01	2.98E+01	1.00E+00	1.00E+02	U.S. EPA (1997c); Tbl 15-163, 15-164
Exposure frequency	d/y	Constant	3.50E+02					U.S. EPA (1991)
Fraction home caught: fish	Fraction	Constant	1.00E+00					U.S. EPA policy
Fraction home-produced: beef (farmer)	Fraction	Constant	4.85E-01					U.S. EPA (1997b); Tbl 13-71
Fraction home-produced: milk (farmer)	Fraction	Constant	2.54E-01					U.S. EPA (1997b); Tbl 13-71
Fraction home-produced: egg (farmer)	Fraction	Constant	1.46E-01					U.S. EPA (1997b); Tbl 13-71
Fraction home-produced: poultry (farmer)	Fraction	Constant	1.56E-01					U.S. EPA (1997b); Tbl 13-71
Fraction contaminated: soil	Fraction	Constant	1.00E+00					U.S. EPA Policy
Fraction homegrown: exposed fruit (farmer)	Fraction	Constant	3.28E-01					U.S. EPA (1997b); Tbl 13-71
Fraction homegrown: exposed vegetables (farmer)	Fraction	Constant	4.20E-01					U.S. EPA (1997b); Tbl 13-71
Fraction homegrown: root vegetables (farmer)	Fraction	Constant	1.73E-01					U.S. EPA (1997b); Tbl 13-71
Fraction homegrown: exposed fruit (home gardener)	Fraction	Constant	1.16E-01					U.S. EPA (1997b); Tbl 13-71
Fraction homegrown: exposed vegetables (home gardener)	Fraction	Constant	2.33E-01					U.S. EPA (1997b); Tbl 13-71

(continued)

Table J-1. (continued)

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Fraction homegrown: root vegetables (home gardener)	Fraction	Constant	1.06E-01					U.S. EPA (1997b); Tbl 13-71
Fraction food preparation loss: exposed fruit	Fraction	Constant	2.10E-01					U.S. EPA (1997b); Tbl 13-6
Fraction food preparation loss: exposed vegetables	Fraction	Constant	1.61E-01					U.S. EPA (1997b); Tbl 13-7
Fraction food preparation loss: root vegetables	Fraction	Constant	5.30E-02					U.S. EPA (1997b); Tbl 13-7
Percent cooking loss: beef	Fraction	Constant	2.70E-01					U.S. EPA (1997b); Tbl 13-5
Percent postcooking loss: beef	Fraction	Constant	2.40E-01					U.S. EPA (1997b); Tbl 13-5
Percent cooking loss: poultry	Fraction	Constant	3.20E-01					U.S. EPA (1997b); Tbl 13-5
Percent postcooking loss: poultry	Fraction	Constant	2.95E-01					U.S. EPA (1997b); Tbl 13-5
Fraction of fish consumed that is trophic level 3 (T3) fish	Fraction	Constant	3.60E-01					U.S. EPA (1997b); Tbl 10-66
Fraction of fish consumed that is trophic level 4 (T4) fish	Fraction	Constant	6.40E-01					U.S. EPA (1997b); Tbl 10-66
Ingestion rate: soil (adult)	kg/d	Constant	5.00E-05					U.S. EPA (1997a); Tbl 4-23
Ingestion rate: soil (child 1)	kg/d	Constant	1.00E-04					U.S. EPA (1997a); Tbl 4-23
Ingestion rate: soil (child 2)	kg/d	Constant	5.00E-05					U.S. EPA (1997a); Tbl 4-23
Ingestion rate: soil (child 3)	kg/d	Constant	5.00E-05					U.S. EPA (1997a); Tbl 4-23
Inhalation (breathing) rate (adult)	m^3/d	Lognormal		1.33E+01	3.99E+00	1.00E+00	5.00E+01	U.S. EPA (1997a), U.S. EPA (2000a)
Inhalation (breathing) rate (child 1)	m^3/d	Lognormal		7.55E+00	3.78E+00	1.00E+00	4.00E+01	U.S. EPA (1997a), U.S. EPA (2000a)
Inhalation (breathing) rate (child 2)	m^3/d	Lognormal		1.18E+01	3.53E+00	1.00E+00	4.50E+01	U.S. EPA (1997a), U.S. EPA (2000a)
Inhalation (breathing) rate (child 3)	m^3/d	Lognormal		1.40E+01	4.20E+00	1.00E+00	5.50E+01	U.S. EPA (1997a), U.S. EPA (2000a)

inhalation rate), data were not adequate to fit a distribution, and the lognormal model was assumed as the default.

Lognormal, gamma, Weibull, and generalized gamma distributions were fit to each factor data set using maximum likelihood estimation (Burmaster and Thompson, 1998). When sample sizes were available, the goodness of fit was calculated for each of the four models using the chi-square test (Bickel and Doksum, 1977). When percentile data were available but sample sizes were unknown, a regression F-test for the goodness of fit against the generalized gamma model was used. For each of the two-parameter models, parameter uncertainty information (i.e., mean, standard deviation, scale, and shape) was provided as parameter estimates for a bivariate normal distribution that could be used for simulating parameter values (Burmaster and Thompson, 1998). The information necessary for such simulations includes estimates of the two model parameters, their standard errors, and their correlation. To obtain this parameter uncertainty information, the asymptotic normality of the maximum likelihood estimate (Burmaster and Thompson, 1998) was used when sample sizes were available, and a regression approach was used when sample sizes were not available (Jennrich and Moore, 1975; Jennrich and Ralston, 1979). In either case, uncertainty can be expressed as a bivariate normal distribution for the model parameters.

This section describes how stochastic or distributed input data for each exposure factor were collected and processed. Section J.1.3 discusses fixed parameters. Section J.1.4 describes, for each exposure factor, the EFH data used to develop the distributions, along with the final distributional statistics. Section J.1.5 describes minimums and maximums. Summary tables provided at the end of this appendix (Tables J-17, J-18, J-19, and J-20) present the final (raw) EFH data used to develop each exposure factor distribution used and the models selected (i.e., lognormal, Weibull, or gamma) and estimated means and standard deviations for each of the two-parameter models fit to the exposure factors data.

J.1.3 Fixed Parameters

Certain parameters were fixed, based on central tendency values from the best available source (usually *Exposure Factors Handbook* recommendations), either because no variability was expected or because the available data were not adequate to generate distributions. Fixed (constant) parameters are shown in Table J-2 along with the value selected for the risk analysis and data source. These constants include variables for which limited or no percentile data were provided in the EFH: exposure frequency and fraction contaminated for the various media and foodstuffs. Most of these values were extracted directly from the EFH. The fraction contaminated for various foodstuffs was assumed to be equivalent to the fraction of household food intake that is attributed to home-produced forms of the food items evaluated (Table 13-71, U.S. EPA, 1997b). The fraction of consumed trophic level 3 (T3) and trophic level 4 (T4) fish was determined from data in Table 10-66 of the EFH (U.S. EPA, 1997b), which contains the only fish consumption data reported in the handbook with an adequate species breakdown to make this distinction. When evaluating carcinogens, total dose is averaged over the lifetime of the individual, assumed to be 70 years.

Table J-2. Summary of Human Exposure Factor Data Used in Modeling: Constants

Description	Units	Average	Source
Fraction homegrown: exposed fruit (farmer)	Fraction	0.328	EFH, Table 13-71
Fraction homegrown: exposed fruit (home gardener)	Fraction	0.116	EFH, Table 13-71
Fraction homegrown: exposed vegetables (farmer)	Fraction	0.42	EFH, Table 13-71
Fraction homegrown: exposed vegetables (home gardener)	Fraction	0.233	EFH, Table 13-71
Fraction homegrown: root vegetables (farmer)	Fraction	0.173	EFH, Table 13-71
Fraction homegrown: root vegetables (home gardener)	Fraction	0.106	EFH, Table 13-71
Fraction home-raised: beef (farmer)	Fraction	0.485	EFH, Table 13-71
Fraction home-produced: milk (farmer)	Fraction	0.254	EFH, Table 13-71
Fraction home-produced: egg (farmer)	Fraction	0.146	EFH, Table 13-71
Fraction home-produced: poultry (farmer)	Fraction	0.156	EFH, Table 13-71
Fraction food preparation loss: exposed fruit	Fraction	0.21	EFH, Table 13-6
Fraction food preparation loss: exposed vegetables	Fraction	0.161	EFH, Table 13-7
Fraction food preparation loss: root vegetables	Fraction	0.053	EFH, Table 13-7
Percent cooking loss: beef	Fraction	0.27	EFH, Table 13-5
Percent postcooking loss: beef	Fraction	0.24	EFH, Table 13-5
Percent cooking loss: poultry	Fraction	0.32	EFH, Table 13-5
Percent postcooking loss: poultry	Fraction	0.295	EFH, Table 13-5
Fraction home caught: fish (recreational fisher)	Fraction	1	EPA policy
Fraction of trophic level 3 (T3) fish consumed	Fraction	0.36	EFH, Table 10-66
Fraction of trophic level 4 (T4) fish consumed	Fraction	0.64	EFH, Table 10-66
Fraction contaminated: soil	Fraction	1	EPA policy
Exposure frequency (adult home gardener, fisher, farmer; child home gardener, farmer)	d/yr	350	EPA policy
Averaging time for carcinogens (adult home gardener, fisher, farmer; child home gardener, farmer)	yr	70	U.S. EPA, 1989, RAGS
Ingestion rate: soil (adult, 6- to 11-yr-old child, 12- to 19-yr-old child)	kg/d	5.0E-5	EFH, Table 4-23
Ingestion rate: soil (1- to 5-yr-old child)	kg/d	1.0E-4	EFH, Table 4-23
Biological half-life of contaminant in lactating women	d	2555	U.S. EPA, 1998, 2000b
Concentration in aqueous phase of maternal milk	mg/kg	0	U.S. EPA, 1998
Fraction of fat in maternal breast milk	Fraction	0.04	U.S. EPA, 1998, 2000b
Fraction of ingested contaminant absorbed by the infant	Fraction	0.9	U.S. EPA, 1998, 2000c
Fraction of ingested contaminant absorbed by the mother	Fraction	1	U.S. EPA, 1998
Fraction of mother's weight that is fat	Fraction	0.3	U.S. EPA, 1998, 2000b
Proportion of contaminant stored in maternal fat	Fraction	0.9	U.S. EPA, 1998, 2000b

Source: EFH (U.S. EPA, 1997a, 1997b, 1997c)

The fraction contaminated for soil was assumed to be 1 (i.e., all soil available for consumption at a site is potentially contaminated), with actual concentrations depending on fate and transport model results. Exposure frequency was set to 350 days per year in accordance with EPA policy, assuming that residents take an average of 2 weeks' vacation time away from their homes each year.

Mean soil ingestion rates were cited as 100 mg/d for children and 50 mg/d for adults (Table 4-23, U.S. EPA, 1997a). No percentile data were recommended for use in the EFH. Adult data were also used for the 6- to 11- and 12- to 19-yr-olds. The soil ingestion rates were not varied for the probabilistic analysis.

J.1.4 Variable Parameters

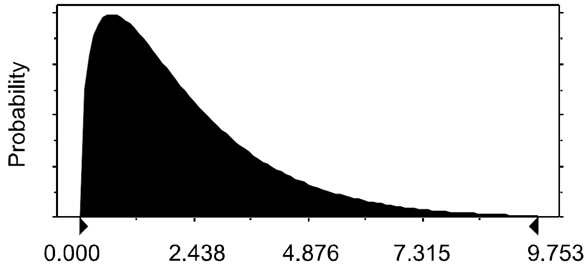
J.1.4.1 Exposed Fruit Consumption. Table J-3 presents exposed fruit consumption data. Data for consumption of homegrown exposed fruit were obtained from Table 13-61 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg-d) were presented by age groups and for farmers and home gardeners (adults). For the 1- to 5-yr old age group, data were only available for those ages 3 to 5 years (not available for 1- to 2-yr-olds); therefore, these data were used for the entire 1- to 5-yr-old age group. Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of exposed fruit intake that is home-produced is 0.328 for households that farm and 0.116 for households that garden (Table 13-71, U.S. EPA, 1997b).

Table J-3. Exposed Fruit Consumption Data and Distributions

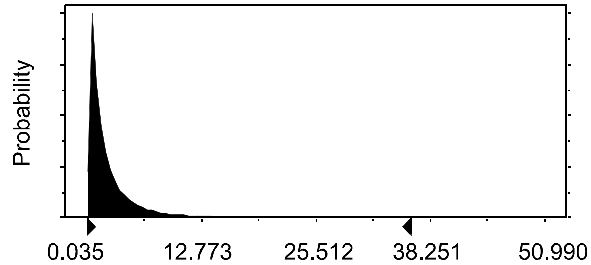
		EFH Data (g WW/kg-d)											Distributions		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	49	2.6	3.947			0.373	1	1.82	2.64	5.41	6.07		Gamma	2.25	1.89
6-11	68	2.52	3.496		0.171	0.373	0.619	1.11	2.91	6.98	11.7		Lognormal	2.78	5.12
12-19	50	1.33	1.457		0.123	0.258	0.404	0.609	2.27	3.41	4.78		Lognormal	1.54	2.44
Adult Farmer	112	2.32	2.646	0.072	0.276	0.371	0.681	1.3	3.14	5	6.12	15.7	Lognormal	2.36	3.33
Home gard.	596	1.55	2.226	0.042	0.158	0.258	0.449	0.878	1.73	3.41	5	12.9	Lognormal	1.57	2.3

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

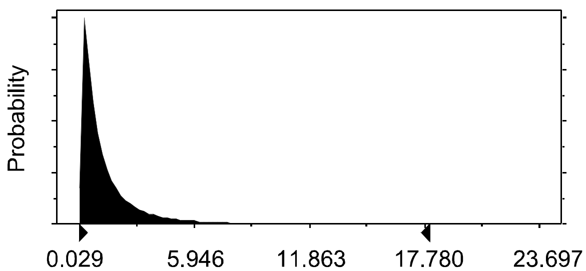
Exposed Fruit Consumption for Child 1
(g WW/kg/d)



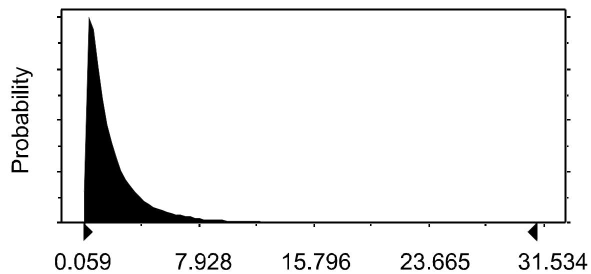
Exposed Fruit Consumption for Child 2
(g WW/kg/d)



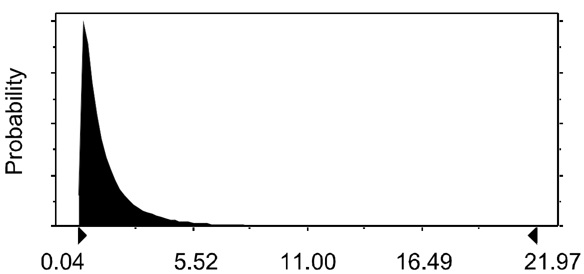
Exposed Fruit Consumption for Child 3
(g WW/kg/d)



Exposed Fruit Consumption for Adult Farmer
(g WW/kg/d)



Exposed Fruit Consumption for Adult Gardener
(g WW/kg/d)

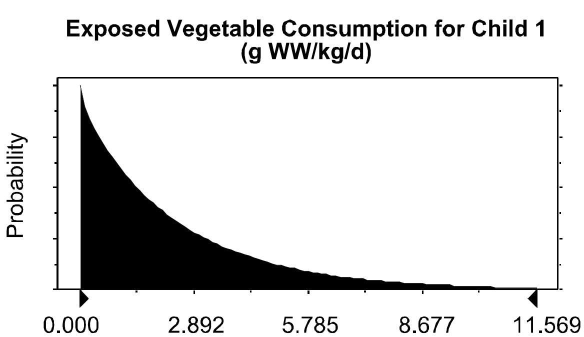


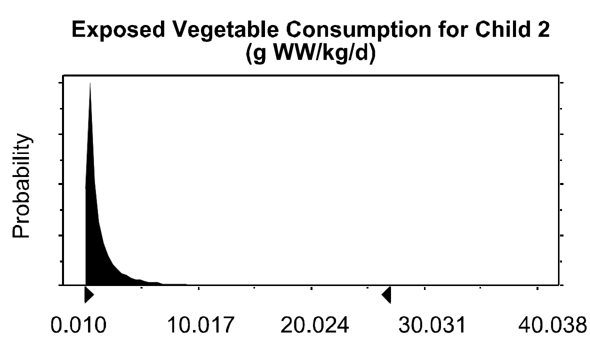
J.1.4.2 <u>Exposed Vegetable Consumption</u>. Table J-4 presents exposed vegetable consumption data and distribution. Data for consumption of homegrown exposed vegetables were obtained from Table 13-63 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg/d) were presented for those ages 1 to 2, 3 to 5, 6 to 11, 12 to 19, 20 to 39, and 40 to 69 years, as well as farmers and home gardeners. Weighted averages of percentiles, means, and standard deviations were calculated for the 1- to 5-yr-old age group (combining groups of those ages 1 to 2 years and 3 to 5 years). Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of exposed vegetable intake that is home-produced is 0.42 for households that farm and 0.233 for households that garden (Table 13-71, U.S. EPA, 1997b).

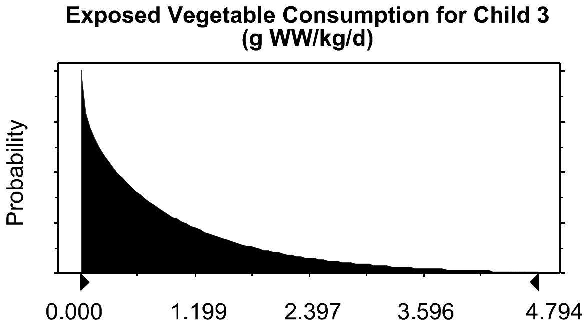
Table J-4. Exposed Vegetable Consumption Data and Distributions

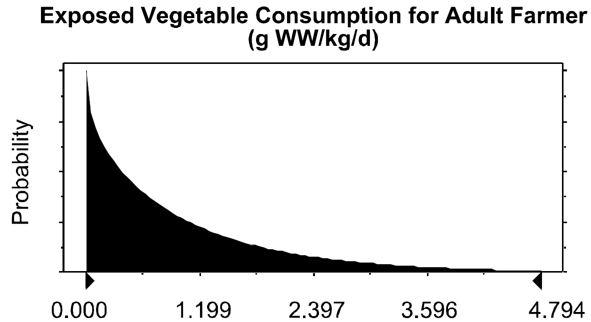
		EFH Data (g WW/kg-d)											Distributions		
Age Cohort	N	Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5	105	2.453	2.675		0.102	0.37	0.833	1.459	3.226	6.431	8.587		Gamma	2.55	2.58
6-11	134	1.39	2.037		0.044	0.094	0.312	0.643	1.6	3.22	5.47	13.3	Lognormal	1.64	3.95
12-19	143	1.07	1.128		0.029	0.142	0.304	0.656	1.46	2.35	3.78	5.67	Gamma	1.08	1.13
Adult farmer	207	2.17	2.316		0.184	0.372	0.647	1.38	2.81	6.01	6.83	10.3	Lognormal	2.38	3.5
Home gard.	1,361	1.57	2.029	0.003	0.089	0.168	0.413	0.889	1.97	3.63	5.45	10.3	Weibull	1.57	1.76

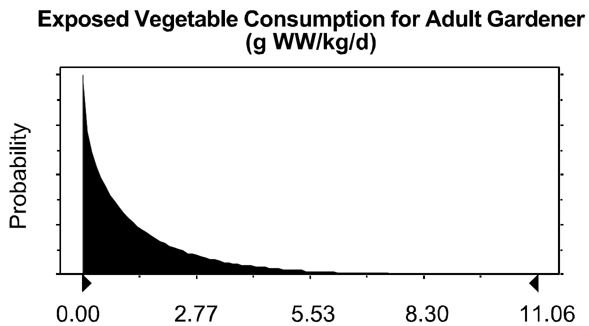
N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.









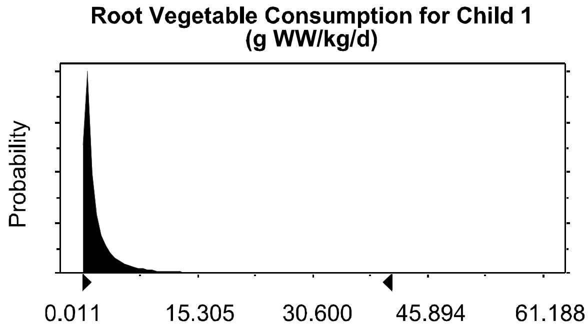


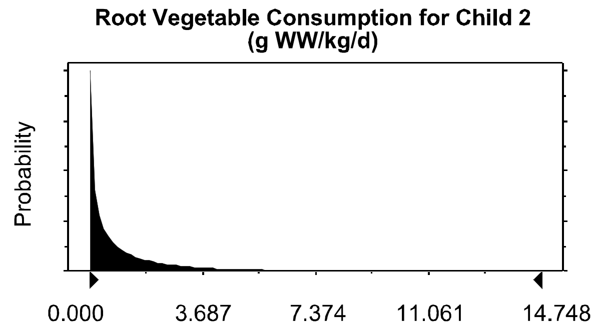
J.1.4.3 <u>Root Vegetable Consumption</u>. Table J-5 presents root vegetable consumption rate and distributions. Homegrown root vegetable consumption data were obtained from Table 13-65 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg/d) were presented for those ages 1 to 2, 3 to 5, 6 to 11, 12 to 19, 20 to 39, 40 to 69 years, and adult farmers and home gardeners. Weighted averages of percentiles, means, and standard deviations were calculated for the child1 age group (combining groups of those ages 1 to 2 and 3 to 5 years). Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of root vegetable intake that is home-produced is 0.173 for households that farm and 0.106 for households that garden (Table 13-71, U.S. EPA, 1997b).

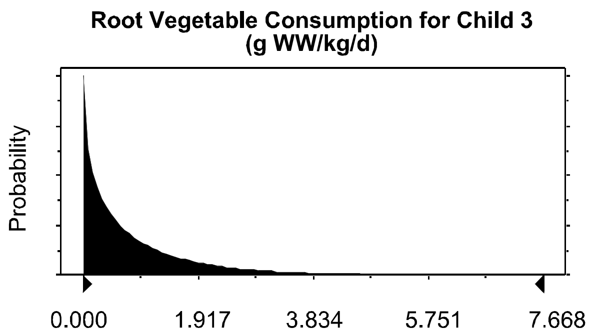
Table J-5. Root Vegetable Consumption Data and Distributions

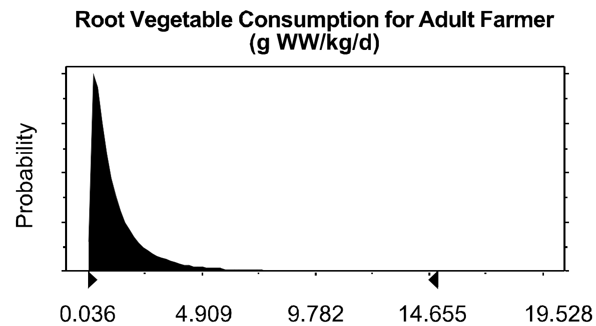
		EFH Data (g WW/kg-d)											Distributions		
Age Cohort	**N**	**Data Mean**	**Data SDev**	**P01**	**P05**	**P10**	**P25**	**P50**	**P75**	**P90**	**P95**	**P99**	**Distribution**	**Pop-Estd Mean**	**Pop-Estd SDev**
1-5	45	1.886	2.371		0.081	0.167	0.291	0.686	2.653	5.722	7.502		Lognormal	2.31	6.05
6-11	67	1.32	1.752		0.014	0.036	0.232	0.523	1.63	3.83	5.59		Weibull	1.38	2.07
12-19	76	0.937	1.037		0.008	0.068	0.269	0.565	1.37	2.26	3.32		Weibull	0.99	1.19
Adult farmer	136	1.39	1.469	0.111	0.158	0.184	0.365	0.883	1.85	3.11	4.58	7.47	Lognormal	1.45	2.06
home gard.	682	1.15	1.494	0.005	0.036	0.117	0.258	0.674	1.5	2.81	3.64	7.47	Weibull	1.15	1.32

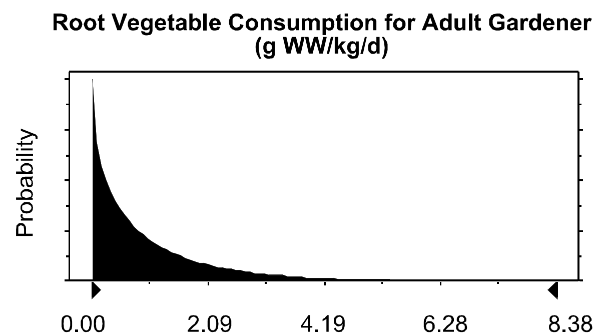
N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.











J.1.4.4 <u>Dairy Products (Milk) Consumption</u>. Table J-6 presents summary statistics on consumption of dairy products. Home-produced dairy product consumption rate data were obtained from Table 13-28 of the EFH (U.S. EPA, 1997b) for farmers, all ages combined, and individual age groups. No age-specific data for children were available for home-produced dairy products consumption. Per capita intake data for dairy products (including store-bought products), however, were available for those 1 to 2, 3 to 5, 6 to 11, and 12 to 19 years old from the EFH and from USDA (1997); the data in the EFH was based on the 1989-1991 CSFII and it was decided to use the more recent 1994-96 CSFII raw data. Therefore, data for the general population were used to calculate adjustment factors to develop distributions for the non-adult age groups for consumption of home-produced dairy products.

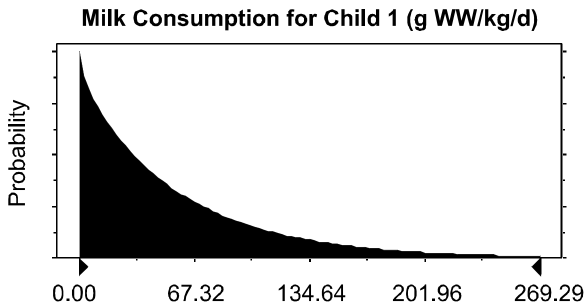
Percentile data (USDA, 1997) were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select gamma as the most appropriate model in all cases. Tables J-19 and J-20 (see end of appendix) provide the data used to develop the distributions and adjustment factors. It was assumed that the relative standard deviations (RSD) for consumption rates were the same for all age groups; the similarity of coefficients of variation (CV) suggest that this is a reasonable approximation for the general population. The other assumption used to develop distributions for the child age groups for the consumption of home-produced dairy products was that the mean intake rates have the same fixed ratio for all the age groups of a given food type. That is, the ratio of the mean amount consumed of home-produced dairy products divided by the mean amount of dairy products consumed in the general population is the same for any two age groups. These two assumptions, of constant RSD and constant mean ratio, were used to infer the parameters of the gamma distributions for the home-produced foods from those of the general population (i.e., mean, standard deviation, shape, and scale).

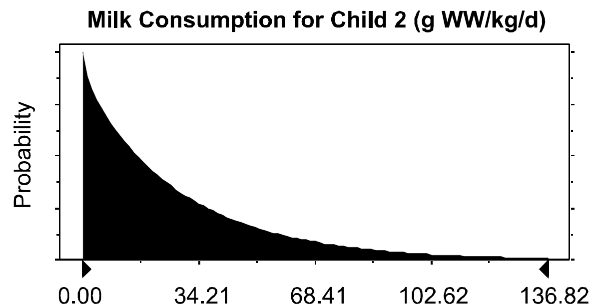
The fraction of dairy product intake that is home-produced is 0.254 for households that farm (Table 13-71, U.S. EPA, 1997b).

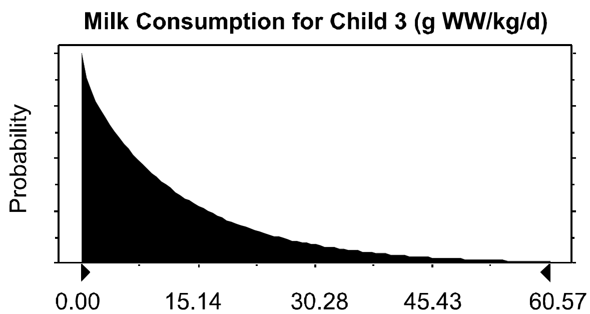
Table J-6. Dairy Products (Milk) Consumption Data and Distributions

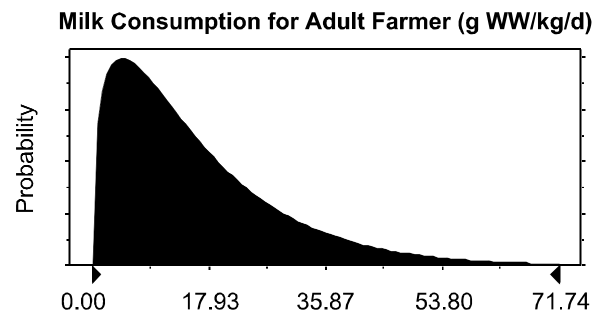
		Data (g WW/kg-d)									Distributions		
Source	**Age Cohort**	**Data Mean**	**Data SDev**	**P05**	**P10**	**P25**	**P50**	**P75**	**P90**	**P95**	**Distribution**	**Pop-Estd Shape**	**Pop-Estd Scale**
CSFII (gen)	All	6.81	10.8	0.199	0.392	1.14	3.25	7.59	16.9	26.1			
CSFII (gen)	1-5	27.4	22.3	1.12	4.39	12.2	22.3	37.1	55.9	70.1			
CSFII (gen)	6-11	14	10	0.826	2.16	6.48	12.3	19.2	27.3	33.5			
CSFII (gen)	12-19	6.2	5.87	0.264	0.484	1.88	4.55	8.88	13.5	17.8			
CSFII (gen)	20-69	3.23	3.3	0.162	0.303	0.854	2.22	4.48	7.45	9.88			
HP	1-5										Gamma	0.961	61.80
HP	6-11										Gamma	0.961	31.40
HP	12-19										Gamma	0.961	13.90
EFH (HP)	20_39	7.41	6.12	0.396	0.446	1.89	6.46	12.1	15.4	19.5	Gamma	0.961	8.01
EFH (HP)	All	14	15.28	0.446	0.508	3.18	10.2	19.5	34.2	44	Gamma	0.78	18.26
EFH (HP)	Adult farmer	17.1	15.8	0.736	3.18	9.06	12.1	20.4	34.9	44	Gamma	1.38	11.85

CSFII = USDA (1997); gen = general population data; EFH = U.S. EPA (1997b); HP = home-produced data; P05-P95 = Percentiles; Sdev = standard deviation; Pop-Estd = population-estimated









J.1.4.5 <u>Beef Consumption</u>. Table J-7 presents beef consumption data and distributions. Home-produced beef consumption data were obtained from Table 13-36 of the EFH (U.S. EPA, 1997b). Data (in g WW/kg-d) were presented for farmers and those 6 to 11, 12 to 19, 20 to 39, and 40 to 69 years old. Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model.

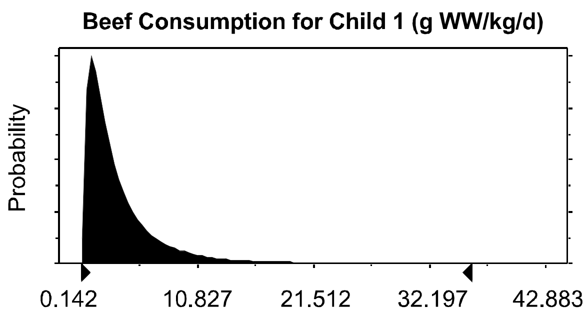
Data were not available for those 1 to 2 and 3 to 5 years old. For beef consumption for 1- to 5-yr-olds, the lognormal model was used because, among the other age groups, it was the best-fitted model in all but one case. The population-estimated mean and standard deviation for 6- to 11-yr-olds were used for 1- to 5-yr-olds for the analysis (normalized for body weight) and are supported by data in Table 11-3 (per capita intake for beef, including store-bought products), which indicate that those 1 to 2, 3 to 5, and 6 to 11 years old have the highest consumption rate of beef on a gram/kilogram/day basis. The fraction of beef intake that is home-produced is 0.485 for households that farm (Table 13-71, U.S. EPA, 1997b).

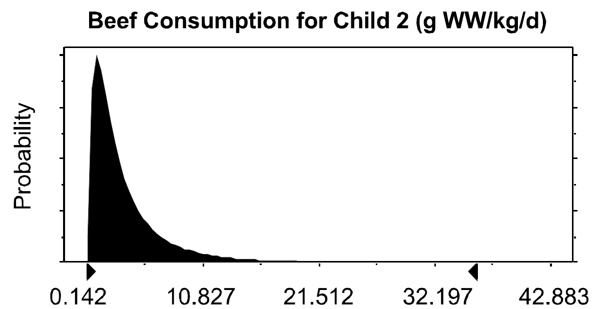
Beef consumption rate data were adjusted to account for food preparation and cooking losses. A mean net cooking loss of 27 percent accounts for dripping and volatile losses during cooking (averaged over various cuts and preparation methods). A mean net postcooking loss of 24 percent accounts for losses from cutting, shrinkage, excess fat, bones, scraps, and juices. These data were obtained from Table 13-5 of the EFH (U.S. EPA, 1997b).

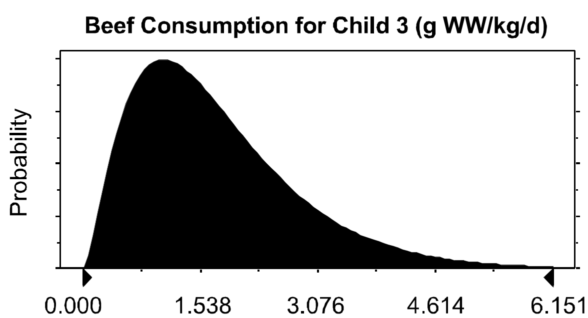
Table J-7. Beef Consumption Data and Distributions

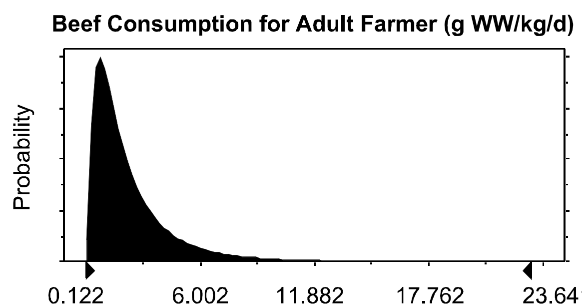
Age Cohort	N	EFH Data (g WW/kg-d) Data Mean	Data SDev	P01	P05	P10	P25	P50	P75	P90	P95	P99	Distributions Distribution	Pop-Estd Mean	Pop-Estd SDev
1-5		ND	ND										Lognormal	3.88	4.71
6-11	38	3.77	3.662		0.663	0.753	1.32	2.11	4.43	11.4	12.5		Lognormal	3.88	4.71
12-19	41	1.72	1.044		0.478	0.513	0.896	1.51	2.44	3.53	3.57		Gamma	1.77	1.12
Adult farmer	182	2.63	2.644	0.27	0.394	0.585	0.896	1.64	3.25	5.39	7.51	11.3	Lognormal	2.5	2.69

N = Number of samples; P01-P99 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.









J.1.4.6 Egg Consumption. Table J-8 presents summary statistics on consumption of eggs. Home-produced egg consumption rate data were obtained from Table 13-43 of the EFH (U.S. EPA, 1997b) for farmers, all ages combined, and individual age groups 20-39 and 40-69; statistics for the 20- to 69-yr-old age group were calculated as simple averages of the statistics for the 20- to-39- and 40- to 69-yr-old age groups. No age-specific data for children were available for home-produced egg consumption. Per capita intake data for eggs (including store-bought products), however, were available for those 1 to 2, 3 to 5, 6 to 11, and 12 to 19 years old from the EFH and from USDA (1997); the data in the EFH were based on the 1989-1991 CSFII and it was decided to use the more recent 1994-1996 CSFII raw data. Therefore, data for the general population were used to calculate adjustment factors to develop distributions for the nonadult age groups for consumption of home-produced eggs.

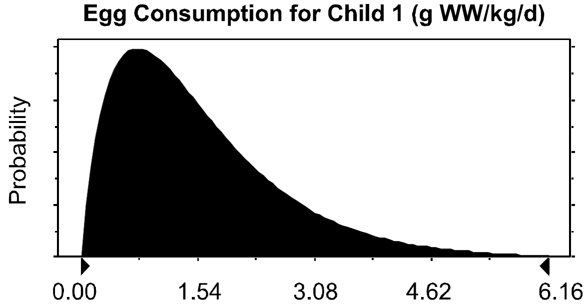
Percentile data (USDA, 1997) were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select gamma as the most appropriate model in all cases. Tables J-19 and J-20 (see end of appendix) provide the data used to develop the distributions and adjustment factors. It was assumed that the relative standard deviations (RSD) for consumption rates were the same for all age groups; the similarity of coefficients of variation (CV) suggest that this is a reasonable approximation for the general population. The other assumption used to develop distributions for the child age groups for the consumption of home-produced eggs was that the mean intake rates have the same fixed ratio for all the age groups of a given food type. That is, the ratio of the mean amount consumed of home-produced eggs divided by the mean amount of eggs consumed in the general population is the same for any two age groups. These two assumptions, of constant RSD and constant mean ratio, were used to infer the parameters of the gamma distributions for the home-produced foods from those of the general population (i.e., mean, standard deviation, shape, and scale).

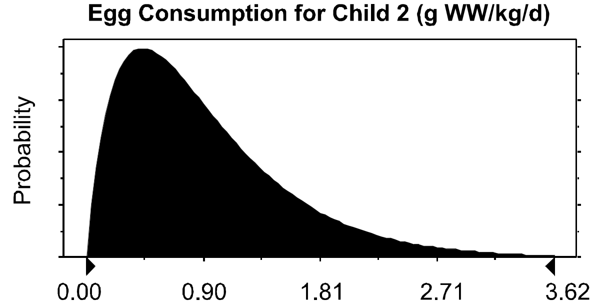
The fraction of egg intake that is home-produced is 0.146 for households that farm (Table 13-71, U.S. EPA, 1997b).

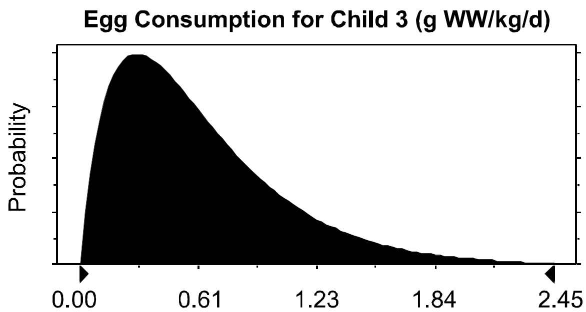
Table J-8. Egg Consumption Data and Distributions

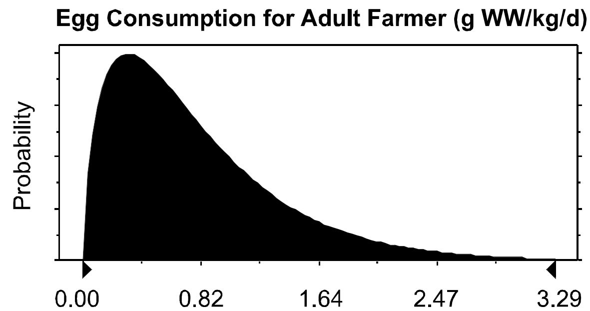
		Data (g WW/kg-d)									Distributions		
Source	**Age Cohort**	**Data Mean**	**Data SDev**	**P05**	**P10**	**P25**	**P50**	**P75**	**P90**	**P95**	**Distribution**	**Pop-Estd Shape**	**Pop-Estd Scale**
CSFII (gen)	All	1.01	1.04	0.133	0.253	0.422	0.724	1.22	1.99	2.82			
CSFII (gen)	1-5	2.41	1.94	0.101	0.328	1.16	1.88	3.23	5.03	6.15			
CSFII (gen)	6-11	1.44	1.25	0.125	0.302	0.641	1.08	1.87	2.95	3.45			
CSFII (gen)	12-19	0.962	0.708	0.092	0.328	0.469	0.821	1.22	1.71	2.24			
CSFII (gen)	20-69	0.792	0.663	0.145	0.248	0.389	0.633	1.01	1.52	1.88			
HP	1-5										Gamma	1.88	0.839
HP	6-11										Gamma	1.88	0.493
HP	12-19										Gamma	1.88	0.334
EFH (HP)	20-69	0.611	0.442	0.106	0.183	0.308	0.465	0.829	1.31	1.645	Gamma	1.88	0.336
EFH (HP)	All	0.731	1.114	0.15	0.175	0.268	0.466	0.902	1.36	1.69	Gamma	1.81	0.357
EFH (HP)	Adult farmer	0.898	1.128	0.165	0.177	0.272	0.666	1.19	1.65	1.85	Gamma	1.64	0.488

CSFII = USDA (1997); gen = general population data; EFH = U.S. EPA (1997b); HP = home-produced data; Sdev = standard deviation; Pop-Estd = population-estimated









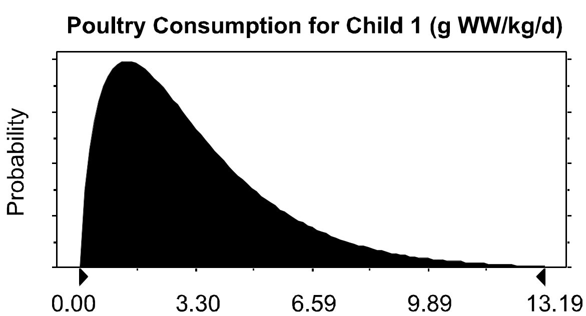
J.1.4.7 <u>Poultry Consumption</u>. Table J-9 presents summary statistics on consumption of poultry. Home-produced poultry consumption rate data were obtained from Table 13-55 of the EFH (U.S. EPA, 1997b) for farmers, all ages combined, and individual age groups 20 to 39 and 40 to 69; statistics for the 20- to 69-yr-old age group were calculated as simple averages of the statistics for the 20- to 39 and 40- to 69-yr-old age groups. No age-specific data for children were available for home-produced poultry consumption. Per capita intake data for poultry (including store-bought products), however, were available for those 1 to 2, 3 to 5, 6 to 11, and 12 to 19 years old from the EFH and from USDA (1997); the data in the EFH were based on the 1989-1991 CSFII and it was decided to use the more recent 1994-1996 CSFII raw data. Therefore, data for the general population were used to calculate adjustment factors to develop distributions for the nonadult age groups for consumption of home-produced poultry.

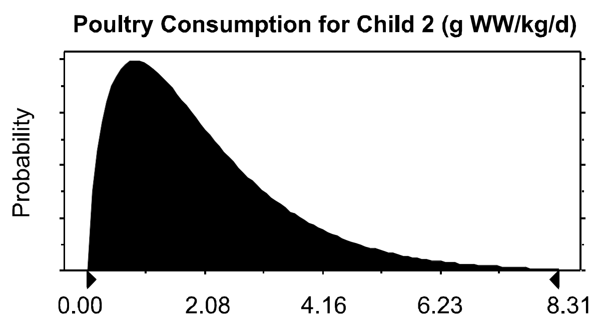
Percentile data (USDA, 1997) were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select gamma as the most appropriate model in all cases. Tables J-19 and J-20 (see end of appendix) provide the data used to develop the distributions and adjustment factors. Constant RSD and constant mean ratio were assumed and these data were used to infer the parameters of the gamma distributions for the home-produced foods from those of the general population (i.e., mean, standard deviation, shape, and scale). The fraction of poultry intake that is home-produced is 0.156 for households that farm (Table 13-71, U.S. EPA, 1997b).

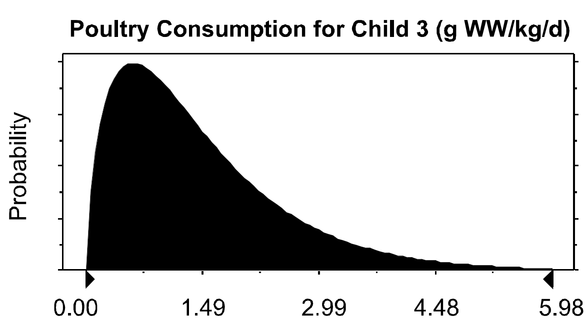
Table J-9. Poultry Consumption Data and Distributions

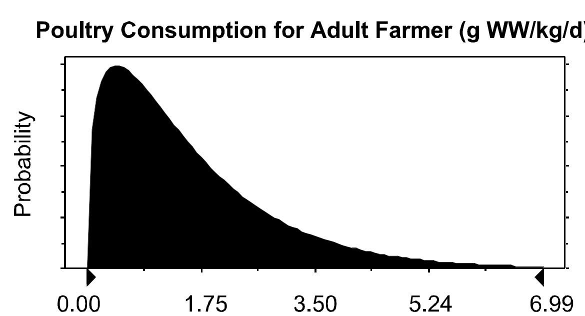
Source	Age Cohort	Data (g WW/kg-d) Data Mean	Data SDev	P05	P10	P25	P50	P75	P90	P95	Distributions Distribution	Pop-Estd Shape	Pop-Estd Scale
CSFII (gen)	All	0.688	0.942	0.018	0.034	0.111	0.334	0.917	1.76	2.47			
CSFII (gen)	1-5	1.43	1.73	0.025	0.056	0.192	0.736	2.2	3.63	4.66			
CSFII (gen)	6-11	0.884	1.15	0.019	0.036	0.116	0.365	1.29	2.42	3.22			
CSFII (gen)	12-19	0.645	0.795	0.019	0.034	0.103	0.346	0.896	1.71	2.23			
CSFII (gen)	20-69	0.57	0.712	0.017	0.032	0.105	0.303	0.804	1.4	1.92			
HP	1-5										Gamma	1.69	1.92
HP	6-11										Gamma	1.69	1.21
HP	12-19										Gamma	1.69	0.87
EFH (HP)	20-69	1.34	1.088	0.299	0.352	0.524	0.962	2.03	2.545	3.765	Gamma	1.69	0.80
EFH (HP)	All	1.57	1.178	0.303	0.418	0.637	1.23	2.19	3.17	3.83	Gamma	1.83	0.85
EFH (HP)	Adult farmer	1.54	1.375	0.228	0.303	0.595	1.06	2.18	3.47	4.83	Gamma	1.38	1.16

CSFII = USDA (1997); gen = general population data; EFH = U.S. EPA (1997b); HP = home-produced data; P05-P95 = Percentiles; Sdev = standard deviation; Pop-Estd = population-estimated







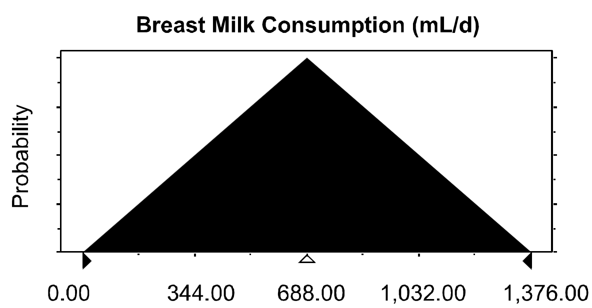


J.1.4.8 Breast Milk Consumption. Table J-10 presents breast milk consumption data for infants. The data mean and upper percentile for breast milk consumption in 1- to 12-month-olds were 688 and 980 mL/d, respectively (Table 14-16, U.S. EPA, 1997b). The triangular model was used for breast milk consumption (12-month-olds) because no percentile or related data were available; other distributions (e.g., lognormal) resulted in overestimation of the upper percentile. The EFH population mean for breast milk consumption was 688 mL/d and was assumed to equal the mode.

Table J-10. Breast Milk Consumption Data and Distribution

Age Cohort	Data Mean (mL/d)	Data SDev	Upper Percentile	Distribution	Pop-Estd Mode (mL/d)	Pop-Estd SDev (mL/d)
<1	688	ND	980	Triangular	688	688

Pop-Estd = population-estimated; SDev = Standard deviation.
ND =



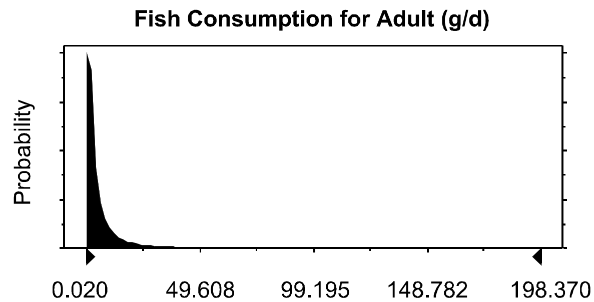
J.1.4.9 Fish Consumption. Table J-11 presents fish consumption data and distribution. Fish consumption data were obtained from Table 10-64 of the EFH (U.S. EPA, 1997b). Data (in g/d) were available for adult freshwater anglers in Maine. The Maine fish consumption study was one of four recommended freshwater angler studies in the EFH (U.S. EPA, 1997b). The other recommended fish consumption studies (i.e., Michigan and New York) had large percentages of anglers who fished from the Great Lakes, which is not consistent with the modeling scenarios used in this risk analysis. The anglers in the Maine study fished from streams, rivers, and ponds; these data are more consistent with modeling scenarios for this risk analysis. Although the Maine data have a lower mean than the Michigan data, the Maine data compared better with a national U.S. Department of Agricultural (USDA) study. Also, the Maine study had percentile data available, which were necessary to develop a distribution.

Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) and measures of goodness of fit were used to select lognormal as the most appropriate model. The fraction of fish intake that is locally caught is 0.325 for adult fishers (Table 13-71, U.S. EPA, 1997b). The fraction of consumed trophic level 3 (T3) and trophic level 4 (T4) fish was 0.36 and 0.64, respectively (Table 10-66, U.S. EPA, 1997b).

Table J-11. Fish Consumption Data and Distributions

Age Cohort	N	EFH Data (g/d)							Distributions		
		Data Mean	Data SDev	P50	P66	P75	P90	P95	Distribution	Pop-Estd Mean	Pop-Estd SDev
Adult	1,053	6.4		2	4	5.8	13	26	Lognormal	6.48	19.9

N = Number of samples; P50-P95 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.

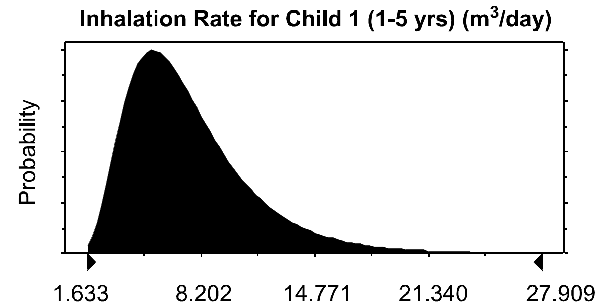


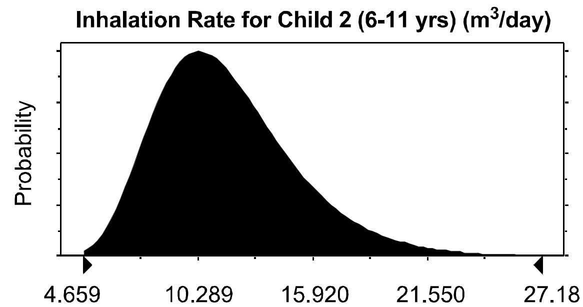
J.1.4.10 Inhalation Rate. Table J-12 presents inhalation rate data and distribution. No percentile data were available for the inhalation rate, and the default lognormal model was assumed. In an analysis of inhalation data, Myers et al. (U.S. EPA, 2000a) found that, for those younger than 3 years, CV was close to 70 percent; for other age groups, it was close to 30 percent. The lognormal distribution was fitted by using CV=50 percent [(30+70)/2] for the 1- to 5-yr-old age group and CV=30 percent for the 6- to 11-yr-olds, 12- to 19-yr-olds, and adult age groups.

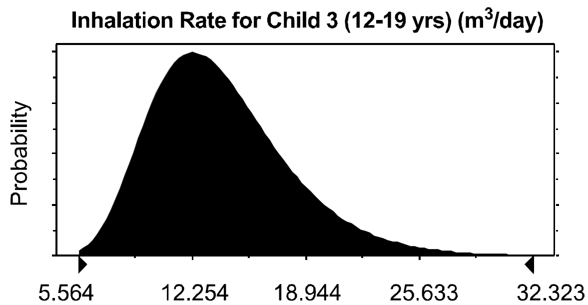
Table J-12. Inhalation Rate Data and Distribution

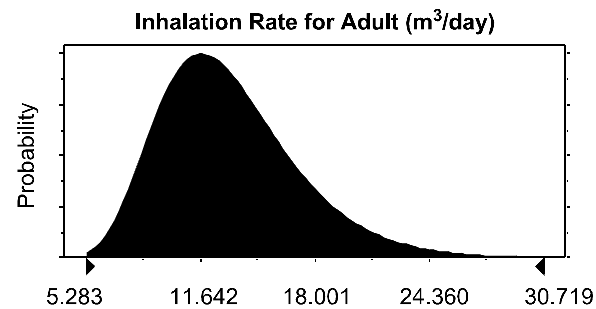
Age Cohort	Distribution	Population-Estimated Mean (m^3/d)	Population-Estimated SDev (m^3/d)
1-5	Lognormal	7.55	3.78
6-11	Lognormal	11.75	3.53
12-19	Lognormal	14.0	4.2
Adult	Lognormal	13.3	3.99

SDev = Standard deviation.







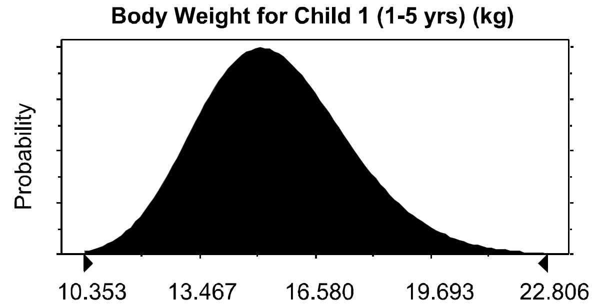


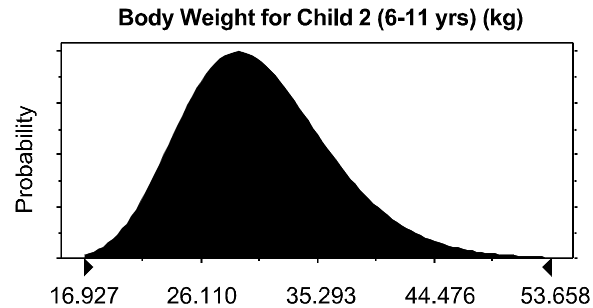
J.1.4.11 Body Weight. Table J-13 presents body weight data and distribution. Body weight data were obtained from Tables 7-2 through 7-7 of the EFH (U.S. EPA, 1997a). Data (in kg) were presented by age and gender. Weighted averages of percentiles, means, and standard deviations were calculated for infants (<1 year old), 1- to 5-yr-olds, 6- to 11-yr-olds, 12- to 19-year olds, and adult age groups; male and female data were weighted and combined for each age group. These percentile data were used as the basis for fitting distributions. These data were analyzed to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model.

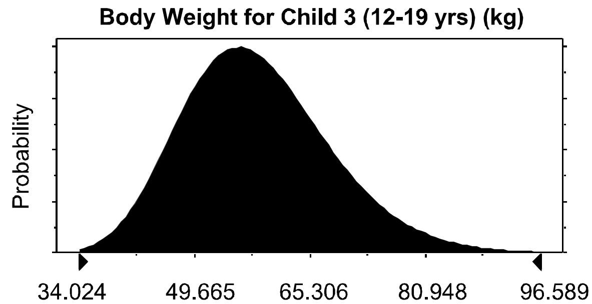
Table J-13. Body Weight Data and Distributions

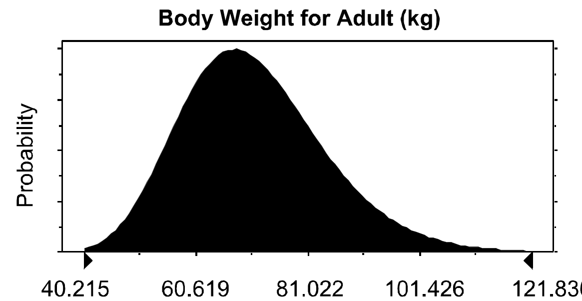
		EFH Data (kg)											Distributions		
Age Cohort	**N**	**Data Mean**	**Data SDev**	**P05**	**P10**	**P15**	**P25**	**P50**	**P75**	**P85**	**P90**	**P95**	**Distribution**	**Pop-Estd Mean**	**Pop-Estd SDev**
<1	356	9.102	1.287	7.053	7.451	7.852	8.252	9.151	9.752	10.4	10.65	11.15	Gamma	9.09	1.23
1-5	3,762	15.52	3.719	12.5	13.1	13.45	14.03	15.26	16.67	17.58	18.32	19.45	Lognormal	15.5	2.05
6-11	1,725	30.84	9.561	22.79	24.05	25.07	26.44	29.58	33.44	36.82	39.66	43.5	Lognormal	30.7	5.96
12-19	2,615	58.45	13.64	43.84	46.52	48.31	50.94	56.77	63.57	68.09	71.98	79.52	Lognormal	58.2	10.2
20+	12,504	71.41	15.45	52.86	55.98	58.21	61.69	69.26	78.49	84.92	89.75	97.64	Lognormal	71.2	13.3

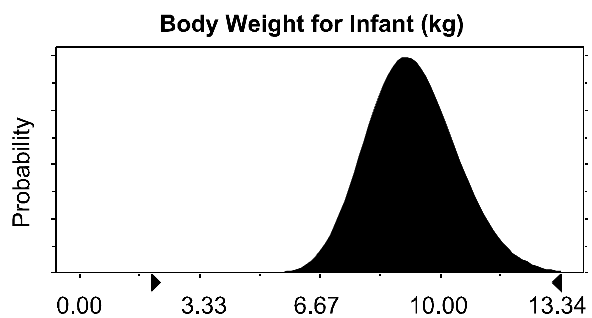
N = Number of samples; P05-P95 = Percentiles; Pop-Estd = Population-estimated; SDev = Standard deviation.











J.1.4.12 <u>Exposure Duration</u>. Table J-14 presents exposure duration data and distributions. Exposure duration was assumed to be equivalent to the average residence time for each receptor. Exposure durations for adult residents and children (resident and farmer) were determined using data on residential occupancy from the EFH, Table 15-168 (U.S. EPA, 1997c). The data represent the total time a person is expected to live at a single location, based on age. The table presented male and female data combined. For adult residents, age groups from 21 to 90 were pooled. For children, the 3-yr-old age group was used for the 1- to 5-yr-olds.

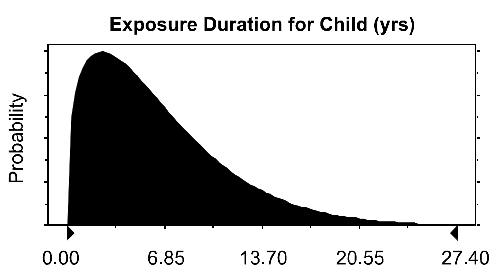
In an analysis of residential occupancy data, Myers et al. (U.S. EPA, 2000a) found that the data, for most ages, were best fit by a Weibull distribution. The Weibull distribution as implemented in Crystal Ball® is characterized by three parameters: location, shape, and scale. Location is the minimum value and, in this case, was presumed to be 0. Shape and scale were determined by fitting a Weibull distribution to the pooled data, as follows. To pool residential occupancy data for the age cohorts, an arithmetic mean of data means was calculated for each age group. Then, assuming a Weibull distribution, the variance within each age group (e.g., 6-yr-olds) was calculated in the age cohort. These variances in turn were pooled over the age cohort using equal weights. This is not the usual type of pooled variance, which would exclude the variation in the group means. However, this way the overall variance reflected the variance of means within the age groups (e.g., within the 6-yr-old age group). The standard deviation was estimated as the square root of the variance. The coefficient of variation was calculated as the ratio of the standard deviation divided by the Weibull mean. For each cohort, the population-estimated parameter uncertainty information (e.g., shape and scale) was calculated based on a Weibull distribution, the calculated data mean for the age cohort, and the CV.

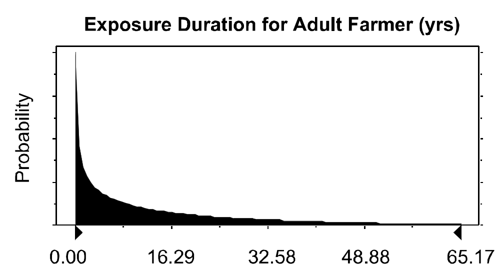
Exposure duration for adult farmers was determined using data on residential occupancy from the EFH, Tables 15-163 and 15-164 (U.S. EPA, 1997c). The data represent the total time a person is expected to live at a single location, based on household type. Age-specific data were not provided. For residence duration of farmers (U.S. EPA 1997c, Tables 15-163 and 15-164), the gamma model was used because it was the best-fitted model in five age groups and was the second-best-fitted model in two cases (based on data in U.S. EPA 1997c, Tables 15-167 and 15-168). A population mean of 18.07 years and a population standard deviation of 23.19 years were calculated for adult farmers.

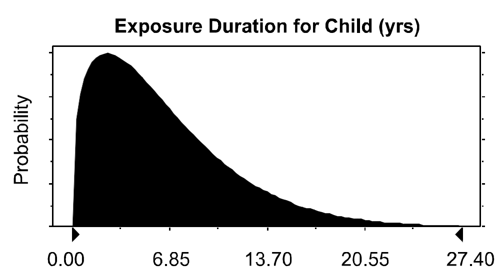
Table J-14. Exposure Duration Data and Distributions

EFH Data		**Distributions**		
Age Cohort	**Data Mean (yr)**	**Distribution**	**Pop-Estd Shape (yr)**[a]	**Pop-Estd Scale (yr)**
Child (1- to 5-yr-olds)	6.5	Weibull	1.32	7.059
Adult resident	16.0	Weibull	1.34	17.38
Adult farmer	18.75	Gamma	0.607	29.76

Pop-Estd = Population-estimated.
[a] Distributions used in risk assessment.







J.2 Minimums/Maximums

Probabilistic risk analyses involve “sampling” values from probability distribution functions (PDFs) and using the values to estimate risk. In some cases, distributions are infinite, and there is a probability, although very small, that very large or very small values might be selected from the distributions. Because selecting extremely large or extremely small values is unrealistic (e.g., the range of adult body weights is not infinite), maximum and minimum values were imposed on the distributions. The minimum and maximum values are summarized in Table J-15. For the probabilistic analyses, the maximum intake rates for most food items were defined as 2 × (mean + 3 SD). For adult farmer beef, adult farmer eggs, adult farmer exposed fruit, adult home gardener exposed fruit, child3 exposed vegetable, and adult home gardener root vegetable, 2 × 99th percentile value was used as the maximum intake rates. For fish, adult subsistence fisher ingestion rates were used as the maximum. Minimum intake values for all food items were zero.

Table J-15. Minimum and Maximum Values

Receptor	Parameter Name	Minimum	Source	Maximum	Source
General	Averaging time for carcinogens				
Adult resident	Body weight (adult)	15	0.5*(mean-3SD)	300	Prof. judgment
Child resident	Body weight (child 1)	4	0.5*(mean-3SD)	50	Prof. judgment
Child resident	Body weight (child 2)	6	0.5*(mean-3SD)	200	Prof. judgment
Child resident	Body weight (child 3)	13	0.5*(mean-3SD)	300	Prof. judgment
Infant resident	Body weight (infant)	2	0.5*(mean-3SD)	26	2*(mean+3SD)
Adult farmer	Consumption rate: beef (adult farmer)	0		23	2*(P99)
Child farmer	Consumption rate: beef (child 1 farmer)	0		36	2*(mean+3SD)
Child farmer	Consumption rate: beef (child 2 farmer)	0		36	2*(mean+3SD)
Child farmer	Consumption rate: beef (child 3 farmer)	0		10	2*(mean+3SD)
Infant resident	Consumption rate: breast milk (infant)	0		1376	2*mean
Adult farmer	Consumption rate: eggs (adult farmer)	0		13	2*(P99)
Child farmer	Consumption rate: eggs (child 1 farmer)	0		10	2*(mean+3SD)
Child farmer	Consumption rate: eggs (child 2 farmer)	0		6	2*(mean+3SD)
Child farmer	Consumption rate: eggs (child 3 farmer)	0		4	2*(mean+3SD)
Adult farmer	Consumption rate: exposed fruit (adult farmer)	0		31	2*(P99)
Adult home gardener	Consumption rate: exposed fruit (adult home gardener)	0		26	2*(P99)

(continued)

Table J-15. (continued)

Receptor	Parameter Name	Minimum	Source	Maximum	Source
Child farmer, home gardener	Consumption rate: exposed fruit (child 1 farmer, home gardener)	0		16	2*(mean+3SD)
Child farmer, home gardener	Consumption rate: exposed fruit (child 2 farmer, home gardener)	0		36	2*(mean+3SD)
Child farmer, home gardener	Consumption rate: exposed fruit (child 3 farmer, home gardener)	0		18	2*(mean+3SD)
Adult farmer	Consumption rate: exposed vegetables (adult farmer)	0		26	2*(mean+3SD)
Adult home gardener	Consumption rate: exposed vegetables (adult home gardener)	0		21	2*(mean+3SD)
Child farmer, home gardener	Consumption rate: exposed vegetables (child 1 farmer, home gardener)	0		21	2*(mean+3SD)
Child farmer, home gardener	Consumption rate: exposed vegetables (child 2 farmer, home gardener)	0		27	2*(mean+3SD)
Child farmer, home gardener	Consumption rate: exposed vegetables (child 3 farmer, home gardener)	0		11	2*(P99)
Adult fisher	Consumption rate: fish (adult fisher)	0		1500	EFH-subsist
Adult farmer	Consumption rate: milk (adult farmer)	0		117	2*(mean+3SD)
Child farmer	Consumption rate: milk (child 1 farmer)	0		482	2*(mean+3SD)
Child farmer	Consumption rate: milk (child 2 farmer)	0		245	2*(mean+3SD)
Child farmer	Consumption rate: milk (child 3 farmer)	0		109	2*(mean+3SD)
Adult farmer	Consumption rate: poultry (adult farmer)	0		11	2*(mean+3SD)
Child farmer	Consumption rate: poultry (child 1 farmer)	0		21	2*(mean+3SD)
Child farmer	Consumption rate: poultry (child 2 farmer)	0		14	2*(mean+3SD)
Child farmer	Consumption rate: poultry (child 3 farmer)	0		10	2*(mean+3SD)
Adult farmer	Consumption rate: root vegetables (adult farmer)	0		15	2*(mean+3SD)
Adult home gardener	Consumption rate: root vegetables (adult home gardener)	0		15	2*(P99)
Child farmer, home gardener	Consumption rate: root vegetables (child 1 farmer, home gardener)	0		41	2*(mean+3SD)

(continued)

Table J-15. (continued)

Receptor	Parameter Name	Minimum	Source	Maximum	Source
Child farmer, home gardener	Consumption rate: root vegetables (child 2 farmer, home gardener)	0		15	2*(mean+3SD)
Child farmer, home gardener	Consumption rate: root vegetables (child 3 farmer, home gardener)	0		9	2*(mean+3SD)
Adult resident	Exposure duration (adult resident)	1		100	
Child resident	Exposure duration (child)	1		100	
Adult farmer	Exposure duration (adult farmer)	1		100	
Adult resident	Inhalation (breathing) rate (adult resident)	1	0.5*(mean-3SD)	50	2*(mean+3SD)
Child resident	Inhalation (breathing) rate (child 1 resident)	1	0.5*(mean-3SD)	40	2*(mean+3SD)
Child resident	Inhalation (breathing) rate (child 2 resident)	1	0.5*(mean-3SD)	45	2*(mean+3SD)
Child resident	Inhalation (breathing) rate (child 3 resident)	1	0.5*(mean-3SD)	55	2*(mean+3SD)

J.3 Exposure Parameters Used in Deterministic Analysis

For most exposure factor parameters, data used in the deterministic analyses were based on distributions developed from data and recommendations in the EFH (U.S. EPA, 1997a, 1997b, 1997c). Central tendency values were represented by the 50^{th} percentile (median) values. High-end values were represented by the 90^{th} percentile values. The exposure factors parameters used in the biosolids deterministic analyses are summarized in Table J-16.

Three deterministic analyses were performed for the farmer scenario:

Scenario 1: Central tendency values were used for all exposure parameters.

Scenario 2: High-end values were used for exposure duration and consumption rates for produce and animal products (i.e., exposed fruit, exposed vegetables, root vegetables, beef, dairy, poultry, and eggs) while central tendency values were used for all other exposure parameters (i.e., body weight, inhalation rate, soil consumption rate, and breast milk consumption rate).

Scenario 3: Central tendency values were used for all exposure parameters except exposure duration, for which the high-end value was used.

Table J-16. Summary of Exposure Parameters Used in Deterministic Analyses

Scenario	1	1	1	2	2	2	3	3	3	
Receptor	**Adult Farmer**	**Child Farmer**	**Infant Farmer**	**Adult Farmer**	**Child Farmer**	**Infant Farmer**	**Adult Farmer**	**Child Farmer**	**Infant Farmer**	**Units**
Waste management unit	LAU	LAU	LAU	LAU	LAU	LAU	LAU	LAU	LAU	
Averaging time	70	70		70	70		70	70		yr
Inhalation rate	1.27E+01	9.73E+00		1.27E+01	9.73E+00		1.27E+01	9.73E+00		m^3/d
Body weight	7.00E+01	2.41E+01	9.16E+00	7.00E+01	2.41E+01	9.16E+00	7.00E+01	2.41E+01	9.16E+00	kg
Consumption rate: exposed fruit	1.36E+00	1.69E+00		5.16E+00	4.91E+00		1.36E+00	1.69E+00		g WW/kg-d
Consumption rate: exposed vegetable	1.38E+00	1.29E+00		5.21E+00	4.44E+00		1.38E+00	1.29E+00		g WW/kg-d
Consumption rate: root vegetable	8.20E-01	9.09E-01		3.14E+00	3.72E+00		8.20E-01	9.09E-01		g WW/kg-d
Consumption rate: egg	6.47E-01	1.02E+00		1.63E+00	2.26E+00		6.47E-01	1.02E+00		g WW/kg-d
Consumption rate: poultry	1.26E+00	2.14E+00		3.44E+00	4.76E+00		1.26E+00	2.14E+00		g WW/kg-d
Consumption rate: beef	1.73E+00	2.60E+00		5.17E+00	7.24E+00		1.73E+00	2.60E+00		g WW/kg-d
Consumption rate: fish	1.99E+00			1.40E+01			1.99E+00			g/d
Consumption rate: milk	1.26E+01	2.98E+01		3.55E+01	9.02E+01		1.26E+01	2.98E+01		g WW/kg-d
Consumption rate: soil	5.00E-05	7.00E-05		5.00E-05	7.00E-05		5.00E-05	7.00E-05		kg/d
Consumption rate: breast milk			6.87E+02			6.87E+02			6.87E+02	mL/d
Exposure duration	10	5		47	13		47	13		yr

Table J-17. Exposure Factor Raw Data: Descriptive Statistics by Standardized Age Groups

Parameter	Age Cohort	N	Avg	SDev	Units	P01	P02	P05	P10	P15	P25	P50	P75	P85	P90	P95	P98	P99
beef	6-11	38	3.77	3.662	g WW/kg-d			0.663	0.753		1.32	2.11	4.43		11.4	12.5		
beef	12-19	41	1.72	1.044	g WW/kg-d			0.478	0.513		0.896	1.51	2.44		3.53	3.57		
beef	Farmer	182	2.63	2.644	g WW/kg-d	0.27		0.394	0.585		0.896	1.64	3.25		5.39	7.51		11.3
bodywt	1-5	3,762	15.52	3.719	kg			12.5	13.1	13.45	14.03	15.26	16.67	17.58	18.32	19.45		
bodywt	6-11	1,725	30.84	9.561	kg			22.79	24.05	25.07	26.44	29.58	33.44	36.82	39.66	43.5		
bodywt	12-19	2,615	58.45	13.64	kg			43.84	46.52	48.31	50.94	56.77	63.57	68.09	71.98	79.52		
bodywt	20+	12,504	71.41	15.45	kg			52.86	55.98	58.21	61.69	69.26	78.49	84.92	89.75	97.64		
expfruit	1-5	49	2.6	3.947	g WW/kg-d				0.373		1	1.82	2.64		5.41	6.07		
expfruit	6-11	68	2.52	3.496	g WW/kg-d			0.171	0.373		0.619	1.11	2.91		6.98	11.7		
expfruit	12-19	50	1.33	1.457	g WW/kg-d			0.123	0.258		0.404	0.609	2.27		3.41	4.78		
expfruit	Farmer	112	2.32	2.646	g WW/kg-d	0.072		0.276	0.371		0.681	1.3	3.14		5	6.12		15.7
expveg	1-5	105	2.453	2.675	g WW/kg-d			0.102	0.37		0.833	1.459	3.226		6.431	8.587		
expveg	6-11	134	1.39	2.037	g WW/kg-d			0.044	0.094		0.312	0.643	1.6		3.22	5.47		13.3
expveg	12-19	143	1.07	1.128	g WW/kg-d			0.029	0.142		0.304	0.656	1.46		2.35	3.78		5.67
expveg	Farmer	207	2.17	2.316	g WW/kg-d			0.184	0.372		0.647	1.38	2.81		6.01	6.83		10.3
rootveg	1-5	45	1.886	2.371	g WW/kg-d			0.081	0.167		0.291	0.686	2.653		5.722	7.502		
rootveg	6-11	67	1.32	1.752	g WW/kg-d			0.014	0.036		0.232	0.523	1.63		3.83	5.59		
rootveg	12-19	76	0.937	1.037	g WW/kg-d			0.008	0.068		0.269	0.565	1.37		2.26	3.32		
rootveg	Farmer	136	1.39	1.469	g WW/kg-d	0.111		0.158	0.184		0.365	0.883	1.85		3.11	4.58		7.47

Avg = average; N = number of samples; P01-P99 = percentiles; SDev = standard deviation.
Source: *Exposure Factors Handbook* (U.S. EPA, 1997a, 1997b, 1997c).

Table J-18. Population-Estimated Averages, Standard Deviations, and Coefficients of Variation

Parameter	Age Cohort	N	First	Data Mean	Gam Mean	Log Mean	WEI Mean	Data SDev	Gam SDev	Log SDev	WEI CV	Data CV	Gam CV	Log CV	WEI CV
beef	6-11	38	Lognormal	3.77	3.83	3.88	3.86	3.66	3.48	4.71	3.67	0.97	0.91	1.22	0.95
beef	12-19	41	Gamma	1.72	1.77	1.82	1.76	1.04	1.12	1.41	1.07	0.61	0.64	0.78	0.61
beef	Farmer	182	Lognormal	2.63	2.47	2.5	2.49	2.64	2.02	2.69	2.09	1.01	0.82	1.07	0.84
bodywt	1-5	3,762	Lognormal	15.5	15.5	15.5	15.4	3.72	2.05	2.05	2.35	0.24	0.13	0.13	0.15
bodywt	6-11	1,725	Lognormal	30.8	30.7	30.7	30.4	9.56	5.94	5.96	6.87	0.31	0.19	0.19	0.23
bodywt	12-19	2,615	Lognormal	58.5	58.1	58.2	57.7	13.6	10.2	10.2	11.6	0.23	0.17	0.18	0.2
bodywt	20+	12,504	Lognormal	71.4	71.2	71.2	70.7	15.5	13.2	13.3	14.8	0.22	0.18	0.19	0.21
expfruit	1-5	49	Gamma	2.6	2.25	2.46	2.25	3.95	1.89	2.91	1.84	1.52	0.84	1.18	0.82
expfruit	6-11	68	Lognormal	2.52	2.63	2.78	2.63	3.5	2.9	5.12	3.16	1.39	1.1	1.84	1.2
expfruit	12-19	50	Lognormal	1.33	1.43	1.54	1.44	1.46	1.44	2.44	1.51	1.1	1.01	1.59	1.05
expfruit	Farmer	112	Lognormal	2.32	2.24	2.36	2.24	2.65	2.1	3.33	2.18	1.14	0.94	1.41	0.97
expveg	1-5	105	Gamma	2.45	2.55	3.06	2.56	2.68	2.58	5.61	2.65	1.09	1.01	1.83	1.04
expveg	6-11	134	Lognormal	1.39	1.4	1.64	1.39	2.04	1.66	3.95	1.81	1.47	1.19	2.41	1.3
Expveg	12-19	143	Gamma	1.07	1.08	1.32	1.08	1.13	1.13	2.69	1.15	1.05	1.05	2.03	1.07
Expveg	Farmer	207	Lognormal	2.17	2.22	2.38	2.22	2.32	2.13	3.5	2.18	1.07	0.96	1.47	0.98
Fish	Adult	1,053	Lognormal	6.4	5.24	6.48	5.45		8.3	19.9	9.79		1.58	3.07	1.8
Rootveg	1-5	45	Lognormal	1.89	1.95	2.31	1.95	2.37	2.37	6.05	2.63	1.26	1.22	2.62	1.35
Rootveg	6-11	67	Weibull	1.32	1.35	2.3	1.38	1.75	1.78	10.6	2.07	1.33	1.32	4.62	1.5
Rootveg	12-19	76	Weibull	0.94		1.7	0.99	1.04		5.97	1.19	1.11		3.51	1.2
Rootveg	Farmer	136	Lognormal	1.39	1.39	1.45	1.39	1.47	1.31	2.06	1.36	1.06	0.95	1.42	0.98

CV = Coefficient of variation; CV = SDev/avg. GAM = Gamma; LOG = Lognormal; N = Number of samples; SDev = Standard deviation; WEI = Weibull.

Table J-19. Exposure Factor Raw Data for Egg, Dairy, and Poultry Consumption Rates: Descriptive Statistics by Standardized Age Groups

Paramter	Age Cohort	Data Mean	Data SDev	Data CV	P05	P10	P25	P50	P75	P90	P95
eggs_gen	All	1.01	1.04	1.03	0.133	0.253	0.422	0.724	1.22	1.99	2.82
eggs_gen	1-5	2.41	1.94	0.807	0.101	0.328	1.16	1.88	3.23	5.03	6.15
eggs_gen	6-11	1.44	1.25	0.872	0.125	0.302	0.641	1.08	1.87	2.95	3.45
eggs_gen	12-19	0.962	0.708	0.736	0.092	0.328	0.469	0.821	1.22	1.71	2.24
eggs_gen	20-69	0.792	0.663	0.836	0.145	0.248	0.389	0.633	1.01	1.52	1.88
eggs_hp	20-69	0.611	0.442	0.72	0.106	0.183	0.308	0.465	0.829	1.31	1.645
eggs_hp	All	0.731	1.114	1.523	0.15	0.175	0.268	0.466	0.902	1.36	1.69
eggs_hp	Adult farmer	0.898	1.128	1.256	0.165	0.177	0.272	0.666	1.19	1.65	1.85
milk_gen	All	6.81	10.8	1.59	0.199	0.392	1.14	3.25	7.59	16.9	26.1
milk_gen	1-5	27.4	22.3	0.817	1.12	4.39	12.2	22.3	37.1	55.9	70.1
milk_gen	6-11	14	10	0.717	0.826	2.16	6.48	12.3	19.2	27.3	33.5
milk_gen	12-19	6.2	5.87	0.946	0.264	0.484	1.88	4.55	8.88	13.5	17.8
milk_gen	20-69	3.23	3.3	1.02	0.162	0.303	0.854	2.22	4.48	7.45	9.88
milk_hp	20_39	7.41	6.12	0.826	0.396	0.446	1.89	6.46	12.1	15.4	19.5
milk_hp	All	14	15.28	1.092	0.446	0.508	3.18	10.2	19.5	34.2	44
milk_hp	Adult farmer	17.1	15.8	0.924	0.736	3.18	9.06	12.1	20.4	34.9	44
poul_gen	All	0.688	0.942	1.37	0.018	0.034	0.111	0.334	0.917	1.76	2.47
poul_gen	1-5	1.43	1.73	1.21	0.025	0.056	0.192	0.736	2.2	3.63	4.66
poul_gen	6-11	0.884	1.15	1.3	0.019	0.036	0.116	0.365	1.29	2.42	3.22
poul_gen	12-19	0.645	0.795	1.23	0.019	0.034	0.103	0.346	0.896	1.71	2.23
poul_gen	20-69	0.57	0.712	1.25	0.017	0.032	0.105	0.303	0.804	1.4	1.92
poul_hp	20-69	1.34	1.088	0.802	0.299	0.352	0.524	0.962	2.03	2.545	3.765
poul_hp	All	1.57	1.178	0.751	0.303	0.418	0.637	1.23	2.19	3.17	3.83
poul_hp	Adult farmer	1.54	1.375	0.893	0.228	0.303	0.595	1.06	2.18	3.47	4.83

Sdev = standard deviation; CV = coefficient of variation; HP = home produced; gen = general population; poul = poultry

Table J-20. Population-Estimated Means, Standard Deviations, Coefficients of Variation, and Crystal Ball Parameters for Egg, Dairy, and Poultry Consumption Rates

Parameter	Group	N	Distribution Type	Data Mean	Gam Mean	Data SDev	Gam SDev	Data CV	Gam CV	Shape	Scale	Minimum	Maximum
eggs_hp	1-5		gamma		1.58		1.15		0.73	1.88	0.839	0	10
eggs_hp	6-11		gamma		0.92		0.67		0.73	1.88	0.493	0	6
eggs_hp	12-19		gamma		0.63		0.46		0.73	1.88	0.334	0	4
eggs_hp	20-69	73	gamma	0.611	0.63	0.442	0.46	0.72	0.73	1.88	0.336	0	4
eggs_hp	All	124	gamma	0.731	0.647	1.11	0.481	1.52	0.74	1.81	0.357	0	4
eggs_hp	Adult farmer	44	gamma	0.898	0.803	1.13	0.621	1.26	0.77	1.64	0.488	0	13
milk_hp	1-5		gamma		59.40		60.59		1.02	0.961	61.80	0	482
milk_hp	6-11		gamma		30.24		30.78		1.02	0.961	31.40	0	245
milk_hp	12-19		gamma		13.41		13.63		1.02	0.961	13.90	0	109
milk_hp	20-69	36	gamma	7.41	7.7	6.12	7.87	0.826	1.02	0.961	8.01	0	63
milk_hp	All	89	gamma	14	14.3	15.3	16.1	1.09	1.13	0.78	18.26	0	126
milk_hp	Adult farmer	63	gamma	17.1	16.4	15.8	13.9	0.924	0.85	1.38	11.85	0	117
poul_hp	1-5		gamma		3.26		2.50		0.77	1.69	1.92	0	21
poul_hp	6-11		gamma		2.04		1.57		0.77	1.69	1.21	0	14
poul_hp	12-19		gamma		1.47		1.13		0.77	1.69	0.87	0	10
poul_hp	20-69	63	gamma	1.34	1.36	1.09	1.04	0.802	0.77	1.69	0.80	0	9

(continued)

Table J-20. (continued)

Parameter	Group	N	Distribution Type	Data Mean	Gam Mean	Data SDev	Gam SDev	Data CV	Gam CV	Shape	Scale	Minimum	Maximum
poul_hp	All	105	gamma	1.57	1.56	1.18	1.15	0.751	0.74	1.83	0.85	0	10
poul_hp	Adult farmer	59	gamma	1.54	1.6	1.37	1.36	0.893	0.86	1.38	1.16	0	11
eggs_gen	All	2728	gamma	1.01	0.99	1.04	0.79	1.03	0.8				
eggs_gen	1-5	585	gamma	2.41	2.41	1.94	2	0.81	0.83				
eggs_gen	6-11	219	gamma	1.44	1.41	1.25	1.11	0.87	0.78				
eggs_gen	12-19	223	gamma	0.96	0.96	0.71	0.62	0.74	0.65				
eggs_gen	20-69	1700	gamma	0.79	0.78	0.66	0.53	0.84	0.68				
milk_gen	All	8284	gamma	6.81	6.62	10.8	8.15	1.59	1.23				
milk_gen	1-5	1736	gamma	27.4	27.5	22.3	22.7	0.82	0.82				
milk_gen	6-11	892	gamma	14	14	10	11.1	0.72	0.79				
milk_gen	12-19	860	gamma	6.2	6.21	5.87	6.34	0.95	1.02				
milk_gen	20-69	4797	gamma	3.23	3.22	3.3	3.31	1.02	1.03				
poul_gen	All	7718	gamma	0.69	0.68	0.94	0.85	1.37	1.24				
poul_gen	1-5	1632	gamma	1.43	1.42	1.73	1.81	1.21	1.27				
poul_gen	6-11	836	gamma	0.88	0.89	1.15	1.16	1.3	1.3				
poul_gen	12-19	829	gamma	0.64	0.64	0.8	0.79	1.23	1.22				
poul_gen	20-69	4420	gamma	0.57	0.57	0.71	0.67	1.25	1.19				

N= number; GAM = gamma; SDEV = standard deviation; CV = coefficient of variation; hp = home produced; gen = general population; poul = poultry

J.4 References

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Appendix K

Sensitivity Analysis Results

Sensitivity Analysis Results

K.1 Introduction

The probabilistic risk analysis conducted in support of the agricultural application of biosolids considered the variability in the following types of parameters:

- Agricultural field size and biosolids characteristics
- Agricultural practices
- Regional-specific environmental conditions
- Exposure factors for each receptor.

Taken together, these variables provide nationally applicable distribution of risk for dioxins, furans, and PCBs in biosolids.

K.2 Sensitivity Analysis Methods

A statistically based sensitivity analysis was performed to rank the variables in the analysis according to their contribution to the variability of the risk for each pathway and for the total exposure of a receptor (i.e., adult farmer, child of farmer, etc). The method used for this risk assessment is referred to as a response surface regression approach. Response surface methodology is frequently used as a statistical approach to designing experiments and an associated model estimation methodology. The terminology "response surface" derives from the fact that a regression model involving a number of continuous independent variables can be viewed as providing an estimated surface of the results in space. Often a goal of response surface experimentation is to ascertain the combination(s) of input variable values that will yield a minimum or a maximum response. The complexity of the model (e.g., whether it contains only first- and second-order terms or terms of higher degree) determines the general shape of the contours and the degree to which the "true" surface can be approximated.

In this analysis, a regression analysis was applied to a linear equation to estimate the relative change in the output (risk results) of a probabilistic simulation relative to the changes in the input variable values (e.g., exposure factors). This methodology is one of the recommended methods for conducting a sensitivity analysis based on the results of a Monte Carlo analysis described in *Appendix B of RAGS 3A - Process For Conducting Probabilistic Risk Assessment - Draft (1999)* (U.S. EPA, 1999).

Historically sensitivity analyses for risk assessments were conducted by evaluating how much change in risk occurred in risk as a result of varying an individual input variable from a median or mean value to a 90^{th} percentile or high-end value. However, when the risk depends on the aggregate impact of a number of input variables, such an approach may not necessarily identify the most important one. This may occur for several reasons:

- The ranges chosen for the various input variables may not be defined consistently.

- Various input variables may interact with one another (i.e., the effect of one input on risk may depend on the level of other inputs, so that the observed effect of the first input also depends on the values chosen for the other variables as well).

- Nonlinear effects may obscure the effect of the input variable (e.g., if only low and high values of an input variable are examined, but the relationship between the risk and the input variable is of a quadratic nature, then the importance of the input variable may be overlooked).

To address such issues, statistical regression methods were used to perform the sensitivity analyses. Although regression methods have distinct advantages over previous approaches, certain limitations remain. Regression methods are not capable of determining the sensitivity of model results to input variables that are not varied in the analysis (e.g., assumptions) or are not otherwise included within the scope of the analysis (e.g., model-derived variables). If, for some reason, the most important variables are not varied or their variability is improperly characterized, the sensitivity analysis may not identify them as being important.

The sensitivity analysis was conducted on a data set generated during modeling of risk for each pathway. For example, a set of input variables was used in the modeling simulation were associated with the risk results for that patheway..

The individual risk calculated for each pathway as a result of exposure to all dioxin-like congeners as expressed as a TEQ was the outcome of concern in this sensitivity analysis. In this case, the input parameters are associated with agricultural practices, site, environmental conditions, and exposure parameters.

The regression approach uses the various combinations of input values that were used during the simulation and the resulting risk values as input data to a regression model. Functions of the results variables (denoted as Ys) were treated as dependent variables; for example, Y denoted the logarithm of the risk. Functions of the input variables were treated as independent variables. The goals of the approach were

1. To determine a fairly simple polynomial approximation to the simulation results that expressed the risks (Ys) as functions of the inputs (Xs)

2. To optimize this “response surface” and assess the importance of the various inputs by performing statistical tests on the model parameters

3. To rank the inputs based on their relative contribution (in terms of risk) to the final response surface regression model.

These goals were realized using a second-order regression model. Such a model takes the following form:

$$\hat{Y} = \hat{\beta}_0 + \sum_{k=1}^{p} \hat{\beta}_k x_k + \sum_{k=1}^{p} \hat{\beta}_{kk} x_k^2 + \sum_{k=1}^{p-1} \sum_{j=k+1}^{p} \hat{\beta}_{kj} x_k x_j \qquad \text{(K-1)}$$

where the βs are the least squares regression estimates of the model parameters.

The statistical significance of the parameters associated with the first-order, squared, and cross product terms were tested and all nonsignificant terms were removed from the model. The parameters in this reduced model were then reestimated and the process of testing was repeated. This was done to capture the most important independent variables inputs (Xs) that influence the dependent variables risk results (Ys).

Once the final regression model was developed, the input parameters (Xs) were ranked based on percentage of risk accounted for by that parameter. The percent of the risk accounted for by each important variable was calculated using the following equation:

$$Percent\ Risk = \frac{[FMSS - RMSS]}{[FMSS + ERSS]} \qquad \text{(K-2)}$$

where

FMSS = model sum of squares for the final model

RMSS = model sum of squares for a model in which all terms involving x_u are removed (i.e., a reduced model)

ERSS = model error sum of squares.

The major steps in the analysis once the initial data set of corresponding input and output values have been assembled are identified below, along with details on the reasons for these steps.

- **Perform any necessary manipulations to the data set.** To perform the sensitivity analysis, the data set must contain only one record for each Monte Carlo iteration, and all variables in the data set must be numeric.

- **Remove any variables that are constants.** Any variable that was constant across all the probabilistic iterations does not have any effect on the resulting risk and was removed from the data set prior to the start of the regression analysis.

- **Perform transformations (log, square root, etc.) to the continuous input variables, if necessary, so that all input variables will have approximately symmetric distributions.** Transforming the input variables so that each one has an approximately symmetric distribution is necessary to make the standardization of the variables meaningful (i.e., so the mean is near the midpoint of the extremes, and the mean and standard deviation are not highly related).

- **Check the correlations of the transformed input variables. Remove any input variables that are highly correlated with other input variables in the data set.** Regression analysis measures the linear relationship between the terms in the model and the response variable. If two or more input variables are highly correlated with one another, then there is a strong linear relationship between those input variables. Keeping all highly correlated variables in the model will reduce the significance of each of the correlated input variables since each one is essentially explaining the same linear relationship with the response variable (i.e., the effect of one such variable may mask the effect of another). One must keep in mind that the effect of the variable remaining in the analysis also applies the correlated variable removed from the analysis. For example, frequently many soil parameters are correlated and all but one of them, therefore, are removed from the analysis. When the sensitivity analysis results are presented it is important to present the results for the retained variable as the results for the group of correlated soil variables not just the single variable retained in the analysis.

- **Standardize the transformed variables.** Standardizing the input variables (i.e., subtracting the mean and dividing by the standard deviation) allows the regression results to be independent of the magnitude of the value of the input variables. The larger value input variables could cause the regression results to seriously underestimate the effects of the smaller value input variables on the changes in environmental concentration and risk. The combination of transforming and standardizing the input variables creates more optimal conditions for regression analysis.

- **Use response surface regression methods to test for the main effects, squared terms and cross products that have the greatest effect on the log(risk). Develop a model for risk based on the results of the regression analysis.** After the response surface regression results are obtained, the significance of each term on risk is evaluated. First, any second-order terms that are determined to not have a significant effect on the risk are dropped from the model. Any first-order term that is part of a significant second-order term will remain in the model, regardless of the level of significance of that first-order term. For example, if the second-order term X1*X2 has a significant effect on the risk and remains in the model, then both of the first-order terms, X1 and X2, will also remain in the model. Any first-order terms that are determined not to be significant and not to have any significant second-order terms are dropped from the model. The regression analysis is then conducted on the reduced model. This process is repeated until all of the second-order terms in the model have significant effects on the environmental concentration and no more terms can be removed. The iterative process of dropping insignificant terms and reevaluating the model allows only the input variables with the most effect on the risk to remain in the model.

- **Test for the effect of each variable on log(risk) and use the p-values to rank the variables by the amount of effect each variable has on log(risk).** Because the final model will most likely contain first- and second-order terms involving the same input variables, F-tests need to be performed to evaluate the effect of each input variable in the final model on the log(risk). The F-tests of each variable will be of the form

$$F = \frac{[FMSS - RMSS] \ / \ [FMDF - RMDF]}{FRSS \ / \ FRDF} \qquad \text{(K-3)}$$

where

FMSS	=	model sum of squares for full model containing all significant terms
RMSS and RMDF	=	model sum of squares and degrees of freedom for reduced model
FMDF	=	model degrees of freedom for full model
FRSS and FRDF	=	residual sum of squares and degrees of freedom, respectively, for full model.

The full model refers to the model containing all significant terms in the final log(risk) model. The reduced model refers to the full model minus all terms containing the input variable X whose significance is being tested. The F-tests evaluate the effect of variable X on the risk by evaluating the differences when variable X is in the regression model (full model) and when all model terms containing variable X are removed (reduced model). If a substantial increase in the residuals results from ignoring terms involving the variable X, then F will be “large,” implying that these factors can be considered important, in the sense that they require different regression coefficients for the Xs. The ordering of the p-values from such tests can then be used to rank the importance of the various factors on the risk. The results of the sensitivity analysis is presented in Tables K-1 through K-10.

Table K-1. Sensitivity Analysis Results - Inhalation of Ambient Air

Variable Name	Reduced ModelSS	Reduced ModelDF	Full ModelSS	Full ModelDF	VariableSS	Variable DF	FullErrorSS	Full ErrorDF	Variable MS	FullErrorMS	Percent Variation	F test Statistic	F test P Value
ED	2620.713453	65	7607.497505	66	4986.784052	1	132.2476372	2933	4986.784052	0.045089546	65.60%	110597.3455	0.00E+00
BRi	7328.56038	65	7607.497505	66	278.9371249	1	132.2476372	2933	278.9371249	0.045089546	3.70%	6186.292659	0.00E+00
b	7467.670372	52	7607.497505	66	139.8271327	14	132.2476372	2933	9.987652334	0.045089546	1.80%	221.5070524	0.00E+00
RapplP	7486.122527	64	7607.497505	66	121.3749784	2	132.2476372	2933	60.68748918	0.045089546	1.60%	1345.932597	0.00E+00
BW	7506.657846	65	7607.497505	66	100.8396594	1	132.2476372	2933	100.8396594	0.045089546	1.30%	2236.431041	0.00E+00
CutOffYrC	7508.654601	63	7607.497505	66	98.84290393	3	132.2476372	2933	32.94763464	0.045089546	1.30%	730.7156065	0.00E+00
AvgPeriodStartYrP	7514.936434	60	7607.497505	66	92.56107088	6	132.2476372	2933	15.42684515	0.045089546	1.20%	342.1379601	0.00E+00
AreaCrCr	7533.129076	62	7607.497505	66	74.36842877	4	132.2476372	2933	18.59210719	0.045089546	1.00%	412.3374266	0.00E+00
MetID	7552.120719	62	7607.497505	66	55.37678625	4	132.2476372	2933	13.84419656	0.045089546	0.70%	307.0378373	0.00E+00
CYVPaCr	7553.173882	64	7607.497505	66	54.32362323	2	132.2476372	2933	27.16181161	0.045089546	0.70%	602.3971026	0.00E+00
uw	7554.753302	63	7607.497505	66	52.7442036	3	132.2476372	2933	17.5814012	0.045089546	0.70%	389.9218982	0.00E+00
Runoff_LWS	7571.316609	61	7607.497505	66	36.18089664	5	132.2476372	2933	7.236179327	0.045089546	0.50%	160.4846364	0.00E+00
foc_soil	7574.315839	57	7607.497505	66	33.18166614	9	132.2476372	2933	3.686851793	0.045089546	0.40%	81.76733088	0.00E+00
CYVCrPa	7575.398787	64	7607.497505	66	32.09871803	2	132.2476372	2933	16.04935901	0.045089546	0.40%	355.9441286	0.00E+00
DYWVPaWa	7582.785725	64	7607.497505	66	24.71178021	2	132.2476372	2933	12.35589011	0.045089546	0.30%	274.0300428	0.00E+00
DYDPPaPa	7585.503501	63	7607.497505	66	21.99400433	3	132.2476372	2933	7.331334776	0.045089546	0.30%	162.5950025	0.00E+00
SsC	7590.321603	61	7607.497505	66	17.17590196	5	132.2476372	2933	3.435180391	0.045089546	0.20%	76.18573989	0.00E+00
AirTempP	7593.044049	63	7607.497505	66	14.45345566	3	132.2476372	2933	4.817818554	0.045089546	0.20%	106.8500135	0.00E+00
CYPPaPa	7596.407513	63	7607.497505	66	11.08999204	3	132.2476372	2933	3.696664014	0.045089546	0.10%	81.98494721	0.00E+00
CYPCrSt	7596.568503	63	7607.497505	66	10.92900214	3	132.2476372	2933	3.643000715	0.045089546	0.10%	80.79479773	0.00E+00
AreaCrWa	7599.48725	64	7607.497505	66	8.010255537	2	132.2476372	2933	4.005127769	0.045089546	0.10%	88.82608411	0.00E+00
BD	7600.673439	62	7607.497505	66	6.824065808	4	132.2476372	2933	1.706016452	0.045089546	0.10%	37.83618642	0.00E+00
CnwmuP	7600.762842	63	7607.497505	66	6.734663227	3	132.2476372	2933	2.244887742	0.045089546	0.10%	49.78732239	0.00E+00
DYDPPaRe	7602.983544	63	7607.497505	66	4.513960732	3	132.2476372	2933	1.504653577	0.045089546	0.10%	33.37034246	0.00E+00
T	7603.227361	64	7607.497505	66	4.270143907	2	132.2476372	2933	2.135071954	0.045089546	0.10%	47.35181795	0.00E+00
DYWPPaPa	7604.565438	63	7607.497505	66	2.932066911	3	132.2476372	2933	0.977355637	0.045089546	0.00%	21.67588128	6.98E-14
Huc_Region	7604.728964	62	7607.497505	66	2.768541083	4	132.2476372	2933	0.692135271	0.045089546	0.00%	15.35023833	1.98E-12
Td	7607.080223	64	7607.497505	66	0.41728249	2	132.2476372	2933	0.208641245	0.045089546	0.00%	4.627264305	9.85E-03

Table K-2. Sensitivity Analysis Results - Ingestion of Beef

VariableName	Reduced ModelSS	Reduced ModelDF	Full ModelSS	FullModelDF	VariableSS	VariableDF	FullErrorSS	FullErrorDF	VariableMS	FullErrorMS	Percent Variation	FTestStatistic	FTestPValue
ED	3337.456434	57	8352.08	58	5014.621413	1	64.3679406	2941	5014.621413	0.021886413	60.00%	229120.2956	0.00E+00
Crb	6148.995979	57	8352.08	58	2203.081868	1	64.3679406	2941	2203.081868	0.021886413	26.40%	100659.7961	0.00E+00
RapplP	8237.512756	56	8352.08	58	114.565091	2	64.3679406	2941	57.28254549	0.021886413	1.40%	2617.265128	0.00E+00
AvgPeriodStartYrP	8254.746331	51	8352.08	58	97.33151559	7	64.3679406	2941	13.90450223	0.021886413	1.20%	635.3029267	0.00E+00
CutOffYrC	8281.122348	54	8352.08	58	70.9554992	4	64.3679406	2941	17.7388748	0.021886413	0.80%	810.4971248	0.00E+00
b	8312.893697	47	8352.08	58	39.18414959	11	64.3679406	2941	3.562195418	0.021886413	0.50%	162.7583021	0.00E+00
AreaCrCr	8338.834047	55	8352.08	58	13.24380013	3	64.3679406	2941	4.414600042	0.021886413	0.20%	201.7050507	0.00E+00
AirTempP	8342.071905	56	8352.08	58	10.00594172	2	64.3679406	2941	5.002970859	0.021886413	0.10%	228.5879766	0.00E+00
foc_soil	8343.937202	53	8352.08	58	8.14064527	5	64.3679406	2941	1.628129054	0.021886413	0.10%	74.3899448	0.00E+00
CYVPaRe	8344.759165	57	8352.08	58	7.318681576	1	64.3679406	2941	7.318681576	0.021886413	0.10%	334.3938351	0.00E+00
DYWPPaPa	8345.778292	56	8352.08	58	6.29955492	2	64.3679406	2941	3.14977746	0.021886413	0.10%	143.9147412	0.00E+00
Huc_Region	8345.871885	53	8352.08	58	6.205961578	5	64.3679406	2941	1.241192316	0.021886413	0.10%	56.71063213	0.00E+00
MetID	8348.106143	54	8352.08	58	3.971704206	4	64.3679406	2941	0.992926051	0.021886413	0.00%	45.36723546	0.00E+00
Runoff_LWS	8348.476291	51	8352.08	58	3.601556404	7	64.3679406	2941	0.514508058	0.021886413	0.00%	23.50810332	0.00E+00
uw	8349.169422	54	8352.08	58	2.908424971	4	64.3679406	2941	0.727106243	0.021886413	0.00%	33.22180949	0.00E+00
SsC	8349.273034	54	8352.08	58	2.804813291	4	64.3679406	2941	0.701203323	0.021886413	0.00%	32.03829349	0.00E+00
BD	8349.451315	55	8352.08	58	2.626532462	3	64.3679406	2941	0.875510821	0.021886413	0.00%	40.00248105	0.00E+00
CnwmuP	8349.794431	51	8352.08	58	2.283415681	7	64.3679406	2941	0.32620224	0.021886413	0.00%	14.90432627	0.00E+00
CYVPaCr	8350.284739	57	8352.08	58	1.793107678	1	64.3679406	2941	1.793107678	0.021886413	0.00%	81.92789193	0.00E+00
CYPPaPa	8350.603134	57	8352.08	58	1.474713213	1	64.3679406	2941	1.474713213	0.021886413	0.00%	67.3803064	3.33E-16
CYPCrSt	8350.834037	55	8352.08	58	1.243810165	3	64.3679406	2941	0.414603388	0.021886413	0.00%	18.94341429	3.63E-12
DYDPPaRe	8351.089134	57	8352.08	58	0.988713539	1	64.3679406	2941	0.988713539	0.021886413	0.00%	45.17476386	2.16E-11
T	8351.103141	57	8352.08	58	0.974706318	1	64.3679406	2941	0.974706318	0.021886413	0.00%	44.53476767	2.97E-11
CYVCrPa	8351.532642	56	8352.08	58	0.545205465	2	64.3679406	2941	0.272602733	0.021886413	0.00%	12.4553408	4.11E-06
DYDPCrPa	8351.583507	55	8352.08	58	0.494339661	3	64.3679406	2941	0.164779887	0.021886413	0.00%	7.528866749	5.12E-05
BW	8352.077761	57	8352.08	58	8.57417E-05	1	64.3679406	2941	8.57417E-05	0.021886413	0.00%	0.003917578	9.50E-01
Chem3268879	8389.020624	49	8389.15	51	0.12771062	2	59.64467238	2948	0.06385531	0.02023225	1.52233E-05	3.156115139	4.27E-02
BW	8389.138359	50	8389.15	51	0.009975025	1	59.64467238	2948	0.009975025	0.02023225	1.18904E-06	0.493025987	4.83E-01

Table K-3. Sensitivity Analysis Results - Ingestion of Eggs

VariableName	Reduced ModelSS	Reduced ModelDF	FullModelSS	Full ModelDF	VariableSS	VariableDF	FullErrorSS	FullErrorDF	VariableMS	FullErrorMS	Percent Variation	FTestStatistic	FTestPValue
ED	3387.13499	75	8402.22	76	5015.089043	1	95.38972003	2923	5015.089043	0.032634184	59.70%	153675.944	0.00E+00
CR_egg	6036.879632	75	8402.22	76	2365.3444	1	95.38972003	2923	2365.3444	0.032634184	28.20%	72480.57422	0.00E+00
AvgPeriodStartYrP	8202.934582	67	8402.22	76	199.2894511	9	95.38972003	2923	22.14327234	0.032634184	2.40%	678.5299824	0.00E+00
RapplP	8286.605569	74	8402.22	76	115.6184638	2	95.38972003	2923	57.8092319	0.032634184	1.40%	1771.431815	0.00E+00
CutOffYrC	8356.18199	68	8402.22	76	46.04204311	8	95.38972003	2923	5.755255388	0.032634184	0.50%	176.3566503	0.00E+00
foc_soil	8357.66654	62	8402.22	76	44.5574926	14	95.38972003	2923	3.182678043	0.032634184	0.50%	97.52589604	0.00E+00
AirTempP	8376.138898	72	8402.22	76	26.08513447	4	95.38972003	2923	6.521283617	0.032634184	0.30%	199.829835	0.00E+00
AreaCrCr	8387.161443	71	8402.22	76	15.06258948	5	95.38972003	2923	3.012517896	0.032634184	0.20%	92.31172717	0.00E+00
Runoff_LWS	8387.576398	69	8402.22	76	14.64763449	7	95.38972003	2923	2.092519212	0.032634184	0.20%	64.12046975	0.00E+00
b	8387.86771	68	8402.22	76	14.35632272	8	95.38972003	2923	1.79454034	0.032634184	0.20%	54.98958809	0.00E+00
uw	8393.899577	71	8402.22	76	8.3244553	5	95.38972003	2923	1.66489106	0.032634184	0.10%	51.01678217	0.00E+00
T1	8395.703646	68	8402.22	76	6.520386997	8	95.38972003	2923	0.815048375	0.032634184	0.10%	24.97529501	0.00E+00
T	8397.361067	72	8402.22	76	4.862965382	4	95.38972003	2923	1.215741346	0.032634184	0.10%	37.2536155	0.00E+00
CnwmuP	8398.299104	73	8402.22	76	3.92492836	3	95.38972003	2923	1.308309453	0.032634184	0.00%	40.09015365	0.00E+00
DYWVPaWa	8398.54711	73	8402.22	76	3.676923124	3	95.38972003	2923	1.225641041	0.032634184	0.00%	37.55696906	0.00E+00
Huc_Region	8398.718821	72	8402.22	76	3.505211425	4	95.38972003	2923	0.876302856	0.032634184	0.00%	26.85229864	0.00E+00
SsC	8398.752529	72	8402.22	76	3.471504013	4	95.38972003	2923	0.867876003	0.032634184	0.00%	26.59407698	0.00E+00
CYVPaRe	8399.091757	73	8402.22	76	3.132275876	3	95.38972003	2923	1.044091959	0.032634184	0.00%	31.99381227	0.00E+00
CYPPaPa	8399.590297	72	8402.22	76	2.633735371	4	95.38972003	2923	0.658433843	0.032634184	0.00%	20.17620056	2.22E-16
ConVsP	8399.898346	73	8402.22	76	2.32568706	3	95.38972003	2923	0.77522902	0.032634184	0.00%	23.75512188	3.44E-15
CYVPaCr	8400.168208	74	8402.22	76	2.055825203	2	95.38972003	2923	1.027912602	0.032634184	0.00%	31.49803284	2.92E-14
DYDPPaRe	8400.197175	72	8402.22	76	2.026858282	4	95.38972003	2923	0.506714571	0.032634184	0.00%	15.52711015	1.42E-12
BD	8400.674306	72	8402.22	76	1.549727098	4	95.38972003	2923	0.387431775	0.032634184	0.00%	11.87196143	1.44E-09
AreaCrWa	8401.007051	74	8402.22	76	1.216981627	2	95.38972003	2923	0.608490814	0.032634184	0.00%	18.64581055	8.98E-09
DYDPPaPa	8401.334425	74	8402.22	76	0.889607828	2	95.38972003	2923	0.444803914	0.032634184	0.00%	13.62999955	1.28E-06
Td	8401.796197	74	8402.22	76	0.427835534	2	95.38972003	2923	0.213917767	0.032634184	0.00%	6.555021154	1.44E-03
CYVCrPa	8401.956682	74	8402.22	76	0.267350482	2	95.38972003	2923	0.133675241	0.032634184	0.00%	4.096172311	1.67E-02
BW	8402.207629	75	8402.22	76	0.016403316	1	95.38972003	2923	0.016403316	0.032634184	0.00%	0.502642147	4.78E-01

Table K-4. Sensitivity Analysis Results - Ingestion of Fish

VariableName	Reduced ModelSS	Reduced ModelDF	Full ModelSS	Full ModelDF	VariableSS	VariableDF	FullErrorSS	FullErrorDF	VariableMS	FullErrorMS	Percent Variation	FTestStatistic	FTestPValue
CRf	7933.15	77	14870.22	78	6937.07099	1	166.4878162	2921	6937.07099	0.056996856	46.70%	121709.7132	0.00E+00
ED	9863.72	77	14870.22	78	5006.497445	1	166.4878162	2921	5006.497445	0.056996856	33.70%	87838.13355	0.00E+00
AvgPeriodStartYrP	14741.71	68	14870.22	78	128.5037167	10	166.4878162	2921	12.85037167	0.056996856	0.90%	225.4575529	0.00E+00
RapplP	14750.21	77	14870.22	78	120.0081235	1	166.4878162	2921	120.0081235	0.056996856	0.80%	2105.521813	0.00E+00
foc_soil	14762.18	67	14870.22	78	108.0424016	11	166.4878162	2921	9.822036509	0.056996856	0.70%	172.3259353	0.00E+00
BW	14771.65	77	14870.22	78	98.57022414	1	166.4878162	2921	98.57022414	0.056996856	0.70%	1729.397569	0.00E+00
CutOffYrC	14805.54	71	14870.22	78	64.68190439	7	166.4878162	2921	9.240272056	0.056996856	0.40%	162.1189784	0.00E+00
b	14823.49	69	14870.22	78	46.72695589	9	166.4878162	2921	5.191883988	0.056996856	0.30%	91.09070844	0.00E+00
Runoff_LWS	14827.09	70	14870.22	78	43.13190001	8	166.4878162	2921	5.391487502	0.056996856	0.30%	94.59271764	0.00E+00
BD	14842.77	70	14870.22	78	27.44348098	8	166.4878162	2921	3.430435123	0.056996856	0.20%	60.18639213	0.00E+00
CYVPaRe	14844.39	74	14870.22	78	25.82359275	4	166.4878162	2921	6.455898188	0.056996856	0.20%	113.2676194	0.00E+00
AreaCrWa	14846.17	75	14870.22	78	24.04679403	3	166.4878162	2921	8.015598011	0.056996856	0.20%	140.6322836	0.00E+00
DYWVPaWa	14846.99	76	14870.22	78	23.22625032	2	166.4878162	2921	11.61312516	0.056996856	0.20%	203.7502765	0.00E+00
AirTempP	14847.65	75	14870.22	78	22.56788179	3	166.4878162	2921	7.522627264	0.056996856	0.20%	131.9831969	0.00E+00
DYDPCrPa	14851.50	73	14870.22	78	18.717369	5	166.4878162	2921	3.7434738	0.056996856	0.10%	65.6786017	0.00E+00
SsC	14852.20	75	14870.22	78	18.01531116	3	166.4878162	2921	6.005103721	0.056996856	0.10%	105.3585083	0.00E+00
CYVCrPa	14852.74	75	14870.22	78	17.48137523	3	166.4878162	2921	5.827125076	0.056996856	0.10%	102.2359037	0.00E+00
Huc_Region	14854.15	75	14870.22	78	16.07205158	3	166.4878162	2921	5.357350525	0.056996856	0.10%	93.99379028	0.00E+00
T1	14857.23	73	14870.22	78	12.9886068	5	166.4878162	2921	2.59772136	0.056996856	0.10%	45.57657289	0.00E+00
uw	14863.00	75	14870.22	78	7.213705683	3	166.4878162	2921	2.404568561	0.056996856	0.00%	42.18774037	0.00E+00
DYDPPaRe	14863.67	74	14870.22	78	6.550315753	4	166.4878162	2921	1.637578938	0.056996856	0.00%	28.73103983	0.00E+00
DYWPPaPa	14863.82	76	14870.22	78	6.3975787	2	166.4878162	2921	3.19878935	0.056996856	0.00%	56.12220703	0.00E+00
MetID	14863.85	76	14870.22	78	6.369316802	2	166.4878162	2921	3.184658401	0.056996856	0.00%	55.87428197	0.00E+00
T	14863.96	74	14870.22	78	6.25814691	4	166.4878162	2921	1.564536728	0.056996856	0.00%	27.44952685	0.00E+00
CYVPaCr	14864.24	77	14870.22	78	5.975909524	1	166.4878162	2921	5.975909524	0.056996856	0.00%	104.8463012	0.00E+00
CnwmuP	14864.89	75	14870.22	78	5.324894891	3	166.4878162	2921	1.774964964	0.056996856	0.00%	31.14145393	0.00E+00
DYDPPaPa	14864.93	77	14870.22	78	5.284500244	1	166.4878162	2921	5.284500244	0.056996856	0.00%	92.71564468	0.00E+00
PICrWa	14865.96	75	14870.22	78	4.261201193	3	166.4878162	2921	1.420400398	0.056996856	0.00%	24.92067981	6.66E-16
AreaCrCr	14866.37	75	14870.22	78	3.849895658	3	166.4878162	2921	1.283298553	0.056996856	0.00%	22.51525161	2.08E-14
CYPPaPa	14867.78	76	14870.22	78	2.43975138	2	166.4878162	2921	1.21987569	0.056996856	0.00%	21.40250843	5.92E-10
ConVsP	14869.34	76	14870.22	78	0.880077742	2	166.4878162	2921	0.440038871	0.056996856	0.00%	7.720406038	4.53E-04

Table K-5. Sensitivity Analysis Results - Ingestion of Fruit

VariableName	Reduced ModelSS	Reduced ModelDF	Full ModelSS	Full ModelDF	VariableSS	VariableDF	FullErrorSS	FullErrorDF	VariableMS	FullErrorMS	Percent Variation	F test Statistic	F test P Value
ED	3975.822986	59	9073.53	60	5097.705376	1	928.3449001	2939	5097.705376	0.315871011	56.20%	16138.56671	0.00E+00
CR_exfruit	8118.356119	59	9073.53	60	955.1722421	1	928.3449001	2939	955.1722421	0.315871011	10.50%	3023.93132	0.00E+00
AvgPeriodStartYrP	8858.43654	54	9073.53	60	215.0918209	6	928.3449001	2939	35.84863682	0.315871011	2.40%	113.4913798	0.00E+00
b	8876.308533	47	9073.53	60	197.2198279	13	928.3449001	2939	15.17075599	0.315871011	2.20%	48.02832638	0.00E+00
RapplP	8960.231777	58	9073.53	60	113.2965839	2	928.3449001	2939	56.64829195	0.315871011	1.20%	179.3399522	0.00E+00
CutOffYrC	8995.560762	57	9073.53	60	77.96759882	3	928.3449001	2939	25.98919961	0.315871011	0.90%	82.27788793	0.00E+00
CYVPaCr	9011.953941	55	9073.53	60	61.5744199	5	928.3449001	2939	12.31488398	0.315871011	0.70%	38.98706614	0.00E+00
AirTempP	9025.211189	58	9073.53	60	48.31717202	2	928.3449001	2939	24.15858601	0.315871011	0.50%	76.48244125	0.00E+00
foc_soil	9031.313835	56	9073.53	60	42.21452624	4	928.3449001	2939	10.55363156	0.315871011	0.50%	33.41120649	0.00E+00
uw	9035.870536	56	9073.53	60	37.65782531	4	928.3449001	2939	9.414456326	0.315871011	0.40%	29.80474944	0.00E+00
SsC	9053.512237	55	9073.53	60	20.0161243	5	928.3449001	2939	4.00322486	0.315871011	0.20%	12.6736064	3.32E-12
Runoff_LWS	9054.122539	56	9073.53	60	19.40582266	4	928.3449001	2939	4.851455664	0.315871011	0.20%	15.35897725	1.95E-12
AreaCrCr	9055.859079	57	9073.53	60	17.66928241	3	928.3449001	2939	5.889760802	0.315871011	0.20%	18.64609478	5.58E-12
MetID	9058.754906	55	9073.53	60	14.77345543	5	928.3449001	2939	2.954691086	0.315871011	0.20%	9.35410654	7.44E-09
BD	9059.635562	54	9073.53	60	13.89279913	6	928.3449001	2939	2.315466521	0.315871011	0.20%	7.330417934	8.53E-08
CYPPaPa	9063.692365	58	9073.53	60	9.83599604	2	928.3449001	2939	4.91799802	0.315871011	0.10%	15.56964031	1.88E-07
CYVPaRe	9068.110121	59	9073.53	60	5.418240449	1	928.3449001	2939	5.418240449	0.315871011	0.10%	17.15333243	3.55E-05
DYDPPaRe	9068.197276	58	9073.53	60	5.331085152	2	928.3449001	2939	2.665542576	0.315871011	0.10%	8.438705949	2.22E-04
CnwmuP	9069.443591	56	9073.53	60	4.084769965	4	928.3449001	2939	1.021192491	0.315871011	0.00%	3.232941476	1.17E-02
DYDPPaPa	9069.807265	58	9073.53	60	3.72109585	2	928.3449001	2939	1.860547925	0.315871011	0.00%	5.890214241	2.80E-03
DYWVPaWa	9070.553653	56	9073.53	60	2.974708471	4	928.3449001	2939	0.743677118	0.315871011	0.00%	2.354369641	5.17E-02
DYWPPaPa	9071.182587	59	9073.53	60	2.345774281	1	928.3449001	2939	2.345774281	0.315871011	0.00%	7.426367732	6.47E-03
AreaCrWa	9071.451019	58	9073.53	60	2.077341873	2	928.3449001	2939	1.038670937	0.315871011	0.00%	3.288275599	3.75E-02
Huc_Region	9071.555569	59	9073.53	60	1.972792099	1	928.3449001	2939	1.972792099	0.315871011	0.00%	6.245562374	1.25E-02
zrufP	9073.386809	58	9073.53	60	0.14155266	2	928.3449001	2939	0.07077633	0.315871011	0.00%	0.22406719	7.99E-01
CYPCrSt	9073.488876	58	9073.53	60	0.039484882	2	928.3449001	2939	0.019742441	0.315871011	0.00%	0.062501592	9.39E-01
BW	9073.511579	59	9073.53	60	0.0167824	1	928.3449001	2939	0.0167824	0.315871011	0.00%	0.053130549	8.18E-01

Table K-6. Sensitivity Analysis Results - Ingestion of Milk

VariableName	Reduced ModelSS	Reduced ModelDF	FullModel SS	Full ModelDF	VariableSS	VariableDF	FullErrorSS	FullErrorDF	VariableMS	FullErrorMS	Percent Variation	Ftest Statistic	FTestPValue
ED	4273.625337	58	9278.96	59	5005.332249	1	69.02088415	2940	5005.332249	0.023476491	53.90%	213206.1476	0.00E+00
CRm	6300.509583	58	9278.96	59	2978.448003	1	69.02088415	2940	2978.448003	0.023476491	32.10%	126869.3851	0.00E+00
AvgPeriodStartYrP	9149.041971	51	9278.96	59	129.9156156	8	69.02088415	2940	16.23945195	0.023476491	1.40%	691.7324997	0.00E+00
RapplP	9164.601915	57	9278.96	59	114.3556716	2	69.02088415	2940	57.17783578	0.023476491	1.20%	2435.535842	0.00E+00
CutOffYrC	9203.317994	54	9278.96	59	75.6395926	5	69.02088415	2940	15.12791852	0.023476491	0.80%	644.3858405	0.00E+00
b	9240.253565	46	9278.96	59	38.70402164	13	69.02088415	2940	2.977232434	0.023476491	0.40%	126.8176069	0.00E+00
AreaCrCr	9264.269333	57	9278.96	59	14.68825337	2	69.02088415	2940	7.344126684	0.023476491	0.20%	312.8289751	0.00E+00
AirTempP	9266.177512	56	9278.96	59	12.78007462	3	69.02088415	2940	4.260024875	0.023476491	0.10%	181.4591813	0.00E+00
CYVPaCr	9269.719456	57	9278.96	59	9.238130645	2	69.02088415	2940	4.619065322	0.023476491	0.10%	196.7527976	0.00E+00
CYVCrPa	9273.503456	57	9278.96	59	5.45412996	2	69.02088415	2940	2.72706498	0.023476491	0.10%	116.1615233	0.00E+00
foc_soil	9273.512328	54	9278.96	59	5.44525817	5	69.02088415	2940	1.089051634	0.023476491	0.10%	46.38902911	0.00E+00
Huc_Region	9274.128569	54	9278.96	59	4.8290171	5	69.02088415	2940	0.96580342	0.023476491	0.10%	41.13917244	0.00E+00
MetID	9274.456722	56	9278.96	59	4.500864508	3	69.02088415	2940	1.500288169	0.023476491	0.00%	63.90597965	0.00E+00
CnwmuP	9274.719558	54	9278.96	59	4.238028412	5	69.02088415	2940	0.847605683	0.023476491	0.00%	36.10444487	0.00E+00
SsC	9275.276592	56	9278.96	59	3.680994038	3	69.02088415	2940	1.226998013	0.023476491	0.00%	52.26496591	0.00E+00
Runoff_LWS	9275.40949	53	9278.96	59	3.548096374	6	69.02088415	2940	0.591349396	0.023476491	0.00%	25.1890025	0.00E+00
DYWPPaPa	9275.982086	57	9278.96	59	2.975500473	2	69.02088415	2940	1.487750236	0.023476491	0.00%	63.37191632	0.00E+00
CYPPaPa	9276.271258	56	9278.96	59	2.686328566	3	69.02088415	2940	0.895442855	0.023476491	0.00%	38.14210767	0.00E+00
DYDPCrPa	9276.370547	56	9278.96	59	2.587039029	3	69.02088415	2940	0.862346343	0.023476491	0.00%	36.73233514	0.00E+00
BD	9276.762571	55	9278.96	59	2.195015606	4	69.02088415	2940	0.548753901	0.023476491	0.00%	23.37461321	0.00E+00
uw	9277.169082	57	9278.96	59	1.7885045	2	69.02088415	2940	0.89425225	0.023476491	0.00%	38.09139289	0.00E+00
CYPCrSt	9277.782899	56	9278.96	59	1.174687219	3	69.02088415	2940	0.391562406	0.023476491	0.00%	16.67891521	9.61E-11
DYWVPaWa	9278.240809	58	9278.96	59	0.716777384	1	69.02088415	2940	0.716777384	0.023476491	0.00%	30.53170841	3.57E-08
AreaCrWa	9278.655899	58	9278.96	59	0.301687424	1	69.02088415	2940	0.301687424	0.023476491	0.00%	12.85061816	3.43E-04
fdP	9278.706911	56	9278.96	59	0.250675575	3	69.02088415	2940	0.083558525	0.023476491	0.00%	3.559242488	1.37E-02
BW	9278.957578	58	9278.96	59	8.67E-06	1	69.02088415	2940	8.67E-06	0.023476491	0.00%	0.000369178	9.85E-01

Table K-7. Sensitivity Analysis Results - Ingestion of Poultry

VariableName	Reduced ModelSS	Reduced ModelDF	FullModelSS	Full ModelDF	VariableSS	VariableDF	FullErrorSS	FullError DF	VariableMS	FullErrorMS	Percent Variation	FTestStatistic	FTestPValue
ED	4147.00571	79	9163.65	80	5016.640701	1	99.20504331	2919	5016.640701	0.033985969	54.70%	147609.1711	0.00E+00
CR_poultry	6167.929355	79	9163.65	80	2995.717056	1	99.20504331	2919	2995.717056	0.033985969	32.70%	88145.70101	0.00E+00
AvgPeriodStartYrP	8976.676266	71	9163.65	80	186.9701446	9	99.20504331	2919	20.77446051	0.033985969	2.00%	611.2658006	0.00E+00
RapplP	9046.702808	78	9163.65	80	116.9436031	2	99.20504331	2919	58.47180156	0.033985969	1.30%	1720.46887	0.00E+00
CutOffYrC	9115.244857	73	9163.65	80	48.40155409	7	99.20504331	2919	6.914507727	0.033985969	0.50%	203.4518345	0.00E+00
foc_soil	9117.113329	66	9163.65	80	46.5330817	14	99.20504331	2919	3.32379155	0.033985969	0.50%	97.79893452	0.00E+00
AirTempP	9135.675075	75	9163.65	80	27.97133577	5	99.20504331	2919	5.594267155	0.033985969	0.30%	164.6051983	0.00E+00
b	9147.397568	71	9163.65	80	16.24884253	9	99.20504331	2919	1.805426948	0.033985969	0.20%	53.12271519	0.00E+00
AreaCrCr	9148.324529	75	9163.65	80	15.32188218	5	99.20504331	2919	3.064376436	0.033985969	0.20%	90.16592825	0.00E+00
Runoff_LWS	9151.28198	73	9163.65	80	12.3644309	7	99.20504331	2919	1.766347272	0.033985969	0.10%	51.97283843	0.00E+00
uw	9153.876436	75	9163.65	80	9.769975225	5	99.20504331	2919	1.953995045	0.033985969	0.10%	57.49416911	0.00E+00
T1	9155.18715	72	9163.65	80	8.459261304	8	99.20504331	2919	1.057407663	0.033985969	0.10%	31.11306508	0.00E+00
T	9158.482263	76	9163.65	80	5.164148212	4	99.20504331	2919	1.291037053	0.033985969	0.10%	37.98735459	0.00E+00
SsC	9158.831027	75	9163.65	80	4.815383605	5	99.20504331	2919	0.963076721	0.033985969	0.10%	28.33748018	0.00E+00
DYWVPaWa	9159.915672	76	9163.65	80	3.730738622	4	99.20504331	2919	0.932684655	0.033985969	0.00%	27.44322686	0.00E+00
CYVPaRe	9160.069309	77	9163.65	80	3.577101808	3	99.20504331	2919	1.19236727	0.033985969	0.00%	35.08410403	0.00E+00
CnwmuP	9160.476646	77	9163.65	80	3.169764999	3	99.20504331	2919	1.056588333	0.033985969	0.00%	31.08895718	0.00E+00
Huc_Region	9160.606851	76	9163.65	80	3.039560016	4	99.20504331	2919	0.759890004	0.033985969	0.00%	22.35893305	0.00E+00
CYPPaPa	9160.61957	76	9163.65	80	3.026841219	4	99.20504331	2919	0.756710305	0.033985969	0.00%	22.26537388	0.00E+00
CYVPaCr	9160.778728	78	9163.65	80	2.867683004	2	99.20504331	2919	1.433841502	0.033985969	0.00%	42.18921946	0.00E+00
ConVsP	9161.112732	76	9163.65	80	2.533678764	4	99.20504331	2919	0.633419691	0.033985969	0.00%	18.63768228	3.89E-15
BD	9161.219234	75	9163.65	80	2.427177391	5	99.20504331	2919	0.485435478	0.033985969	0.00%	14.28340852	7.72E-14
DYDPPaPa	9162.80523	78	9163.65	80	0.841181025	2	99.20504331	2919	0.420590513	0.033985969	0.00%	12.37541626	4.45E-06
AreaCrWa	9162.515562	78	9163.65	80	1.130848792	2	99.20504331	2919	0.565424396	0.033985969	0.00%	16.63699502	6.54E-08
DYDPPaPa	9162.80523	78	9163.65	80	0.841181025	2	99.20504331	2919	0.420590513	0.033985969	0.00%	12.37541626	4.45E-06
DYDPCrPa	9163.090214	77	9163.65	80	0.556197238	3	99.20504331	2919	0.185399079	0.033985969	0.00%	5.455165326	9.74E-04
CYVCrPa	9163.172116	78	9163.65	80	0.47429495	2	99.20504331	2919	0.237147475	0.033985969	0.00%	6.977805327	9.48E-04
Td	9163.280144	78	9163.65	80	0.366267363	2	99.20504331	2919	0.183133682	0.033985969	0.00%	5.388508471	4.61E-03
BW	9163.615701	79	9163.65	80	0.030710215	1	99.20504331	2919	0.030710215	0.033985969	0.00%	0.903614515	3.42E-01

Table K-8. Sensitivity Analysis Results - Ingestion of Root Vegetables

VariableName	Reduced ModelSS	Reduced ModelDF	Full ModelSS	FullModel DF	VariableSS	VariableDF	FullErrorSS	FullError DF	VariableMS	FullErrorMS	Percent Variation	FTestStatistic	FTestPValue
ED	5357.374507	26	10421.72	27	5064.341778	1	33.48439082	2972	5064.341778	0.011266619	48.60%	449499.7041	0.00E+00
CR_root	7252.443885	26	10421.72	27	3169.272401	1	33.48439082	2972	3169.272401	0.011266619	30.40%	281297.5642	0.00E+00
foc_soil	9380.070341	22	10421.72	27	1041.645945	5	33.48439082	2972	208.3291889	0.011266619	10.00%	18490.83511	0.00E+00
AvgPeriodStartYrP	10029.08867	23	10421.72	27	392.6276119	4	33.48439082	2972	98.15690296	0.011266619	3.80%	8712.188231	0.00E+00
RapplP	10303.54152	25	10421.72	27	118.1747634	2	33.48439082	2972	59.08738169	0.011266619	1.10%	5244.464483	0.00E+00
CutOffYrC	10392.1281	22	10421.72	27	29.58818894	5	33.48439082	2972	5.917637788	0.011266619	0.30%	525.2363587	0.00E+00
BD	10420.70186	26	10421.72	27	1.014423501	1	33.48439082	2972	1.014423501	0.011266619	0.00%	90.03797204	0.00E+00
b	10420.94787	25	10421.72	27	0.768414846	2	33.48439082	2972	0.384207423	0.011266619	0.00%	34.10139571	2.33E-15
DYDPPaRe	10421.12941	25	10421.72	27	0.586877782	2	33.48439082	2972	0.293438891	0.011266619	0.00%	26.04498285	6.12E-12
CYVPaCr	10421.5943	25	10421.72	27	0.121987736	2	33.48439082	2972	0.060993868	0.011266619	0.00%	5.413679978	4.50E-03
SsC	10421.6097	26	10421.72	27	0.106590141	1	33.48439082	2972	0.106590141	0.011266619	0.00%	9.460703655	2.12E-03
DYDPCrPa	10421.6401	25	10421.72	27	0.076181833	2	33.48439082	2972	0.038090917	0.011266619	0.00%	3.380864978	3.41E-02
CYPCrSt	10421.65383	25	10421.72	27	0.062456156	2	33.48439082	2972	0.031228078	0.011266619	0.00%	2.771734677	6.27E-02
Td	10421.66583	25	10421.72	27	0.050458407	2	33.48439082	2972	0.025229204	0.011266619	0.00%	2.239287961	1.07E-01
fdP	10421.68099	25	10421.72	27	0.035295621	2	33.48439082	2972	0.01764781	0.011266619	0.00%	1.566380374	2.09E-01
BW	10421.70642	26	10421.72	27	0.009870501	1	33.48439082	2972	0.009870501	0.011266619	0.00%	0.87608368	3.49E-01

Table K-9. Sensitivity Analysis Results - Ingestion of Soil

VariableName	Reduced ModelSS	Reduced ModelDF	Full ModelSS	FullModelDF	VariableSS	VariableDF	FullErrorSS	FullErrorDF	VariableMS	FullErrorMS	Percent Variation	FTestStatistic	FTestPValue
ED	1401.452624	82	6441.45	83	5039.99811	1	112.8976598	2916	5039.99811	0.038716619	78.20%	130176.6087	0.00E+00
AvgPeriodStartYrP	6230.139895	72	6441.45	83	211.3108386	11	112.8976598	2916	19.21007624	0.038716619	3.30%	496.1713324	0.00E+00
RapplP	6327.240995	81	6441.45	83	114.2097382	2	112.8976598	2916	57.10486911	0.038716619	1.80%	1474.944641	0.00E+00
BW	6344.808583	82	6441.45	83	96.64215015	1	112.8976598	2916	96.64215015	0.038716619	1.50%	2496.141286	0.00E+00
foc_soil	6394.040772	71	6441.45	83	47.4099616	12	112.8976598	2916	3.950830133	0.038716619	0.70%	102.0448137	0.00E+00
CutOffYrC	6398.35841	75	6441.45	83	43.09232322	8	112.8976598	2916	5.386540403	0.038716619	0.70%	139.1273463	0.00E+00
AirTempP	6405.039287	78	6441.45	83	36.41144655	5	112.8976598	2916	7.28228931	0.038716619	0.60%	188.0920797	0.00E+00
Runoff_LWS	6416.771554	76	6441.45	83	24.67917918	7	112.8976598	2916	3.525597026	0.038716619	0.40%	91.06159457	0.00E+00
AreaCrCr	6418.753436	78	6441.45	83	22.6972974	5	112.8976598	2916	4.539459481	0.038716619	0.40%	117.2483457	0.00E+00
T1	6424.49572	71	6441.45	83	16.95501357	12	112.8976598	2916	1.412917798	0.038716619	0.30%	36.49383259	0.00E+00
b	6428.681309	80	6441.45	83	12.76942452	3	112.8976598	2916	4.25647484	0.038716619	0.20%	109.9392197	0.00E+00
CnwmuP	6429.949132	77	6441.45	83	11.50160112	6	112.8976598	2916	1.91693352	0.038716619	0.20%	49.51190443	0.00E+00
T	6433.582111	77	6441.45	83	7.868622024	6	112.8976598	2916	1.311437004	0.038716619	0.10%	33.87271543	0.00E+00
uw	6437.329871	78	6441.45	83	4.120861828	5	112.8976598	2916	0.824172366	0.038716619	0.10%	21.28730234	0.00E+00
SsC	6437.853285	76	6441.45	83	3.597448447	7	112.8976598	2916	0.513921207	0.038716619	0.10%	13.27391764	1.11E-16
CYVPaRe	6438.169114	80	6441.45	83	3.281619067	3	112.8976598	2916	1.093873022	0.038716619	0.10%	28.2533202	0.00E+00
CYPPaPa	6438.20393	81	6441.45	83	3.246802788	2	112.8976598	2916	1.623401394	0.038716619	0.10%	41.93035065	0.00E+00
ConVsP	6438.379239	79	6441.45	83	3.071494601	4	112.8976598	2916	0.76787365	0.038716619	0.00%	19.83317961	4.44E-16
BD	6438.496501	80	6441.45	83	2.954232108	3	112.8976598	2916	0.984744036	0.038716619	0.00%	25.43466015	3.33E-16
CYVPaCr	6438.777548	81	6441.45	83	2.673185387	2	112.8976598	2916	1.336592694	0.038716619	0.00%	34.52245423	1.55E-15
DYDPPaRe	6438.87013	78	6441.45	83	2.58060335	5	112.8976598	2916	0.51612067	0.038716619	0.00%	13.33072692	7.16E-13
Huc_Region	6438.924174	80	6441.45	83	2.526558761	3	112.8976598	2916	0.842186254	0.038716619	0.00%	21.75257768	6.26E-14
CYVCrPa	6439.080105	78	6441.45	83	2.370628538	5	112.8976598	2916	0.474125708	0.038716619	0.00%	12.24605156	9.02E-12
DYWPPaPa	6439.541852	82	6441.45	83	1.908881325	1	112.8976598	2916	1.908881325	0.038716619	0.00%	49.30392668	2.72E-12
DYDPCrPa	6440.254072	81	6441.45	83	1.196660939	2	112.8976598	2916	0.59833047	0.038716619	0.00%	15.45409933	2.11E-07
DYWVPaWa	6440.291159	81	6441.45	83	1.159574282	2	112.8976598	2916	0.579787141	0.038716619	0.00%	14.97514923	3.38E-07
Td	6440.667465	80	6441.45	83	0.783268014	3	112.8976598	2916	0.261089338	0.038716619	0.00%	6.743598679	1.57E-04
DYDPPaPa	6440.93677	81	6441.45	83	0.513963071	2	112.8976598	2916	0.256981536	0.038716619	0.00%	6.637499477	1.33E-03
zrufP	6440.975209	80	6441.45	83	0.47552372	3	112.8976598	2916	0.158507907	0.038716619	0.00%	4.094053467	6.55E-03

Table K-10. Sensitivity Analysis Results - Ingestion of Exposed Vegetables

VariableName	Reduced ModelSS	Reduced ModelDF	FullModelSS	Full ModelDF	VariableSS	VariableDF	FullErrorSS	FullError DF	VariableMS	FullErrorMS	Percent Variation	FTestStatistic	FTestPValue
ED	3521.661562	59	8673.73	60	5152.069762	1	1328.141937	2939	5152.069762	0.451902667	59.40%	11400.83948	0.00E+00
CR_exveg	8118.356119	59	8673.73	60	555.375205	1	1328.141937	2939	555.375205	0.451902667	6.40%	1228.970852	0.00E+00
AvgPeriodStartYrP	8460.593064	54	8673.73	60	213.1382605	6	1328.141937	2939	35.52304342	0.451902667	2.50%	78.60773136	0.00E+00
b	8484.162602	47	8673.73	60	189.5687224	13	1328.141937	2939	14.58220941	0.451902667	2.20%	32.26847392	0.00E+00
RapplP	8557.124651	58	8673.73	60	116.6066736	2	1328.141937	2939	58.30333681	0.451902667	1.30%	129.0174657	0.00E+00
CutOffYrC	8601.903567	57	8673.73	60	71.82775756	3	1328.141937	2939	23.94258585	0.451902667	0.80%	52.98173174	0.00E+00
CYVPaCr	8607.684061	55	8673.73	60	66.04726352	5	1328.141937	2939	13.2094527	0.451902667	0.80%	29.23074741	0.00E+00
foc_soil	8622.735216	56	8673.73	60	50.9961079	4	1328.141937	2939	12.74902697	0.451902667	0.60%	28.21188702	0.00E+00
AirTempP	8626.387122	58	8673.73	60	47.34420252	2	1328.141937	2939	23.67210126	0.451902667	0.50%	52.3831856	0.00E+00
uw	8640.614631	56	8673.73	60	33.11669362	4	1328.141937	2939	8.279173405	0.451902667	0.40%	18.32070049	6.99E-15
MetID	8651.687508	55	8673.73	60	22.04381668	5	1328.141937	2939	4.408763335	0.451902667	0.30%	9.756002035	2.94E-09
SsC	8654.485671	55	8673.73	60	19.2456537	5	1328.141937	2939	3.84913074	0.451902667	0.20%	8.51761015	5.11E-08
Runoff_LWS	8657.321824	56	8673.73	60	16.40950047	4	1328.141937	2939	4.102375118	0.451902667	0.20%	9.078005997	2.76E-07
BD	8659.891861	54	8673.73	60	13.83946305	6	1328.141937	2939	2.306577176	0.451902667	0.20%	5.104145972	3.18E-05
AreaCrCr	8660.37038	57	8673.73	60	13.36094375	3	1328.141937	2939	4.453647917	0.451902667	0.20%	9.855325596	1.82E-06
CYVPaRe	8663.192844	59	8673.73	60	10.53848066	1	1328.141937	2939	10.53848066	0.451902667	0.10%	23.32024447	1.44E-06
CYPPaPa	8666.994532	58	8673.73	60	6.736792284	2	1328.141937	2939	3.368396142	0.451902667	0.10%	7.453808952	5.90E-04
DYDPPaRe	8667.798196	58	8673.73	60	5.933128144	2	1328.141937	2939	2.966564072	0.451902667	0.10%	6.564608468	1.43E-03
CnwmuP	8668.661463	56	8673.73	60	5.069861186	4	1328.141937	2939	1.267465297	0.451902667	0.10%	2.804730731	2.44E-02
DYDPPaPa	8669.371374	58	8673.73	60	4.359949751	2	1328.141937	2939	2.179974875	0.451902667	0.10%	4.823992059	8.10E-03
DYWPPaPa	8669.826492	59	8673.73	60	3.90483185	1	1328.141937	2939	3.90483185	0.451902667	0.00%	8.640869237	3.31E-03
AreaCrWa	8670.655917	58	8673.73	60	3.075407303	2	1328.141937	2939	1.537703652	0.451902667	0.00%	3.402731971	3.34E-02
DYWVPaWa	8670.919898	56	8673.73	60	2.811426312	4	1328.141937	2939	0.702856578	0.451902667	0.00%	1.555327352	1.84E-01
Huc_Region	8672.742755	59	8673.73	60	0.98856895	1	1328.141937	2939	0.98856895	0.451902667	0.00%	2.187570518	1.39E-01
CYPCrSt	8673.244684	58	8673.73	60	0.486640128	2	1328.141937	2939	0.243320064	0.451902667	0.00%	0.538434672	5.84E-01
zrufP	8673.49621	58	8673.73	60	0.235113957	2	1328.141937	2939	0.117556978	0.451902667	0.00%	0.260137829	7.71E-01
BW	8673.720186	59	8673.73	60	0.011138345	1	1328.141937	2939	0.011138345	0.451902667	0.00%	0.024647664	8.75E-01

Parameter Codes for Variables in Sensitivity Analysis

Parameter code	Units	Description
AirTemp	°C	Long-Term Average Air Temperature
b	unitless	Soil moisture coefficient b
BD	g/cm3	Bulk soil density
BRi	m3/day	Breathing rate
BW	kg	average body weight
CN	unitless	SCS curve number
CR_exfruit	g WW/kg BW/day	consumption rate of exposed fruits
CR_exveg	g WW/kg BW/day	consumption rate of exposed vegetables
CR_root	g WW/kg BW/day	consumption rate of root vegetables
CRb	g WW/kg BW/day	consumption rate of beef
CRe	g/day	consumption rate of eggs
CRf	g WW/day	consumption rate of fish
CRl	g/day	consumption rate of above ground vegetables
CRm	g WW/kg BW/day	consumption rate of milk
CRp	g/day	consumption rate of poultry
CRw	L/day	consumption of drinking water
CutOffYr	year	Number of years over which biosolids are applied
Cwmu	unitless	USLE cover factor for the pasture
Cyp	ug-s/g-m3	particulate concentration all correlated
Cyv	ug-s/g-m3	vapor concentration - all correlated
Dydp	ug-s/g-m3	dry particulate deposition all locations correlated
Dywp	s/m2-yr	wet particulate concentration deposition all correlated
Dywv	s/m2-yr	wet vapor concentration due to deposition all correlated
ED	year	Exposure duration
foc_soil	mass fraction	Fraction organic carbon for soil
K	kg/m2	USLE soil erodibility factor
Ksat	cm/h	Saturated hydraulic conductivity
Lc	unitless	Roughness ratio
LS	unitless	USLE length-slope factor
MetID	unitless	Climate region designation
n	ml/cm3	Saturated volumetric water content, porosity for soil
P	unitless	USLE erosion control factor of rural agricultural land
Precip	cm/yr	meteorological parameter - average annual precipitation
Psoil	g/cm3	particle density of soil
R	1/yr	USLE rainfall/erosivity factor
Rappl	Mg/m2-year	Waste application rate

(continued)

Parameter Codes for Variables in Sensitivity Analysis (continued)

Parameter code	Units	Description
Rf	cm/yr	Average annual runoff
Rh	cm	roughness height
SiteLatitude	degrees	Latitude
SMFC	volume %	Soil moisture field capacity
SMWP	volume %	Soil moisture wilting point
SrcArea	m^2	Area of the agricultural field
SrcLWSBufferArea	m2	Area of buffer (Residence)
SrcLWSNumSubArea	unitless	Number of local watershed subareas
Ss	mass percent	Silt content for surface soil
Sw	mass percent	Silt content (waste solids)
SY	year	Start time exposure begins
T	degrees K	Waterbody temperature
Td	year	Time period of deposition
Theta	degrees	Slope of local watershed
Tss	mg/l	Total suspended solids in water column
TSSb	mg/l	total suspended solids in bed sediments
Tvol	sec	time over which volatilization occurs
uw	m/sec	Mean annual wind speed
V	m3	flow independent mixing volume
veg	fraction	Fraction vegetative cover
Vf	m/s	threshold friction velocity
Vfx	m3/yr	Waterbody flow mixing volume
Wai_LWS	m2	Impervious watershed area for local watershed
Wai_percent_LWS	percent	percent of impervious watershed area for local watershed
Wai_percent_RWS	percent	percent of impervious watershed area for regional watershed
Wai_RWS	m2	Impervious watershed area for regional watershed
Wat	m2	Total area of watershed
Waw	m2	Area of waterbody
WCS	volume fraction	Saturated volumetric water content, porosity for soil
zav	m	Averaging depth for soil concentration

Appendix L

Screening Ecological Risk Assessment Data

Table L-1. Bioaccumulation Factors (BAFs) for TCDD

Receptor Type	BAF (Wet weight basis)	Data Source
Worms	1.9	Dry weight basis BAF taken from Sample et al. (1998a); wet weight basis value was derived assuming a moisture content of 83.3% (U.S. EPA 1997a)
Other Invertebrates	0.15	Dry weight basis BAF taken from Meyn et al (1997); wet weight basis value was derived assuming a moisture content of 65% (Sample et al., 1997).
Small Mammals	0.35	Dry weight basis BAF for terrestrial vertebrates taken from Sample et al. (1998b); wet weight value was derived assuming a moisture content of 68% (Sample et al., 1997).
Herbivorous Vertebrates	0.35	Dry weight basis BAF for terrestrial vertebrates taken from Sample et al. (1998b); wet weight value was derived assuming a moisture content of 68% (Sample et al., 1997).
Omnivorous Vertebrates	0.35	Dry weight basis BAF for terrestrial vertebrates taken from Sample et al. (1998b); wet weight value was derived assuming a moisture content of 68% (Sample et al., 1997).
Small Birds	0.35	Dry weight basis BAF for terrestrial vertebrates taken from Sample et al. (1998b); wet weight value was derived assuming a moisture content of 68% (Sample et al., 1997).
Small Herpetofauna	0.35	Dry weight basis BAF for terrestrial vertebrates taken from Sample et al. (1998b); wet weight value was derived assuming a moisture content of 68% (Sample et al., 1997).

The terrestrial BAFs for TCDD identified in the literature were calculated on a dry weight basis. Wet weight BAFs were derived by multiplying the dry weight BAF by a moisture adjustment factor (MAF). MAFs were calculated based on the moisture contents shown in Table L-1 above. BAFs were not identified for terrestrtial vertebrates other than small mammals; therefore, the small mammal BAF was used for all terrestrial vertebrates.

Table L-2. Biota-to-Sediment Bioaccumulation Factors (BSAFs)

CAS	Constituent_short	Benthic Flter Feeders*	T3 fish	T4 fish	Aquatic Plants*
1746016	TCDD, 2,3,7,8-	1	0.09	0.09	1
3268879	OCDD, 1,2,3,4,6,7,8,9-	1	0.001	0.001	1
19408743	HxCDD, 1,2,3,7,8,9-	1	0.013	0.013	1
31508006	PeCB, 2,3',4,4',5-	1	3.59	3.59	1
32598133	TeCB, 3,3',4,4'-	1	2.205	2.205	1
32598144	PeCB, 2,3,3',4,4'-	1	4.18	4.18	1
32774166	HxCB, 3,3',4,4',5,5'-	1	11.85	11.85	1
35822469	HpCDD, 1,2,3,4,6,7,8-	1	0.003	0.003	1
38380084	HxCB, 2,3,3',4,4',5-	1	3.97	3.97	1
39001020	OCDF	1	0.001	0.001	1
39227286	HxCDD, 1,2,3,4,7,8-	1	0.028	0.028	1
39635319	HpCB, 2,3,3',4,4',5,5'-	1	2.08	2.08	1
40321764	PeCDD, 1,2,3,7,8-	1	0.083	0.083	1
51207319	TCDF, 2,3,7,8-	1	0.072	0.072	1
52663726	HxCB, 2,3',4,4',5,5'-	1	8.35	8.35	1
55673897	HpCDF, 1,2,3,4,7,8,9-	1	0.035	0.035	1
57117314	PeCDF, 2,3,4,7,8-	1	0.144	0.144	1
57117416	PeCDF, 1,2,3,7,8-	1	0.02	0.02	1
57117449	HxCDF, 1,2,3,6,7,8-	1	0.017	0.017	1
57465288	PeCB, 3,3',4,4',5-	1	3.21	3.21	1
57653857	HxCDD, 1,2,3,6,7,8-	1	0.011	0.011	1
60851345	HxCDF, 2,3,4,6,7,8-	1	0.057	0.057	1
65510443	PeCB, 2',3,4,4',5-	1	6.4	6.4	1
67562394	HpCDF, 1,2,3,4,6,7,8-	1	0.001	0.001	1
70362504	TeCB, 3,4,4',5-	1	1.005	1.005	1
70648269	HxCDF, 1,2,3,4,7,8-	1	0.007	0.007	1
72918219	HxCDF, 1,2,3,7,8,9-	1	0.06	0.06	1
74472370	PeCB, 2,3,4,4',5-	1	6.4	6.4	1

* Because of a lack of data, a default BSAF of 1 was used for fish and aquatic plants.

Appendix L

Benchmark Development

For the biosolids SERA, exposure for all 29 congeners in the assessment was expressed in terms of 2,3,7,8-TCDD toxicity equivalence. Benchmark doses for TCDD for mammals and birds were identified in the literature (from Murray et al. (1979) and Nosek et al. (1992), respectively), and species-specific scaled benchmarks were calculated for each mammal and bird receptor. These benchmarks are based on measures of effect (e.g., reproductive studies; survival) that are considered appropriate to infer risks to ecological receptors at various levels of biological organization, including individual organisms and wildlife populations. In identifying appropriate studies to develop benchmarks, study selection criteria were developed to ensure consistency in the interpretation of ecotoxicological data and to satisfy relevant data quality objectives. The study selection criteria address the appropriateness of the study data and the quality of the study with respect to endpoint selection, dose-response information, and appropriate use of extrapolation techniques (e.g., tools for statistical inference).

The benchmarks represent de minimis levels of effect and were developed to infer risks to species populations of mammals and birds exposed through the ingestion of contaminated media and prey. In order of importance, the study selection criteria included the following: (1) relevance of study endpoints to population-level effects, (2) adequate data to demonstrate the dose-response relationship, (3) appropriateness of study design with respect to the exposure route (e.g., gavage versus dietary exposure) and exposure duration, and (4) quality of the study as determined by the use of appropriate dosing regimes, statistical tools, etc.

Methodology for Deriving Benchmarks

- <u>Assessment Endpoint</u>: *maintain viable mammalian and avian wildlife populations*. The attribute to be protected was the reproductive and developmental success of representative species.

- <u>Measure of Effect</u>: *a de minimis threshold for developmental and reproductive toxicity in mammalian and avian wildlife species*. The threshold was calculated as the geometric mean of the NOAEL and LOAEL, frequently referred to as the MATL. Implicit in this calculation is the assumption that the toxicological sensitivity is lognormal.

For mammals and birds, ecotoxicological data were evaluated to determine the most appropriate study with which to develop ecological benchmarks (in units of dose) to infer risk to the population level. Once the benchmark study was identified, a scaled benchmark was calculated for each receptor species. This method used an allometric scaling equation based on body weight to extrapolate test species doses to estimate wildlife species doses. For mammals, a scaling factor of 1/4 was used (Equation L-1). This is the default methodology EPA proposes for carcinogenicity assessments and reportable quantity documents for adjusting animal data to an equivalent human dose (U.S. EPA, 1992).

For birds, research suggests that the cross-species scaling equation used for mammals is not appropriate for avian species (Mineau et al., 1996). Using a database that characterized acute toxicity of pesticides to avian receptors of various body weights, Mineau et al. (1996) concluded that applying mammalian scaling equations may not sufficiently predict protective doses for avian species. Mineau et al. further suggested that a scaling factor of 1 provided a better dose estimate for birds. Therefore, a scaling factor of 1 was applied for avian receptors (Equation 2).

$$EB_w = MATL_t \times \left(\frac{bw_t}{bw_w} \right)^{1/4} \qquad \text{(L-1)}$$

$$EB_w = MATL_t \times \left(\frac{bw_t}{bw_w} \right)^{1} \qquad \text{(L-2)}$$

where

EB_w	=	scaled ecological benchmark for species *w* (mg/kg-d)
$MATL_t$	=	maximum acceptable toxicant concentration (mg/kg-d)
bw_t	=	body weight of the surrogate test species (kg)
bw_w	=	body weight of the representative wildlife species (kg).

Table L-3. Ecological Benchmarks

Receptor Name	Class	NOAEL (mg/kg-day)	MATL (mg/kg-day)	LOAEL (mg/kg-day)
American kestrel	B	1.40E-05	1.40E-04	4.40E-05
American robin	B	1.40E-05	1.40E-04	4.40E-05
American woodcock	B	1.40E-05	1.40E-04	4.40E-05
Bald eagle	B	1.40E-05	1.40E-04	4.40E-05
Beaver	M	3.96E-07	3.96E-06	1.25E-06
Belted kingfisher	B	1.40E-05	1.40E-04	4.40E-05
Black bear	M	2.46E-07	2.46E-06	7.79E-07
Canada goose	B	1.40E-05	1.40E-04	4.40E-05
Cooper's hawk	B	1.40E-05	1.40E-04	4.40E-05
Coyote	M	4.36E-07	4.36E-06	1.38E-06
Deer mouse	M	2.22E-06	2.22E-05	7.02E-06
Eastern cottontail rabbit	M	7.89E-07	7.89E-06	2.49E-06
Great blue heron	B	1.40E-05	1.40E-04	4.40E-05
Green heron	B	1.40E-05	1.40E-04	4.40E-05
Herring gull	B	1.40E-05	1.40E-04	4.40E-05
Least weasel	M	1.85E-06	1.85E-05	5.84E-06
Lesser scaup	B	1.40E-05	1.40E-04	4.40E-05
Little brown bat	M	2.71E-06	2.71E-05	8.57E-06
Long-tailed weasel	M	1.26E-06	1.26E-05	3.98E-06
Mallard duck	B	1.40E-05	1.40E-04	4.40E-05
Meadow vole	M	2.19E-06	2.19E-05	6.91E-06
Mink	M	8.32E-07	8.32E-06	2.63E-06
Muskrat	M	8.59E-07	8.59E-06	2.72E-06
Northern bobwhite	B	1.40E-05	1.40E-04	4.40E-05
Osprey	B	1.40E-05	1.40E-04	4.40E-05
Prairie vole	M	1.84E-06	1.84E-05	5.81E-06
Raccoon	M	5.37E-07	5.37E-06	1.70E-06
Red fox	M	5.69E-07	5.69E-06	1.80E-06
Red-tailed hawk	B	1.40E-05	1.40E-04	4.40E-05
River otter	M	4.84E-07	4.84E-06	1.53E-06
Short-tailed shrew	M	2.37E-06	2.37E-05	7.50E-06
Short-tailed weasel	M	1.24E-06	1.24E-05	3.92E-06
Tree swallow	B	1.40E-05	1.40E-04	4.40E-05
Western meadowlark	B	1.40E-05	1.40E-04	4.40E-05
White-tailed deer	M	2.88E-07	2.88E-06	9.10E-07

Table L-4. Ecological Exposure Factors

Receptor Name	Body weight (kg)	Consumption rate of food items (kg/day)	Water consumption rate (L/day)	Sediment fraction of total diet (unitless)	Soil fraction of total diet (unitless)
American kestrel	0.118915339	0.095734522	0.014166462	-999	0.01
American robin	0.0773	0.072325853	0.0106153	-999	0.01
American woodcock	0.17747325	0.124243659	0.018525548	-999	0.104
Bald eagle	3.75	0.905280301	0.143038505	0.059	-999
Beaver	19.30859066	5.111207944	1.421709	0.033	-999
Belted kingfisher	0.147057068	0.109931471	0.01633306	0.059	-999
Black bear	128.874222	24.3328554	7.848463546	-999	0.028
Canada goose	2.996629957	0.782306383	0.123082469	-999	0.082
Cooper’s hawk	0.404864593	0.212543287	0.03219212	-999	0.01
Coyote	13.12889529	3.722375189	1.00470962	-999	0.028
Deer mouse	0.0196	0.017695835	0.002875184	-999	0.02
Eastern cottontail rabbit	1.226135331	0.530169998	0.118937762	-999	0.063
Great blue heron	2.229	0.645220815	0.10094522	0.094	-999
Green heron	0.226035395	0.145431199	0.021784632	0.094	-999
Herring gull	1.091233068	0.405296655	0.06255424	0.059	-999
Least weasel	0.040830303	0.032349254	0.005565697	-999	0.01
Lesser scaup	0.792389627	0.329077252	0.050482516	0.033	-999
Little brown bat	0.008789198	0.009152987	0.001396978	-999	0
Long-tailed weasel	0.188646952	0.113820557	0.022065817	-999	0.028
Mallard duck	1.170158282	0.424146567	0.065550484	0.033	-999
Meadow vole	0.020821722	0.018597615	0.003035989	-999	0.024
Mink	0.992422597	0.445575413	0.098324597	0.094	-999
Muskrat	0.873	0.401005459	0.087608857	0.033	-999
Northern bobwhite	0.19125764	0.130443532	0.019477652	-999	0.093
Osprey	1.601382632	0.520253528	0.080884208	0.059	-999
Prairie vole	0.041567017	0.032828281	0.005655997	-999	0.024
Raccoon	5.691468746	1.872539541	0.473518678	0.094	-999
Red fox	4.532144522	1.552809787	0.385752341	-999	0.028
Red-tailed hawk	1.130926184	0.41483407	0.064069741	-999	0.01
River otter	8.660254038	2.644154065	0.690896135	0.094	-999
Short-tailed shrew	0.015	0.014203115	0.003538614	-999	0.01
Short-tailed weasel	0.201530285	0.120172285	0.023417551	-999	0.028
Tree swallow	0.02095	0.030915731	0.004426346	-999	0.01
Western meadowlark	0.106442473	0.089071866	0.013152825	-999	0
White-tailed deer	69.41716207	14.63262799	4.497336296	-999	0.068

Table L-5. Exposure Factor Data Sources

Species	Scientific Name	References
American kestrel	*Falco sparverius*	Terres, 1980; U.S. EPA, 1993; Lane and Fischer, 1997; Stokes and Stokes, 1996
American robin	*Turdus migratorius*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
American woodcock	*Scolopax minor*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
Bald eagle	*Haliaeetus leucocephalus*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
Beaver	*Castor canadensis*	Stokes and Stokes, 1986; Whitaker, 1997; Jenkins and Busher, 1979
Belted kingfisher	*Ceryle alcyon*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
Black bear	*Ursus americanus*	Schaefer and Sargent, 1990; Stokes and Stokes, 1986; Whitaker, 1997
Canada goose	*Branta canadensis*	Terres, 1980; U.S. EPA, 1993; Niering, 1985; Stokes and Stokes, 1996
Cooper's hawk	*Accipiter cooperi*	Terres, 1980; Sample et al., 1997; Stokes and Stokes, 1996
Coyote	*Canis latrans*	Bekoff, 1977; Sample et al, 1997; Whitaker, 1997; Stokes and Stokes, 1986
Deer mouse	*Peromyscus maniculatus*	Whitaker, 1997; U.S. EPA, 1993; Stokes and Stokes, 1986
Eastern cottontail rabbit	*Sylvilagus floridanus*	Stokes and Stokes, 1986; Chapman et al., 1980; Whitaker, 1997; U.S. EPA, 1993
Great blue heron	*Ardea herodias*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996; Niering, 1985
Green heron	*Butorides virescens*	Terres, 1980; Sample et al., 1997; Stokes and Stokes, 1996; Niering, 1985
Herring gull	*Larus argentatus*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
Least weasel	*Mustela nivalis*	Whitaker, 1997; Stokes and Stokes, 1986; Sample et al., 1997
Lesser scaup	*Aythya affinis*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996

(continued)

Table L-5. (continued)

Species	Scientific Name	References
Little brown bat	*Myotis lucifugus*	Whitaker, 1997; Sample et al., 1997.
Long-tailed weasel	*Mustela frenata*	Sutton and Sutton, 1985; Sample et al., 1997; Stokes and Stokes, 1996
Mallard	*Anas platyrhynchos*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996; Niering, 1985
Marsh wren	*Cistothorus palustris*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996; Niering, 1985
Meadow vole	*Microtus pennsylvanicus*	Whitaker, 1997; U.S. EPA, 1993; Stokes and Stokes, 1986
Mink	*Mustela vison*	Niering, 1985; U.S. EPA, 1993; Whitaker, 1997; Stokes and Stokes,1986
Muskrat	*Ondatra zibethicus*	Niering, 1985; U.S. EPA, 1993; Stokes and Stokes, 1986; Willner et al., 1980; Whitaker, 1997
Northern bobwhite	*Colinus virginianus*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
Osprey	*Pandion haliaetus*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
Prairie vole	*Microtus ochrogaster*	Whitaker, 1997; U.S. EPA, 1993
Raccoon	*Procyon lotor*	Lotze and Andersen, 1979; U.S. EPA, 1993; Whitaker, 1997; Stokes and Stokes, 1986
Red fox	*Vulpes vulpes*	Whitaker, 1997; U.S. EPA, 1993; Stokes and Stokes, 1986
Red-tailed hawk	*Buteo jamaicensis*	Terres, 1980; U.S. EPA, 1993; Stokes and Stokes, 1996
River otter	*Lutra canadensis*	Whitaker, 1997; U.S. EPA, 1993; Niering, 1985; Stokes and Stokes, 1986
Short-tailed shrew	*Blarina brevicauda*	Whitaker, 1997; U.S. EPA, 1993; Stokes and Stokes, 1986
Short-tailed weasel	*Mustela erminea*	King, 1983; Sample et al., 1997; Whitaker, 1997
Tree swallow	*Tachycineta bicolor*	Terres, 1980; Sample et al., 1997; Stokes and Stokes, 1996
Western meadowlark	*Sturnella neglecta*	Terres, 1980; Sample et al., 1997; Stokes and Stokes, 1996
White-tailed deer	*Odocoileus virginianus*	Whitaker, 1997; Stokes and Stokes, 1986; Smith, 1991

Table L-6. Phase 2: Dietary Composition for Agricultural Field Habitat

Receptor Name	Worms	Other inverte-brates	Small mammals	Herbivorous verte-brates	Omnivorous verte-brates	Small birds	Exposed fruits	Exposed vegetables	Forage	Grains	Roots	Silage	Small herpetofauna
American kestrel	0	0.38	0.255	0	0	0.11	0	0	0	0	0	0	0.255
American robin	0	0.505	0	0	0	0	0.495	0	0	0	0	0	0
American woodcock	0.86	0.085	0	0	0	0	0	0	0.055	0	0	0	0
Black bear	0	0.4	0.025	0	0	0	0.4	0	0.175	0	0	0	0
Canada goose	0	0	0	0	0	0	0	0	0.6	0.4	0	0	0
Cooper's hawk	0	0	0.43	0	0	0.57	0	0	0	0	0	0	0
Coyote	0	0.055	0.415	0.1	0.1	0.155	0.125	0	0	0	0	0	0.05
Deer mouse	0	0.325	0	0	0	0	0.235	0	0.055	0.385	0	0	0
Eastern cottontail rabbit	0	0	0	0	0	0	0	0	0.875	0	0	0.125	0
Least weasel	0	0.05	0.9	0	0	0.05	0	0	0	0	0	0	0
Little brown bat	0	1	0	0	0	0	0	0	0	0	0	0	0
Long-tailed weasel	0.05	0.05	0.525	0.125	0.125	0.125	0	0	0	0	0	0	0
Meadow vole	0	0	0	0	0	0	0	0	0.75	0.075	0.175	0	0
Northern bobwhite	0	0.18	0	0	0	0	0.125	0	0.125	0.57	0	0	0
Prairie vole	0	0.075	0	0	0	0	0	0	0.75	0	0.175	0	0
Raccoon	0	0.445	0	0	0	0	0.555	0	0	0	0	0	0
Red fox	0	0	0.51	0	0	0.19	0.3	0	0	0	0	0	0
Red-tailed hawk	0	0.125	0.5	0.125	0.125	0.125	0	0	0	0	0	0	0
Short-tailed shrew	0.425	0.3	0.05	0	0	0	0.05	0.175	0	0	0	0	0
Short-tailed weasel	0	0.125	0.65	0	0	0.125	0	0	0	0	0	0	0.1
Tree swallow	0	0.75	0	0	0	0	0.125	0	0.125	0	0	0	0
Western meadowlark	0	0.875	0	0	0	0	0	0	0	0.125	0	0	0
White-tailed deer	0	0	0	0	0	0	0	0	0.75	0.25	0	0	0

Table L-7. Phase 2: Dietary Composition for Stream and Pond/Lake Habitat

Receptor Name	Benthic filter feeders	T3 fish	T4 fish	Aquatic plants
Bald eagle	0	0.505	0.495	0
Beaver	0	0	0	1
Belted kingfisher	0.05	0.95	0	0
Great blue heron	0	0.515	0.485	0
Green heron	0	0.985	0	0.015
Herring gull	0.22	0.39	0.39	0
Lesser scaup	0.75	0	0	0.25
Mallard duck	0.35	0.35	0	0.3
Mink	0	0.55	0.45	0
Muskrat	0.25	0.05	0	0.7
Osprey	0	0.625	0.375	0
Raccoon	0.375	0.345	0.28	0
River otter	0	0.595	0.405	0

Table L-8. Toxicity Equivalence Factors (TEFs)

CAS	Constituent_short	MammalTEF	BirdTEF
1746016	TCDD, 2,3,7,8-	1	1
40321764	PeCDD, 1,2,3,7,8-	1	1
39227286	HxCDD, 1,2,3,4,7,8-	0.1	0.05
57653857	HxCDD, 1,2,3,6,7,8-	0.1	0.01
19408743	HxCDD, 1,2,3,7,8,9-	0.1	0.1
35822469	HpCDD, 1,2,3,4,6,7,8-	0.01	0.001
3268879	OCDD, 1,2,3,4,6,7,8,9-	0.0001	0.00001*
51207319	TCDF, 2,3,7,8-	0.1	1
57117416	PeCDF, 1,2,3,7,8-	0.05	0.1
57117314	PeCDF, 2,3,4,7,8-	0.5	1
70648269	HxCDF, 1,2,3,4,7,8-	0.1	0.1
57117449	HxCDF, 1,2,3,6,7,8-	0.1	0.1
72918219	HxCDF, 1,2,3,7,8,9-	0.1	0.1
60851345	HxCDF, 2,3,4,6,7,8-	0.1	0.1
67562394	HpCDF, 1,2,3,4,6,7,8-	0.01	0.01
55673897	HpCDF, 1,2,3,4,7,8,9-	0.01	0.01
39001020	OCDF	0.0001	0.0001
32598133	TeCB, 3,3’,4,4’-	0.0001	0.05
32598144	PeCB, 2,3,3’,4,4’-	0.0001	0.0001
74472370	PeCB, 2,3,4,4’,5-	0.0005	0.0001
31508006	PeCB, 2,3’,4,4’,5-	0.0001	0.00001
65510443	PeCB, 2’,3,4,4’,5-	0.0001	0.00001
57465288	PeCB, 3,3’,4,4’,5-	0.1	0.1
38380084	HxCB, 2,3,3’,4,4’,5-	0.0005	0.0001
52663726	HxCB, 2,3’,4,4’,5,5’-	0.00001	0.00001
32774166	HxCB, 3,3’,4,4’,5,5’-	0.01	0.001
39635319	HpCB, 2,3,3’,4,4’,5,5’-	0.0001	0.00001
70362504	TeCB, 3,4,4’,5-	0.0001	0.1

Reference: WHO Consensus 1998

No TEF was recommended by the WHO Consensus for birds for OCDD. For modeling purposes, the lowest TEF for birds was used as a surrogate for OCDD.

Table L-9. Aquatic Diet Item Lipid Fractions

PreyType	Lipid raction (whole body)	Reference
Benthic filter feeders	0.05	Gobas, F.A.P.C. and H.A. Morrison. 2000. Bioconcentration and Biomagnification in the Aquatic Environment. In Handbook of Property Estimation Methods for Chemicals: Environmental and Health Sciences. Eds. R. Boethling and D. Mackay. Lewis Publishers: Boca Raton, FL. pp189-231.
T3 Fish	0.0646	Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors, USEPA 1995
T4 Fish	0.1031	Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors, USEPA 1995
Aquatic plants	0.01	Gobas, F.A.P.C. and H.A. Morrison. 2000. Bioconcentration and Biomagnification in the Aquatic Environment. In Handbook of Property Estimation Methods for Chemicals: Environmental and Health Sciences. Eds. R. Boethling and D. Mackay. Lewis Publishers: Boca Raton, FL. pp189-231.

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Appendix M

Climate Region Selection

Appendix M
Climate Region Selection

Background

Dispersion and deposition of volatile and particulate contaminants and air concentrations of contaminants at specified receptor locations are estimated with EPA's Industrial Source Complex, Short-Term Model, version 3 (ISCST3). ISCST3 calculates dispersion, deposition and air concentrations. Running ISCST3 is time consuming and requires extensive technical expertise. Therefore, dispersion and deposition were modeled using ISCST3 for selected scenarios designed to cover a broad range of characteristics. For the dioxins, furans and PCBs in biosolids, these scenarios include

- 41 meteorological stations, chosen to represent the nine general climate regions of the continental United States
- 41 farm sizes representing the median farm size for each climate region

The remainder of this section details how the country was divided into areas that could be adequately represented by one meteorological station.

Approach

Bailey's ecoregions and subregions of the United States (Bailey et al., 1994) are used to associate coverage areas with meteorological stations. This hierarchical classification scheme is based primarily on rainfall regimes; subregions are delineated by elevation and other factors affecting ecology.

The approach used involved two main steps:

1. Identify contiguous areas that are sufficiently similar with regard to the parameters that affect dispersion that they can be reasonably represented by one meteorological station. The parameters used are
   - Surface level meteorological data (e.g., wind patterns and atmospheric stability)
   - Physiographic features (e.g., mountains, plains)
   - Bailey's ecoregions and subregions

- Land cover (e.g., forest, urban areas).

2. For each contiguous area, select one meteorological station to represent the area. The station selection step considered the following parameters:

   - Location within the area
   - Years of meteorological data available
   - Average windspeed.

These steps are described in the following subsections.

Identify Contiguous Areas

A hierarchical procedure based on features affecting wind flow was used to divide the country. The primary delineation of areas was based on geographic features affecting synoptic (broad area) winds, including mountain ranges and plains. These features are also known as physiography. Data were obtained from Fenneman and Johnson (1946). The secondary delineation was based on features affecting mesoscale (10- to 1,000-km) winds, including coastal regions and basic land cover classifications of forest, agriculture, and barren lands. These land cover features were obtained from U.S. Geological Survey (1999).

The methodology for identifying contiguous areas uses wind data and atmospheric stability data derived from surface-level meteorological data as the primary consideration, modified by physiography, Bailey's ecoregions and subregions, and land cover. The approach focuses on how well the windspeed and direction and atmospheric stability patterns measured at a surface-level meteorological station represent the surrounding area. The limit of appropriate representation varies by area of the country and is substantially determined by terrain and topography. For example, a station in the Midwest, where topography and vegetation are uniform, may adequately represent a very large area, while a mountainous station, where ridges and valleys affect the winds, may represent a much smaller area.

Primary Grouping on Wind Rose and Atmospheric Stability Data. The surface-level meteorological data were downloaded from EPA's SCRAM Web site (www.epa.gov/scram001). SCRAM has these data from 1984 to 1991. A 5-year period is commonly used to obtain an averaged depiction of the winds for each station; 5 years covers most of the usual variation in meteorological conditions. Not all stations had 5 years of data in this time period. Three years of data was considered a desirable minimum for stations, therefore, stations that had less than 3 years of data during this time period were not considered for selection.

Two types of wind data were considered: wind directionality and windspeed. Wind directionality describes the tendency of winds to blow from many different directions (weakly directional) or primarily from one direction (strongly directional). Strongly directional winds will tend to disperse air pollutants in a consistent direction, resulting in higher air concentrations in that direction and higher overall maximum air concentrations. Weakly directional winds will tend to disperse pollutants in multiple directions, resulting in lower air concentrations in any one direction and lower overall maximum air concentration.

Windspeed also affects dispersion. A greater average windspeed tends to disperse pollutants more quickly, resulting in lower air concentrations than lower average windspeeds would produce. Windspeed was used in the station selection process, but not to identify contiguous areas of the country.

A wind rose is a graphical depiction of the frequency of windspeeds by wind direction (see Figure 2-1). Wind roses were produced from the surface-level meteorological data for each station using WRPLOT (available from www.epa.gov/scram001/models/relat/wrplot.zip). Winds are plotted in 16 individual directions; thus, if every direction has the same frequency, the wind would blow from each direction 6.25 percent of the time. Based on the wind roses, each station was assigned to one of four bins based on the frequency of wind in the predominant direction (the direction from which the wind blows the greatest percentage of the time). These bins were as follows:

- W, weakly directional: blowing from predominant direction less than 10 percent of the time
- Mildly directional: blowing from predominant direction 10 to 14 percent of the time
- Moderately directional: blowing from predominant direction 15 to 20 percent of the time
- Strongly directional: blowing from predominant direction over 20 percent of the time.

Atmospheric stability class frequency distributions were also used for some stations. Atmospheric stability is a measure of vertical movement of air and can be classified as stable, unstable, or neutral. For sources at ground level sources such as are modeled in the agricultural use scenarion, pollutants tend to stay close to the ground in a stable atmosphere, thereby increasing the air concentration of the pollutant. In an unstable atmosphere, the pollutants will tend to disperse more in the vertical direction, thereby decreasing the air concentration of the pollutant. Atmospheric stability varies throughout the day and year, as well as by location, because atmospheric stability is determined from variable factors such as windspeed, strength of solar radiation, and the vertical temperature profile above the ground. In addition, the presence of large bodies of water, hills, large urban areas, and types and height of vegetation all affect atmospheric stability. If all other factors are the same at two stations, the one with stable air a larger percentage of the time will have higher air concentrations than the station with stable air a smaller percentage of the time.

Secondary Grouping Considerations. After spatially grouping the wind roses in similar bins, the next step was to delineate geographic areas around these groups of meteorological stations using maps of physiography, Bailey's ecoregions, and land cover.

Physiography includes major topographic features such as mountains or plains. Land cover classifications include urban, cropland, grassland, forest, large waterbody, wetland, barren, and snow or ice. Regional boundaries were chosen to coincide with physiographic, Bailey's ecoregion, and land cover boundaries to the extent possible.

Station Selection

The above approach used to delineate contiguous areas ensures that the stations grouped together are fairly similar in most cases. Therefore, the selection of an appropriate station to represent each area was based on other considerations, including

- **Number of years of surface-level meteorological data available.** More years of data provide a more realistic long-term estimate of air concentration.

- **Central location within the area.** All other factors being equal, central locations are more likely to be representative of the entire contiguous geographic area, because they have the smallest average distance from all points in the region.

- **Windspeed**. Lower windspeeds lead to less dispersion and higher air concentrations.

Windspeed was summarized as average speed in the prevailing wind direction. This value is not readily extractable from the wind roses; therefore, it was obtained from the *International Station Meteorological Climate Summary* CD (NOAA, 1992) of meteorological data. For a few stations, this value was unrealistically low; in those cases, an average windspeed in the prevailing wind direction was estimated from the wind rose data.

EPA used a hierarchical procedure to select a representative station, as follows:

- Stations with less than 5 years of data in SCRAM were eliminated, unless no station had 5 years of data.

- Stations centrally located in the area were preferred if the above factors did not identify a clear choice.

- If all other factors were equal, stations with lower average windspeeds were selected to ensure that air concentration was not underestimated. Variations in windspeed within regions were minor.

Table M-1. Surface-Level Meteorology Stations in Dioxins, Furans, and PCBs in Biosolids

Station Number	Station Name	State
13963	Little Rock/Adams Field	AR
23183	Phoenix/Sky Harbor International Airport	AZ
93193	Fresno/Air Terminal	CA
23174	Los Angeles/International Airport	CA
23234	San Francisco/International Airport	CA
23062	Denver/Stapleton International Airport	CO
14740	Hartford/Bradley International Airport	CT
12839	Miami/International Airport	FL
12842	Tampa/International Airport	FL
13874	Atlanta/Atlanta-Hartsfield International	GA
24131	Boise/Air Terminal	ID
94846	Chicago/O'Hare International Airport	IL
03937	Lake Charles/Municipal Airport	LA
12916	New Orleans/International Airport	LA
13957	Shreveport/Regional Airport	LA
14764	Portland/International Jetport	ME
94847	Detroit/Metropolitan Airport	MI
14840	Muskegon/County Airport	MI
14922	Minneapolis-St Paul/International Airport	MN
13865	Meridian/Key Field	MS
24033	Billings/Logan International Airport	MT
03812	Asheville/Regional Airport	NC
13722	Raleigh/Raleigh-Durham Airport	NC
24011	Bismarck/Municipal Airport	ND
14935	Grand Island/Airport	NE
23050	Albuquerque/International Airport	NM
23169	Las Vegas/McCarran International Airport	NV
24128	Winnemucca/WSO Airport	NV
14820	Cleveland/Hopkins International Airport	OH

(continued)

Table M-1. (continued)

Station Number	Station Name	State
13968	Tulsa/International Airport	OK
94224	Astoria/Clatsop County Airport	OR
24232	Salem/McNary Field	OR
14751	Harrisburg/Capital City Airport	PA
13739	Philadelphia/International Airport	PA
14778	Williamsport-Lycoming/County	PA
13880	Charleston/International Airport	SC
13877	Bristol/Tri City Airport	TN
13897	Nashville/Metro Airport	TN
12960	Houston/Intercontinental Airport	TX
24127	Salt Lake City/International Airport	UT
13737	Norfolk/International Airport	VA
14742	Burlington/International Airport	VT
24233	Seattle/Seattle-Tacoma International	WA
03860	Huntington/Tri-State Airport	WV
24089	Casper/Natrona Co International Airport	WY

For purposes of that discussion, we have divided the United States into the following sections: West Coast, Desert Southwest, Western Mountains, Gulf Coast, Southeast, Middle Atlantic, Northeast, Great Lakes, Central States, Alaska, and Hawaii. The process of selecting stations and delineating the region assigned to each station is discussed by these sections.

Table M-1 shows the selected stations for the continental United States.

Figure M-1 shows these stations and their boundaries.

Figure M-1. Climate regions.

West Coast

The West Coast is defined by a narrow coastal plain and mountain chains running parallel to the coast of the Pacific Ocean. In many areas the mountainous region is broken by a large central valley, such as in California. The northwestern Pacific coast contains a narrow plain between the Pacific Ocean and the Coast Ranges.

The California coast is divided just north of Point Conception above Los Angeles. This northern section is represented by the **San Francisco** International Airport (23234). The wind rose shows strong directionality with an average windspeed of 12 knots.

The southern California coast contains the Los Angeles basin south to the California/Mexico border. This region is represented by the **Los Angeles** International Airport (23174). The wind rose shows strong directionality and an average windspeed of 8 knots.

The California central valley region, which encompasses the Sacramento Valley to the north and the San Joaquin Valley to the south, is defined by the Coast Range and Diablo Range on the west and the Sierra Nevada mountains on the east. The valley extends south to the northern rim of the Los Angeles basin.. The region represented by **Fresno** Air Terminal (93193),

The inland portion of Washington is bounded by the Coast Ranges on the west, the edge of the Humid Temperate Domain to the east, the Washington/Canada border to the north and the Columbia River to the south. This region is represented by the **Seattle**-Tacoma International Airport (24233). Its wind rose shows moderate directionality and an average windspeed of 10 knots.

Desert Southwest

The Desert Southwest is defined by various deserts and mountain ranges. One distinguishing feature is the transition between low desert in southern Arizona and high desert in northern Arizona. The southern boundary of this section is the U.S./Mexico border.

Southern Arizona contains the Sonoran Desert. This region of low desert is represented by the station at **Phoenix**/Sky Harbor International Airport (23183). The region is bounded to the north between Phoenix and Prescott, Arizona, along the southern edge of the Columbia Plateau, which represents the transition from low to high desert. The wind rose for Phoenix shows moderate directionality and an average windspeed of 6 knots.

The northern portion of Arizona, southeastern California, southern Nevada, and southern Utah are represented by the station at **Las Vegas**/McCarran International Airport (23169). This is one of the original 29 stations. This region is characterized by high desert, including the Columbia Plateau. Relatively few facilities and people are located here. The wind rose is mildly directional with an average windspeed of 10 knots.

The station at **Albuquerque** International Airport (23050), which is one of the original 29 stations, represents the mountainous region of western New Mexico and far west Texas. This region is bounded on the east by the Sacramento Mountains east of El Paso, Texas, and by the Sangre de Cristo Mountains east of Albuquerque, New Mexico. The wind rose is weakly directional and the average windspeed is 8 knots.

Western Mountains

The Western Mountains include numerous mountain ranges, plateaus, and valleys that affect wind flows. Boundaries between these regions follow major terrain features.

The inland region of Oregon includes both the central valley area and the Great Sandy Desert, east to the Columbia Plateau. The western boundary is the Coast Ranges. The Black Rock Desert forms the southern boundary. This region is represented by the station at McNary Field in **Salem, Oregon** (24232). The wind rose shows moderate directionality and an average windspeed of 9 knots.

The Snake River Plain of southern Idaho forms the region represented by **Boise** Air Terminal (24131) in Idaho. This region is bounded by the Salmon River Mountains on the north and the Columbia Plateau to the west and south. The wind rose shows moderate directionality and average windspeed of 9 knots.

Northern Nevada and northeastern California are represented by the station at **Winnemucca** WSO Airport (24128) in Nevada. This is the Great Basin area. The wind rose shows mild directionality and an average windspeed of 8 knots.

The Salt Lake Basin and the Great Divide Desert in Utah and Colorado are represented by the station at **Salt Lake City** International Airport (24127) in Utah. The eastern boundary of this region is formed by the Wind River Range and the Front Range. The wind rose shows moderate directionality and an average windspeed of 9 knots.

Gulf Coast

The wind regime along the Gulf of Mexico is strongly influenced by that body of water. However, its effects do not reach very far inland. A series of regions have been designated to represent the coastal section.

The middle Texas Gulf Coast is represented by the station at **Houston** Intercontinental Airport (12960). Although Houston itself is somewhat inland, it is expected to have a more coastal environment due to Galveston Bay. This region extends south past Victoria to the vegetative boundary marking Southern Texas. The wind rose in this region is only mildly directional with an average windspeed of 8 knots.

The Central Gulf Coast extends from eastern Louisiana through the Florida panhandle. This entire region is part of the Outer Coastal Plain Mixed Forest Province and is characterized by weakly directional winds. The station at **New Orleans** International Airport (12916) in Louisiana was chosen to represent this region. Its wind rose is weakly directional with an average windspeed of 8 knots.

The West Coast of the Florida Peninsula is heavily influenced by the Gulf of Mexico, which has warmer water than the Atlantic Ocean off the East Coast of the Florida Peninsula. This region extends from the Florida Panhandle to the north to Cape Romano, which is just north of the Everglades in South Florida. The station at **Tampa** International Airport (12842) was chosen to represent this region. The wind rose displays very mild directionality and average windspeed of 7 knots.

Southeast

The Southeast section extends from the Atlantic coastal region of Florida and the Florida keys northward through Georgia and South Carolina. This region has an extremely broad coastal plain, requiring it to be divided between coastal region and more inland regions for Georgia and South Carolina. This section also includes the inland areas of Louisiana, Mississippi, and Alabama.

The southern tip of Florida includes the Everglades, which have been drained along the Atlantic coast to provide land for Miami, Ft. Lauderdale, West Palm Beach, and other coastal cities. This region is represented by the original station at **Miami** International Airport (12839). Its wind rose is mildly directional with an average windspeed of 9 knots. Miami was chosen to represent the keys because its directionality and average windspeed are similar to that of Key West.

A long stretch of the Southeastern Atlantic Coast extends from north of Vero Beach, Florida (i.e., just south of Cape Canaveral), through Georgia and South Carolina. The Atlantic Ocean forms the eastern boundary, and the land cover boundary between the more forested coast and more agricultural inland area forms the western boundary. Wind rose analysis reveals a different wind pattern for this region than for the southern tip of Florida. For example, the wind rose for Vero Beach Municipal Airport, which is assigned to the station at Miami, shows mild directionality, with the wind from the predominant direction 10 percent of the time. Just to the north at Daytona Beach, the wind shows weak directionality, with the predominant direction at 8 percent of the time and an average windspeed of 9 knots. Considering the length of this region, a centrally located station would have been desirable, such as the one at Jacksonville International Airport (predominant wind direction 6 percent of the time, average windspeed 8 knots). The station at **Charleston** International Airport (13880), represents this region. Its wind rose shows weak directionality and an average windspeed of 8 knots.

Further inland in Georgia and South Carolina lies the Blue Ridge region. This region is delineated by physiographic boundaries—the transition to the Coastal Plain on the coastal side and to the Appalachian Plateaus on the inland side. The station at **Atlanta** Hartsfield International Airport (13874) represents this region. The wind rose reveals mild directionality and an average windspeed of 9 knots.

The inland areas of Alabama and Mississippi are represented by the station at **Meridian** Key Field (13865), which is located in Mississippi close to the Alabama border. This region extends from the Central Gulf Coast region northward into southern Tennessee (including

Memphis) and westward into the Coastal Plain region of eastern Arkansas. The wind rose for this region is mildly directional with an average windspeed of 7 knots.

The inland portion of Louisiana and eastern Texas is part of the Coastal Plain. This region extends northward to the Ouachita Mountains, which are just south of the Ozark Plateau in Arkansas. The western boundary is the vegetative transition from the forests in this region to the prairies in Texas. This region is represented by the station at **Shreveport** Regional Airport (13957) in Louisiana. The wind rose is mildly directional with an average windspeed of 9 knots.

Middle Atlantic

The Middle Atlantic section includes coastal areas with bays, sounds, inlets, and barrier islands; a broad coastal plain; and the southern Appalachian Mountains. The physiographic features generally extend from northeast to southwest, parallel to the coast of the Atlantic Ocean.

The coastal region of North Carolina and Virginia is represented by the station at **Norfolk** International Airport (13737) in Virginia. This region is bounded by the Atlantic Ocean on the east, the physiographic boundary to the Piedmont section to the west, the political border between North Carolina and South Carolina to the south, and a line bisecting the Chesapeake Bay to the north. The wind rose is mildly directional with an average windspeed of 10 knots.

The Piedmont region of North Carolina and Virginia is just inland from the coastal region. This region is delineated on the east by the physiographic boundary with the coastal plain, and on the west with the physiographic boundary with the Appalachian Mountains. This region is also part of the Southeastern Mixed Forest Province of Bailey’s ecoregions. The station at **Raleigh-Durham** Airport (13722) in North Carolina represents this region, with a weakly directional wind rose and average windspeed of 8 knots.

The eastern portion of the southern Appalachian Mountains lies to the west of the Piedmont region of North Carolina and Virginia. This region extends to the southwest to include a portion of western South Carolina and northeastern Georgia. The station at **Asheville** Regional Airport (03812) in North Carolina was chosen to represent this region. Its wind rose shows moderate directionality and an average windspeed of 10 knots.

The Appalachian Mountains of West Virginia and eastern Kentucky are characterized by mountainous ridges and valleys extending from northeast to southwest. This region is represented by the station at **Huntington** Tri-State Airport (03860) in West Virginia. The wind rose is mildly directional with an average windspeed of 7 knots.

The inland region encompassing northern Virginia, part of Maryland, and eastern Pennsylvania is composed of another section of the Appalachian Mountains. Boundaries are approximated by the Bailey’s Central Appalachian Forest province. The original station at **Harrisburg**/Capital City Airport (14751) in Pennsylvania represents this region. The wind rose is mildly directional with average windspeed at 9 knots.

The northern portion of the Chesapeake Bay northward through New Jersey, eastern Pennsylvania, and New York City is characterized by the Eastern Broadleaf Forest (Oceanic) Province in the coastal plain. The original station at **Philadelphia** International Airport (13739) in Pennsylvania represents this region. The wind rose is mildly directional with an average windspeed of 9 knots.

Northeast

The Northeast section includes Maine and New England. This region is characterized by forests to the north, large urban areas along the southern coastal plain, and the mountain ridges and valleys of the northern Appalachian Mountains. This section is bounded by the Atlantic Ocean on the east, the U.S. Canada border on the north, and the coastal plain of the eastern Great Lakes to the west.

The station at Bradley International Airport (14740) in **Hartford**, Connecticut, represents the New England region, which encompasses Connecticut, Massachusetts, Rhode Island and a small portion of Vermont, New Hampshire, and eastern New York. The wind rose shows mild directionality with an average windspeed of 8 knots.

Northern New England and Maine are represented by the station located at the International Jetport (14764) in **Portland**, Maine. This region includes Maine and most of New Hampshire and Vermont. The northwest portion of Vermont is in a unique location and represented separately. The wind rose for this region has mild directionality and an average windspeed of 9 knots.

The station at the International Airport (14742) in **Burlington**, Vermont, represents a very small region. Burlington is located in a valley between mountainous areas of the northern Appalachian Mountains. This location is reflected in its wind rose, which blows from its predominant direction 20 percent of the time, and average windspeed of 10 knots.

The remainder of the northern Appalachian Mountains in New York and Pennsylvania is represented by the station at **Williamsport**-Lycoming (14778) in Pennsylvania. This region is bounded on the west by the Adirondack Mountains, just to the east of the coastal plain of Lake Ontario. The wind rose for this region is mildly directional with an average windspeed of 9 knots.

Great Lakes

The Great Lakes are bodies of water large enough to affect weather patterns in that portion of the country. Land and sea breezes affect wind patterns along the coasts, especially along Lake Michigan in the summer. The moisture of the lakes also affects winter precipitation patterns (i.e., lake effect snow storms). This version of IWAIR, therefore, has refined the description of the coastal regions bordering the Great Lakes.

The Eastern Great Lakes divide the United States and Canada. On the U.S. side, the western portion of New York, a small portion of Pennsylvania, and northeastern Ohio border the eastern shores of Lake Ontario and Lake Erie. Mountains form the eastern boundary. The southwestern border is drawn southward from the southern shore of Lake Erie. The original station at Hopkins International Airport (14820) in **Cleveland**, Ohio, represents this region. The wind rose is moderately directional with average windspeed of 10 knots.

The Lower Peninsula of Michigan is bordered by the Great Lakes on three sides. Although this region has relatively few topographic features, the presence of the lakes may result in different dispersion analyses for the eastern and western portions of the state. Therefore, the Lower Peninsula has been divided into two regions—East and West.

The Western region of the Lower Peninsula of Michigan is bordered by Lake Michigan on the west and the Straits of Mackinac on the north. The eastern portion of the Upper Peninsula of Michigan is also included in this region. The station at **Muskegon** County Airport (14840) represents this region, although it has only 2 years of data for this time period. Its wind rose is weakly directional and its average windspeed is 11 knots.

The western shore of Lake Michigan, which includes Green Bay, is formed by the northeastern portion of Illinois, eastern Wisconsin, and part of the Upper Peninsula of Michigan. Lake Superior forms the northern boundary of this region, and the western boundary is formed by the hills to the east of the Wisconsin River and the Upper Mississippi River. This region is represented by the station at O'Hare International Airport (94846) in **Chicago**, Illinois. The wind rose for this region is mildly directional with an average windspeed of 9 knots.

Central States

This section includes the Central Lowlands (south of the Great Lakes), the Midwest, and the Great Plains. The elevation for this section is generally lowest in the Mississippi Valley, which extends through the Midwest and drains a large portion of the center of the continental United States. This section also includes other major river valleys, including the Ohio, Tennessee, and Missouri. This section is bordered on the east by the Appalachian Mountains, on the west by the Rocky Mountains, on the north by the border with Canada, and on the south by the Southeast, Texas, and the Desert Southwest.

Although definitive boundaries are rare within this section the wind roses for stations that were not selected represent additional data useful for drawing boundaries.

The region includes western Kentucky, central and western Tennessee north of Memphis, and southeastern Missouri east of the Ozark Plateau. This region is represented by the station at **Nashville** Metropolitan Airport (13897) in Tennessee. The wind rose is moderately directional with an average windspeed of 8 knots.

A large region is assigned to the station at Adams Field (13963) in **Little Rock**, Arkansas. Little Rock, however, is situated in an area heavily influenced by the Ozark Plateau and its accompanying mountains.. The wind rose for this station is weakly directional with an average windspeed of 7 knots.

The northern portion of the Midwest includes the portion of Wisconsin west of the Lake Michigan coastal plain, Minnesota, and the eastern portion of North and South Dakota. The western boundary through the Dakotas is the physiographic boundary between the Central Lowland and the Great Plains. This region is represented by the station at **Minneapolis-St. Paul** International Airport (14922) in Minnesota. The wind rose is mildly directional with an average windspeed of 11 knots.

The Great Plains lie between the Central Lowlands to the east and the Rocky Mountains to the west. The headwaters of the Mississippi and the Missouri rivers are located in the Great Plains. Lands at higher elevations are more grassland and shrub land used for cattle ranges, while the lower elevations are used more frequently for crops. The region that includes the western portion of North and South Dakota and eastern Montana is represented by the original station at **Bismarck** Municipal Airport (24011) in North Dakota. The wind rose is weakly directional with an average windspeed of 12 knots.

The central portion of Montana is more rugged, but still part of the Great Plains. The Rocky Mountains form the western and southwestern boundaries of this region, which is represented by the station at **Billings** Logan International Airport (24033) in Montana. The wind rose is strongly directional with an average windspeed of 10 knots.

The station at **Casper**/Natrona County International Airport (24089) in Wyoming represents Wyoming east of the Front Range of the Rocky Mountains, southwestern South Dakota, and western Nebraska. The wind rose is strongly directional with an average windspeed of 14 knots. In this region, most cities are located in valleys or near the base of a mountain ridge. The wind regime at Casper, therefore, may not adequately represent other locations in this region.

This region is represented by the station at Stapleton International Airport (23062) in **Denver**, Colorado The southern boundary is formed by the southern edge of the Great Plains. The wind rose for this region is mildly directional with an average windspeed of 8 knots.

The north central portion of the Great Plains includes most of Nebraska, northern Kansas, western Iowa, southwestern South Dakota, and northwestern Missouri. This region is represented by the station at **Grand Island** Airport (14935) in Nebraska (this station is labeled as Lincoln). The wind rose is moderately directional with an average windspeed of 12 knots.

The southern portion of the Great Plains includes most of Kansas, and eastern Oklahoma. This region also includes the lower area of the western Ozark Plateau in southwestern Missouri and northwestern Arkansas. This region is represented by the station at **Tulsa** International Airport (13968). The wind rose is moderately directional with an average windspeed of 11 knots.