Appendix A

Appendix A1: HCB Concentrations in Biota

Table 1 summarizes the findings of research studies done on hexachlorobenzene concentrations in various organisms.

Table 1:

Organism	Conc. HCB *ng/g* wet weight	Time and Place	Reference
Invertebrates			
Freshwater mussels	Range 0.1 - 24	Great Lakes, 1980s	Muncaster et al. 1989
Various invertebrates	Range 0.1 - 26	Beaufort Sea	Hargrave et al., 1989
Aquatic snails *(Lymnea sp.)*	Avg. 0.15	Four Alaskan lakes, 1990s	Allen-Gil et al., 1997
Zooplankton	<0.3	Lake Baikal, 1995	Kucklick et al., 1996
Pelagic amphipod *(Macrohectopus branicii)*	<0.3		
Benthic amphipod *(Acanthogammoarus)*	<0.3		
Fish			
Grayling *(Thymallus arcticus)*	Avg. (liver) 0.64	Four Alaskan lakes, 1990s	Allen-Gil et al., 1997
	Avg. (muscle) 0.33		
Lake trout *(Salvelinus namaycush)*	Avg. (liver) 1.15		
	Avg. (muscle) 0.46		
Pelagic sculpin *(Comephorus baikalenis)*	Avg. 1.5	Lake Baikal, 1995	Kucklick et al., 1996
Pelagic sculpin *(Comephorus dybowskii)*	Avg. 16.02		
Omul *(Coregonus autumnals)*	Avg. 2.96		
Brooke trout (*Salvelinus fontinalis*)	Up to 54	1981-82 NB and NS	Peterson and Ray, 1987
Yellow perch (*Perca flavescens*)	Up to 15		
Juvenile shiner (*Notropis atherinoides*)	Below LOD (1.0)	L. Superior & L. Erie	Suns et al., 1983
Shiners (*Notropis atherinoides*)	Range ND – 13	Lake Ontario	Suns et al., 1985
	Avg. 5	Detroit River	
	Range ND – 8	Niagara River	
	Avg. 231	St. Clair River	
Lake trout *(Salvelinus namaycush)*	Avg. 37	Lake Ontario	Niimi and Oliver, 1989
Brown trout (*Salmo trutta trutta*)	Avg. 10		
Small rainbow trout *(Oncorhynchus mykiss)*	Avg. 5		
Large rainbow trout *(Oncorhynchus mykiss)*	Avg. 16		
Small coho salmon	Avg. 10		
Large coho salmon	Avg. 13-		
Birds			
Black Tern *(Chlidonias niger)* eggs	Avg. 8 Range 5-13	Southern Quebec: 1990-1996	Weseloh et al., 1997

	Avg. 7 Range 5-10	Southern Ontario: 1990-1996	
Herring gull *(Larus argentatus)* eggs	37 and 71	Lake Michigan	Envt. Canada/Dep. of Fisheries and Oceans/Health and Welfare Canada, 1991 in CEPA, 1993
	34 and 41	Lake Superior	
	28 and 39	Lake Ontario	
	28 and 28	Lake Huron	
	16 and 30	Lake Erie	
Peregrine Falcon *(Falco peregrinus pealei)* eggs	Avg. 45 Range 0-230	Across Canada: 1965-1972	Peakall et al., 1990
	Avg. 142 Range 74-190	1980-1986	
Peregrine Falcon *(Falco peregrinus anatum)* eggs	Avg. 27 Range 1-132	1965-1972	
	Avg. 49 Range 0-315	1973-1979	
	Avg. 279 Range 0-1060	1980-1987	
Peregrine Falcon *(Falco peregrinus tundrius)* eggs	Avg. 48 Range 10-133	1973-1979	
	Avg. 45 Range 16-350	1980-1986	
Marine Mammals			
Beluga Whales (*Delphinapterus leucas*)	Avg. 570 Range 540-610	1995 Northern Quebec	Langlois and Langis, 1995
	Avg. 220 Range 90-340	East Hudson Bay	Muir et al., 1990
	Avg. 570 Range 130-1260	Cumberland Strait	
	Avg. 930 Range 220-1900	St. Lawrence Estuary	
Beluga (*Delphinapterus leucas*) males	Up to 1340	St. Lawrence Estuary	Beland et al., 1991
	Avg. 491	Canadian Arctic	Norstrom et al., 1990
Ringed Seals (*Phoca hispida*)	Avg. 19	Canadian Arctic	
Caspian Seal (*Phoca caspica*)	2.4 – 77	Caspian Sea	Watanabe et al., 1999
Lake Baikal Seal *(Phoca siberica)*	Male Avg. 7.15 Female Avg. 9.18	Lake Baikal, 1995	Kucklick et al., 1996
White-beaked dolphins *(Lagenorhynchus albirostris)*	Male 1110 Female 880	Newfoundland, 1988	Muir et al., 1988
Pilot whales *(Globicephala melaena)*	Male 290 Female 100		
Terrestrial Mammals			
Mink *(Mustela vison)* carcasses	<0.5 to 10	Ontario early 1970s	Proulx et al., 1987
Polar Bear (*Ursus maritimus*) fat	Avg. 196	1982-84 Canadian Arctic	Norstrom et al., 1990
Mink *(Mustela vison)*	Avg. 0.41	Northwest Territories	Poole et al., 1997
Hares (*Lepus arcticus*)	Avg. 0.14		
Voles (*Microtus sp.*)	Avg. 0.57		

Appendix A2: HCB Toxicity

Table 2: A summary of laboratory research done on toxic responses of mammals to hexachlorobenzene.

Effect	NOEL[a]	LOEL[b]	Reference
	μg/g b.w./day		
Porphoria and altered liver enzyme activity in pigs with subchronic exposure to HCB in diet.	0.05	0.5	Den Tondelaar et al. 1978
Alteration in Ca metabolism, increased liver weights with subchronic exposure to HCB in diet.	0.07	0.7	Andrews et al. 1990
Alterations in reproductive tissues of female monkeys	--	0.1	Babineau et al. 1991 Sims et al. 1991
Effects on the immune systems of nursing rats from HCB from dams milk	--	0.2 fed dams	Vos et al. 1983
Immunosuppressive response in mice exposed *in utero* and through nursing		0.5 fed dams	Barnett et al. 1987
Effects on the lymphoid tissues of the lung in beagles with exposure to HCB in gelatin capsules	--	0.12	Gralla et al. 1977
Increased organ weights (heart, brain and liver) in male rats and compound-related changes in liver of rats exposed to maternal doses of HCB *in utero*, through nursing and continued through diet for life	0.05-0.07 (fed to dams)	0.27-0.35 (fed to dams	Arnold et al. 1985 Arnold and Krewski 1988
Reduced birth weights and increased mortality to weaning in mink kits with *in utero* plus lactational exposure to HCB	--	0.16 (fed to dams)	Bleavins et al. 1984 Bleavins et al. 1984

[a] - No-observed-effect level

[b] - Low-observed-effect level

Table 3: A summary of toxic response studies done on non-mammals

Organism	Effect	Concentration	Reference
Aquatic Biota			
Alga *(Chlorella pyrenoidosa)*	Increased growth	1 *μg/L HCB* for 3 months	Geike and Parasher, 1976
Protozoa *(Tetrahymena pyriformis)*	Decreased growth	1 *μg/L HCB* for 10 days	
Crayfish *(Procambarus clarki)*	Increase in damage to the hepatopancreas	5 *μg/L HCB* for 10 days	Laster et al., 1976
Invertebrate *(Daphnia magna)*	Fertility reduced by 50%	16 *μg/L HCB* for 14 days	Calamari et al., 1983
Amphipod *(Gammarus lacustris)*	Significantly increased mortality observed	3.3*μg/L HCB* for 28 days	Nebecker et al., 1989
Amphipod *(Hyallela azteca)*	No observed effects to survival, growth and reproduction	4.7 *μg/L HCB*	
Worm *(Lumbriculus variegatus)*			
Fathead minnows *(Pimephales promelas)*	Not adversely affected	5*μg/L HCB*	Ahmad et al., 1984 Nebecker et al., 1989
Rainbow trout *(Oncorhynchus mykiss)*			
Large mouth bass *(Micropterus salmoides)*	Liver necrosis	3.5 *μg/L HCB* for 10 days	Laseter et al., 1976

Birds			
Japanese quail *(Coturnix japonica)*	Mortality increased	100 *µg/g* wet weight HCB in diet for 90 days	Vos et al., 1971; 1972
	Hatchability of eggs reduced	20 *µg/g* wet weight HCB in diet for 90 days	
	Increased liver weight, slight liver damage and increased fecal excretion of coproporphyrin	5 *µg/g* wet weight HCB in diet for 90 days	
Eurasian kestrels *(Falco tinnunculus)*	Weight loss, ruffling of feathers, tremors, increased liver weight, and decreased heart weight	200 *µg/g* wet weight of HCB in contaminated mice for 65 days	Vos et al., 1972
Herring gull *(Larus argentatus)*	Mortality of 50% of eggs	>4.3 *µg/g* wet weight of eggs	Boersma et al., 1986
Peregrine Falcons *(Falco peregrinus)*	Survival of eggs	>4 *µg/g* wet weight of eggs	Peakall et al., 1990

Appendix A3: Chemical fate model inputs

Regional Level Simulation - HCB emissions into air = 0.00858 kg/h (Magnola's reported emissions from BAPE report, 1998 plus our calculations of HCB emissions from the tailings pond).

Local Level Simulation - Air concentration of HCB = 1.37 ng/m^3 (Maximum ground concentration from Magnola's Environmental Impact Assessment); default environmental parameters.

Appendix A4: Chemical fate model output diagrams

Figure 1:

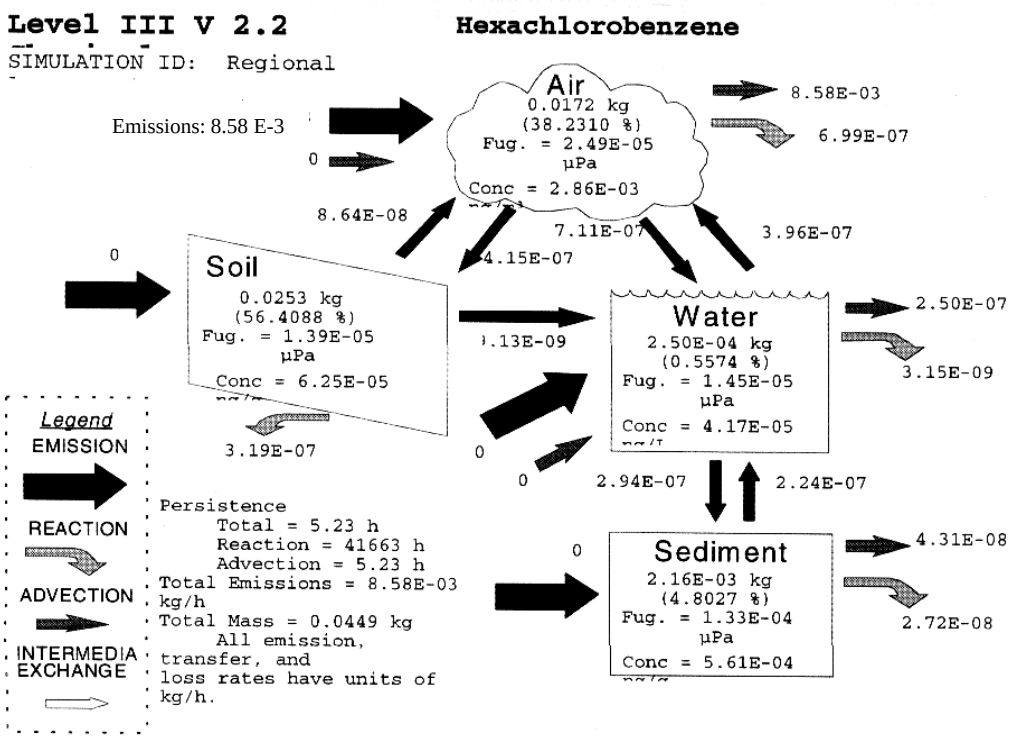

Figure 1 illustrates the results of the Chemical Fate model run for the regional assessment. The only input into the system is emissions into the air from both Magnola's stacks and the tailings pond (8.58E-3 kg of HCB/hour).

Figure 2:

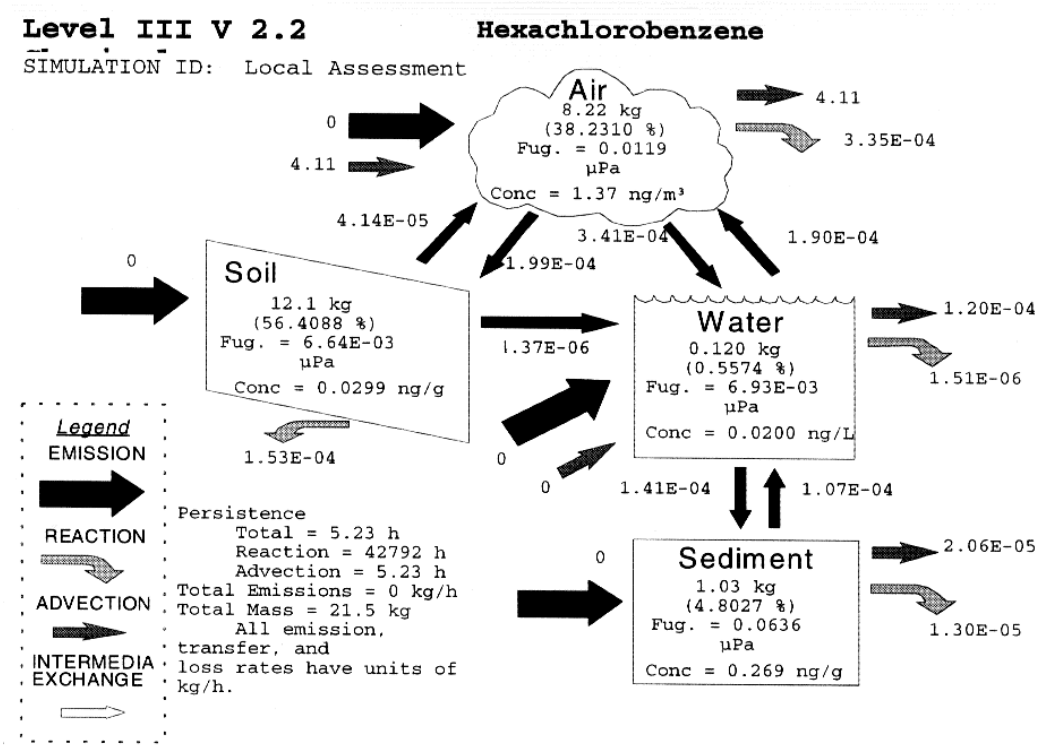

Figure 2 illustrates the results of the Chemical Fate model run for the local analysis. The only input is the air concentration value of 1.37 ng/m^3, which is the maximum ground level air concentration calculated in Magnola's Environmental Impact Assessment.

Appendix A5: Model Parameters for Hexachlorobenzene

Table 3: Properties of Hexachlorobenzene

Molecular Mass (g/mol)	284.700
Data Temperature °C	25
LogKow	5.5
Water Solubility (g/m³)	0.005
Water Solubility (mol/m³)	1.756E-05
Henry's Law Constant (Pa.m³/mol)	131.008
Vapour Pressure (Pa)[a]	0.0023
Melting Point °C	230
Fugacity Ratio	0.009
Sub-cooled Liquid Vapour Pressure	0.245

[a] - The Vapour Pressure is that of the chemical in the state (solid or liquid) corresponding to the data temperature.

Table 4: Half -life of Hexachlorobenzene in various media

Half -Lives	**(hours)**
Half-Life in Air (gaseous)	17000
Half-Life in Water (no sus. Sedmt.)	55000
Half-Life in Soil	55000
Half-Life in Bulk Sediment	55000
Half-Life in Suspended Sediment	55000
Half-Life in Fish	55000
Half-Life in Aerosol	17000

Appendix A6: Model Environmental Parameters

Table 5: Environmental Properties Set by the Fate Model

Phase	Area (m^2)	Depth (m)	Volume (m^3)	Volume Fractions	Density (kg/m^3)	Organic Carbon Lipid (g/g)	Adv. Residence Time (h)
Air: Bulk	3E9	2000	6E+12		1.184		2
Pure Air			6E+12		1.184		
Aerosol			120	2.00E-11	2400		
Water: Bulk	3E8	20	6E9		1000.007		1000
Water			6E9		1000		
Sus. Sediment			30000	5.00E-06	2400	0	
Fish			6000	1.00E-06	1000	0.048	
Soil: Bulk	2.7E9	0.10	2.7E8		1500.237		
Air			5.4E7	0.2	1.185		
Water			8.1E7	0.3	1000		
Solid			1.35E8	0.5	2400	0.020	
Sediment: Bulk	3E8	0.01	3E6		1280	0.040	
Water	-	-	2.4E6	0.8	1000	-	-
Solid	-	-	6E-5	0.2	2400	0.200	-

Table 6: Transport Velocities of Hexachlorobenzene

	m/hour	m/year
Air side air-water MTC	5	43800
Water side air-water MTC	0.050	8.760
Rain rate	0.001	8.760
Aerosol deposition velocity	6E-10	5.256E-06
Soil air phase diffusion MTC	0.02	175.199
Soil water phase diffusion MTC	1E-05	0.087
Soil air boundary layer MTC	5	43800
Sediment-water MTC	1E-04	0.875
Sediment deposition velocity	5E-07	0.004
Sediment resuspension velocity	2E-07	0.001
Soil water runoff rate	5E-05	0.437
Soil solids runoff rate	1E-08	8.76E-05

Appendix A7: Model Results for Regional Assessment

Table 7: Phase Properties (amounts and concentrations) of HCB on a regional scale

Phase Properties							
	Z Values (mol/m³.Pa)	**Amount (kg)**	**Amount (mol)**	**Amount (%)**	**Conc. (mol/m³)**	**Conc. (g/m³)**	**Conc. µ(g/g)**
Air: Bulk	4.03E-4	0.017	0.060	38.231	1.004E-14	2.86E-12	2.413E-09
Pure Air	4.04E-4	0.017	0.060	38.212	1.004E-14	2.858E-12	2.412E-09
Aerosol	9876.912	8.397E-06	2.948E-05	0.019	2.457E-07	6.998E-05	2.916E-05
Water: Bulk	1.012E-2	2.502E-4	8.783E-4	0.557	1.464E-13	4.169E-11	4.169E-11
Water	7.633E-3	1.886E-4	6.622E-4	0.420	1.104E-13	3.143E-11	3.143E-11
Sus. Sediment	475.037	5.879E-05	2.061E-4	0.131	6.869E-09	1.956E-06	8.151E-07
Fish	115.863	2.862E-06	1.005E-05	6.379E-3	1.675E-09	4.771E-07	4.771E-07
Soil: Bulk	23.754	0.025	0.089	56.409	3.292E-10	9.376E-08	6.250E-08
Air	4.034E-4	8.599E-08	3.019E-07	1.916E-4	5.591E-15	1.592E-12	1.344E-09
Water	7.633E-3	2.440E-06	8.569E-06	5.438E-3	1.058E-13	3.013E-11	3.013E-11
Solid	47.504	0.025	0.089	56.403	6.584E-10	1.875E-07	7.813E-08
Sediment: Bulk	19.008	2.155E-3	7.568E-3	4.8034	2.523E-09	7.185E-07	5.613E-07
Water	7.633E-3	6.924E-07	2.431E-06	1.543E-3	1.013E-12	2.885E-10	2.885E-10
Solid	95.007	2.155E-3	7.566E-3	4.801	1.261E-08	3.591E-06	1.496E-06

Table 8: Advection values of HCB on a regional scale

	Residence Time (h)	**Flow Rate (m³/h)**	**Rates (mol/h)**	**% of Total Losses**
Air: Bulk	2	3E+12	3.012E-2	99.984
Pure Air		3E+12	0.0301	99.935
Aerosol		60	1.474E-05	4.893E-2
Water: Bulk	1000	6E6	8.783E-07	2.916E-3
Water		6E6	6.622E-07	2.198E-3
Sus. Sediment		30	2.061E-07	6.840E-4
Fish		6	1.005E-08	3.337E-5
Soil: Bulk				
Sediment: Bulk	0	60	1.5136E-07	0.000502417

Table 9: Losses or reactions of HCB from the regional environment

	Half Life (h)	**Rates (mol/h)**	**% of Total Losses**
Air: Bulk		2.4558E-06	8.152^{E}-03
Pure Air	17000	2.4546E-06	8.148^{E}-03
Aerosol	17000	1.202E-09	3.990E-06
Water: Bulk		1.107E-08	3.673E-05
Water	55000	8.344E-09	2.770E-05
Sus. Sediment	55000	2.596E-09	8.619E-06
Fish	55000	1.267E-10	4.204E-07
Soil: Bulk	55000	1.120E-06	3.718E-03
Sediment: Bulk	55000	9.536E-08	3.170E-03

Table 10: Intermedia transport of HCB on a regional scale

	Half times (h)	Equiv. Flows (m^3/h)	Rate of Transport	
			(kg/h)	(mol/h)
Air to water	1.672E04	2.486E08	7.109E-07	2.496E-06
Air to soil	2.868E04	1.450E08	4.146E-07	1.456E-06
Water to soil	437.227	9.510E06	3.965E-07	1.392E-06
Water to sediments	588.884	7.061E06	2.944E-07	1.034E-06
Soil to air	2.029E05	9.220E02	8.645E-08	3.035E-07
Soil to water	1.922E06	97.375	9.130E-09	3.206E-08
Sediment to water	6.665E03	3.120E02	2.241E-07	7.869E-07

Appendix A8: Model Results for Local Assessment

Table 11: Phase properties (amounts and concentrations) of HCB on a local scale

	Z Values ($mol/m^3.Pa$)	Amount (kg)	Amount (mol)	Amount (%)	Conc. (mol/m^3)	Conc. (g/m^3)	Conc. µ(g/g)
Air: Bulk	4.03E-4	8.219	28.858	38.231	4.810E-12	1.370E-09	1.156E-06
Pure Air	4.03E-4	8.215	28.844	38.212	4.807E-12	1.369E-09	1.155E-06
Aerosol	9876.912	4.022E-3	0.014	0.019	1.177E-3	0.034	0.014
Water: Bulk	0.010	0.120	0.421	0.557	7.013E-11	1.997E-08	1.997E-08
Water	7.633E-3	0.090	0.317	0.420	5.287E-11	1.506E-08	1.506E-08
Sus. Sediment	475.037	0.028	0.099	0.131	3.290E-06	9.371E-4	3.905E-4
Fish	115.863	1.371E-3	4.815E-3	6.379E-3	8.025E-07	2.286E-4	2.286E-4
Soil: Bulk	23.754	12.126	42.579	56.409	1.577E-07	4.491E-05	2.994E-05
Air	4.034E-4	4.119E-05	1.446E-4	1.916E-4	2.678E-12	7.628E-10	6.437E-07
Water	7.633E-3	1.169E-3	4.104E-3	5.437E-3	5.067E-11	1.443E-08	1.443E-08
Solid	47.50	12.125	42.575	56.403	3.154E-07	8.982E-05	3.742E-05
Sediment: Bulk	19.008	1.032	3.625	4.803	1.208E-06	3.442E-4	2.689E-4
Water	7.633E-3	3.317E-4	1.165E-3	1.543E-3	4.853E-10	1.382E-07	1.382E-07
Solid	95.007	1.032	3.624	4.801	6.040E-06	1.720E-3	7.168E-4

Table 12: Advection values of HCB on a local scale

	Residence Time (h)	Flow rate (m^3/h)	(kg/h)	Rates (mol/h)	% of Total Losses
Air: Bulk	2	3E+12	4.109	14.429	99.984
Pure Air		3E+12	4.107	14.422	99.935
Aerosol		60	2.011E-3	7.062E-3	0.049
Water: Bulk	1000	6E6	1.198E-4	4.208E-4	2.916E-3
Water		6E6	9.035E-05	3.172E-4	2.198E-3
Sus. Sediment		30	2.811E-05	9.871E-05	6.840E-4
Fish		6	1.371E-06	4.815E-06	3.337E-05
Soil: Bulk					
Sediment: Bulk	0	60	2.065E-05	7.250E-05	5.02E-4

Table 13: Losses or reactions of HCB from the local environment

	Half-Life (h)	(mol / Pa.h)	Rates (mol/h)	% of Total losses
Air: Bulk		3.35E-4	1.176E-3	8.152E-3
Pure Air	17000	3.349E-4	1.176E-3	8.148E-3
Aerosol	17000	1.64E-07	5.757E-07	3.99E-06
Water: Bulk		1.51E-06	5.302E-06	3.674E-05
Water	55000	1.138E-06	3.997E-06	2.770E-05
Sus. Sediment	55000	3.542E-07	1.244E-06	8.619E-06
Fish	55000	1.728E-08	6.067E-08	4.204E-07
Soil: Bulk	55000	1.527E-4	5.365E-4	3.718E-3
Sediment: Bulk	55000	1.301E-05	4.568E-05	3.165E-4

Table 14: Intermedia transport of HCB on a local scale

	Half times	Equiv. Flows	Rate of Transport	
	(h)	(m^3/h)	(kg/h)	(mol/h)
Air to water	16724.229	2.486E8	3.406E-4	1.196E-3
Air to soil	28681.738	1.450E8	1.985E-4	6.973E-4
Water to soil	437.227	9.510E6	1.899E-4	6.669E-4
Water to sediments	588.884	7.061E6	1.410E-4	4.951E-4
Soil to air	202931.5	922.035	4.141E-05	1.454E-4
Soil to water	1921536.75	97.375	4.373E-06	1.536E-05
Sediment to water	6664.506	311.951	1.074E-4	3.770E-4