Estimation of mercury transport and accumulation from an incinerator

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ABSTRACT

Mercury concentrations in the air, soil, and sediment - water were estimated to determine the levels of mercury that might be present in the environmental media within 5 km of an incinerator in New Jersey. Gaussian dispersion equation was used as a basic tool for estimating mercury concentrations in the air Universal loss equation, atmospheric deposition (wet and dry) and accumulation equations were used to calculate mercury concentrations in soil and sediment - water

Estimated high - ground level concentration of mercury in the air was about 28 ng/m^3 under D - stability, which is slightly higher than the average in the U.S. (2 - 20 ng/m^3) due to the result of near - source calculations (5 km) Mercury in soil and sediment. regardless background concentration, were approximately 0.37 and 0.33 mg/kg, respectively, which is high comparing to another county soil samples

INTRODUCTION

Mercury is considered one of the toxic metals and it can accumulate in the food chain (especially methymercury).[1] In human, mercury can cause paresthesia and developmental neurologic effects in - utero [2] Serveral studied showed that mercury emitted from incinerators causes the increasing of mercury contamination in the environment [3, 4] In Minamata Bay, Japan, widespread problem of mercury contamination caused Minamata disease Mercury pollution has become the subject of much concern and public outcry This paper attempted to estimate mercury concentrations in air, soil, and sediment - water within 5 km downwind from and incinerator in New Jersey with the best available data from literatures

METHODS

1. Determination of mercury concentrations in the air

Gaussian dispersion equation (1) [5,6] was used to estimate the mercury levels downwind. The calculations assumed that the plume from the incinerator behaved similarly to that described by the Gaussian plume model (Figure 1) for simple terrain and that no chemical reactions occur during the transport (5km) :

$$C = \frac{Q}{2\pi u_s \sigma_y \sigma_z} e^{\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]} \cdot \left\{ e^{\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]} + R \cdot e^{\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]} \right\} \quad \text{--- (1)}$$

where C is the downwind concentration of total mercury (g/m^3), Q is the total mercury emission rate (g/s), U_s is the average wind speed at stack height (m/s), σ_y is the horizontal distance from plume centerline (m), Z is the vertical distance from plume centerline (m), R is the reflectioin of plume when it reaches the ground (assumed 10% absorption due to soluble species, Hg^{2+}), and H is the effective stack height (m). Equation (2) and (3) were derived from the User's Guide for ISC3 (1995)[7] to estimate σ_y and σ_z :

$$\sigma_y = 465\ 11628\ (x)\ \mathrm{TAN}\ (\mathrm{TH});\ \mathrm{TH} = 0.017453293\ [c - d\ \ln(x)] \quad \text{--- (2)}$$

$$\sigma_z = a(x)^b \quad \text{--- (3)}$$

where x is the distance in km; a, b, c, and d are coeffcients depending on downwind distance and stability, which are used to fit Pasquill - Gifford curves.[7] In addition effective stack height was calculated from the following equation : [8]

$$H = \Delta H v + h \quad \text{--- (4)}$$

where h is the stack height (m), and ΔH is the plume rise (m) calculated by :

$$\Delta H = \frac{v_s d}{u}\left[1.5 + \left(2.68 \times 10^{-2} (P) \left(\frac{T_s - T_a}{T_s}\right) d\right)\right] \quad \text{--- (5)}$$

where ΔH is the plume rise (m), v_s is the stack exit velocity (m/s), d is the stack diameter (m), P is the atmospheric pressure (kPa), T_s is the stack temperature (°K), and T_a is the atmospheric temperature (°K). Table 1 shows the parameters used in the calculations.

2. Determination of mercury depositions

Once mercury is in the air, it will eventually deposit to the ground, water bodies, plants, and so on. The wet and dry deposition rate of atmospheric mercury were applied to estmate the accumulation of mercury in soil and sediment - water

a) *Wet deposition* : Soluble forms of mercury such as $HgCl_2$, may be removed by precipitation, whereas insoluble, volatile forms such as elemental mercury (Hg°) and dimethylmercury [$(CH_3)_2Hg$] are likely to remain in the atmosphere [9] Wet removal of mercury can be estimated using a washout ratio (WR) approach. WR is defined as $C_{rainwater}$ [ng/m^3]/C_{air} [ng/m^3] ratio.[10, 11] The wet deposition flux (WD) was then estimated from the following equation.[10]

$$WD = (C_{air})(WR)(R_r)(t_r) \quad \text{--- (6)}$$

where C_{air} is the murcury concentration in air (ng/m^3), R_r is the annual average rainfall rate (m/hr), and t_r is the time accounted for rainfall (yr^{-1})

b) Dry deposition : Atmospheric mercury accounts only for a small portion of particulate Hg° (<5%) compared to the gaseous phase [12] Dry deposition flux (DD) was estimated based on deposition velocity (V_d) as described by NJDEPE (1993) [10]

$$\text{Dry deposition flux (DD)} = (C_{air})(V_d) \quad \text{--- (7)}$$

Total mercury deposition (TD) is the total of WD and DD

3. Determination of mercury concentrations in soil (due to depositions)

Universal Loss Equation Developed by USDA[14] was employed to estimate mercury concentration in soil

$$\chi_e = (E_R)(K_{SE})(LS)(c)(P_S)(D_{DF}) \quad \text{--- (8)}$$

where χ_e is the loss rate per unit area watershed over time (g/m^2-yr), E_R is the rainfall erosion index (yr^{-1}),[10] K_{SE} is the soil erodability factor (ton/acre) based on type of soil and organic content, c is the unitless cover and management factor based on the type of land use and the percentage of ground cover, P_s is the unitless supporting practice factor, D_{DF} is the unitless sediment delivery factor, LS is the slope length factor .

$$LS = (\lambda/22.1)^{\xi}(65.41S^2 + 4.565S + 0.065) \quad \text{--- (9)}$$

where LS is the unitless slope length factor to determine the rate of soil loss χ_e, λ is the land surface slope length (m), ξ is the exponent to determine slope length (LS), and S is the land surface slope (m/m).

$$\xi = 0.6\,[1-e^{(-35.835S)}] \qquad \text{--- (10)}$$

The first - order loss rate of mercury calculated based on the following equation :[10] in soil due to soil erosion (k_1 - yr^{-1}) was

$$k_1 = (\chi_e)/[(BD_{soil})\,(SD_{soil})] \qquad \text{--- (11)}$$

where BD_{soil} is the soil mixing depth (m), and SD_{soil} is the soil bulk density (kg/m^3). Mercury concentration from total deposition was calculated :[10]

$$C_{soil} = \frac{TD\left[\dfrac{1-e^{(-k_1)(AT)}}{k_1}\right]}{(SD_{soil})\,(BD_{soil})} \qquad \text{--- (12)}$$

where C_{soil} is the annual concentration of mercury in soil due to wet and dry deposition (mg/kg), TD is the total deposition rate of murcury to soil (g/m^2-yr), and AT is the accumulation rate (yr).

4. Determination of mercury concentrations in sediment - water

Mercury concentrations in sediment - water were calculated from the following :

a) Mercury concentrations in sediment - water due to runoff (C_{sed}) :[10]

$$C_{sed} = \frac{(\chi_e)(WA_L)(C_{soil})(AT)}{(BD_{soil})(SD_{soil})(WA_w)} \qquad \text{--- (13)}$$

where the WA_L is watershed area contributing to runoff (m^2), AT is the accumulation time (yr), and WA_w is the area of waterbody receiving runoff (m^2).

b) Mercury concentrations in sediment - water due to deposition ($C_{sed\,(dep)}$) :[10]

$$C_{sed\,(dep)} = \frac{(\chi_e)(AT)(TD)}{(BD_{soil})(SD_{soil})} \qquad \text{--- (14)}$$

RESULTS

Figure 2 and 3 show the patterns and concentrations of mercury along the plume centerline for X - Z (100m x 50m scale), and X - Y (100m x 10m scale), respectively. The concentrations were calculated in every cell along both X - Z and X - Y axis These calculations (ng/m^3) were examples of the concentrations under neutral stability (D - stability) and u_s of 2 m/s. The plume spread slowly under neutral stability, thus GLC further away (downwind) from the incinerator at 3.7 to 5 km were the highest (approximately 28 ng/m^3).

WR was calculated from data of mercury concentrations in the air and rain collected by Greengerg *et al*. (1992)[14] Estimated WR was 5.04 x 10^3. Then, WD was approximately 4 2 x 10^{-4} g/m^2/yr The estimated DD using v_d of 0 006 cm/s was 5 29 x 10^{-5} g/m^2-yr. Thus, TD of atmospheric mercury to surfaces in the area was 4 73 x 10^{-4} g/m^2/yr

Estimated LS was 3 39 that was used to estimate χ_c of 27 8 g/m^2-yr BD$_{soil}$ is 0 01 m for standard assumption and deposited mercury is obviously retained at the soil surface,[15, 16] SD$_{soil}$ is 1300 Km/m^3 for the most likely value[10] Results showed the K_1 was 2 14 x 10^{-6} yr^{-1} and C_{soil} was 0.37 mg/kg K_{SE} was 0.35 ton/acre (assuming loam or silty loam).[13] The c value of 0.003, the most likely value, was used because the area around the incinerator was assumed to consist of 20 to 70% undisturbed land with greater than 40% litter cover. The default for P is 0.5[13] The D value of 0.4 was given by Bonazountas and Wagner (1984)[17] Estimated C_{sed} was 0.27 mg/kg and C_{water} was 0.063 mg/kg when WA_L of 10,000 m^2 and WA_W of 50,000 m^2 were used (derived from the GIS database of the surrounding watershed)[10] Thus, total mercury in sediment - water was approximatedly 0 33 mg/kg.

DISCUSSIONS AND CONCLUSIONS

Estimated (high) mercury concentrations of 28 ng/m^3 (regardless background concentrations) were higher than average in the U S (2 - 20 ng/m^3)[18] due to the near - source calculations and assumptions used in the calculations (no chemical reactions (loss), total mercury estimations). Background concentrations were reported by NJDEPE (1993) to be about 2 - 5 mg/m^3. WD of mercury accounted for 89% of TD because the wet deposition processes are an important removal process of soluble - mercury species (such as $HgCl_2$) near the incinerator In addition, C_{rain} and C_{air} data from Greenberg *et al* (1992) provided WR of 5 04 x 10^3 which is higher than data reported value (not in New Jersey) by Brosset (1987)[19] of 1 x 10^4 to 5 x 10^4 because the WR was derived from near - source measurement (2 to 3 km). From the results of the depositions, mercury in soil, and sediment - water of 0.37 to 0 33 mg/kg were also high comparing to another county (Atlantic County) soil samples (<0.062 to <0.089 mg/kg)[1, 2] Results from the calculations indicated that high levels of mercury can be found in the air, soil, and sediment - water in the vicinity of the incinerator Thus, the incinerator can be considered a major source of mercury pollution in the area in accordant with the reports by Aucott and Winka (1996), and NJDEPE (1993) Further information about mercury in biota, e.g., fish, can be calculated using bioconcentration factor available in literatures.

Application of Gaussian dispersion equation shows that is can be a very useful tool for preliminary estimation of mercury dispersion point sources for certain assumptions. More accurate calculations can be accomplished with complex models that account for chemical reactions of mercury or complex terrain. Universal loss equation, depositions, and other accumulation equations are some of the methods used by regulatory agencies to estimate the concentrations of mercury in the environment

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APPENDIX

Table 1. : Parameters used in calculations

Parameters	Values	Remarks
Q	0.013 μg/s	Premit Value (NJDEPE, 1993)
h	76.2 m	Radian Corporation (1989)
V_s	18.29 m/s	Martin (1988)
d	2.48 m	Radian Corporation (1989)
R	0.9	Reflection of plume 90% (assume 10% soluble)
P	9.87×10^{-3} kPa	Standard pressure (1 atm)
T_s	388.6°K	Martin (1988)
T_a	293°K	Standard temperature (20°C)
u_s	2 m/s	Chu (1996)
WR	5.04×10^3	Greenberg et al , 1992
R_f	1000 hr/yr	Chu (1996) NJ data
t_r	0.003 m/hr	Chu (1996) NJ data
V_d	0.006 cm/s	Lindberg etaal., 1992
S	0.0433 m/m	Most likely value (NJDEPE, 1993)
	2000 m	NJDEPT, (1993)
E_R	175 yr^{-1}	NJDEPE, (1993)
K_{SE}	0.35 ton/acre	NJDEPE, (1993)
c	0.003	Most likely value (NJDEPE, 1993)
P	0.5	NJDEPE, (1993)
D	0.4	Bonazauntas and Wagner, 1984
BD_{soil}	0.01 m	Standard value (NJDEPE, 1993)
SD_{soil}	1300 kg/m^3	Most likely value (NJDEPE, 1993)
AT	10 yr	NJDEPE, (1993)
WA_L	100,000 m^2	NJDEPE, (1993)
WA_W	50,000 m^2	NJDEPE, (1993)

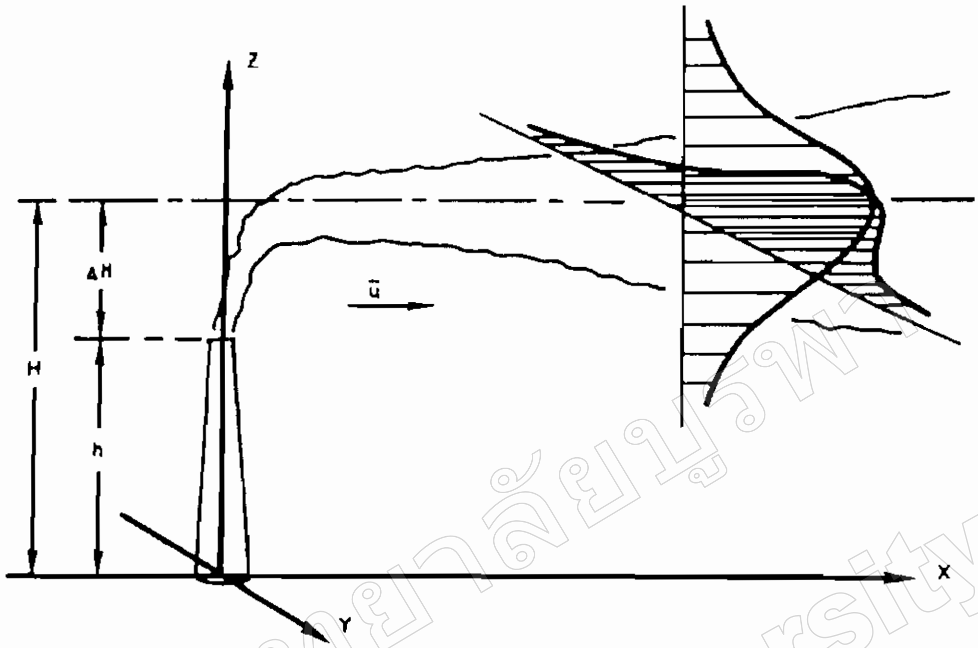

Figure 1 : Gaussian Plume Model

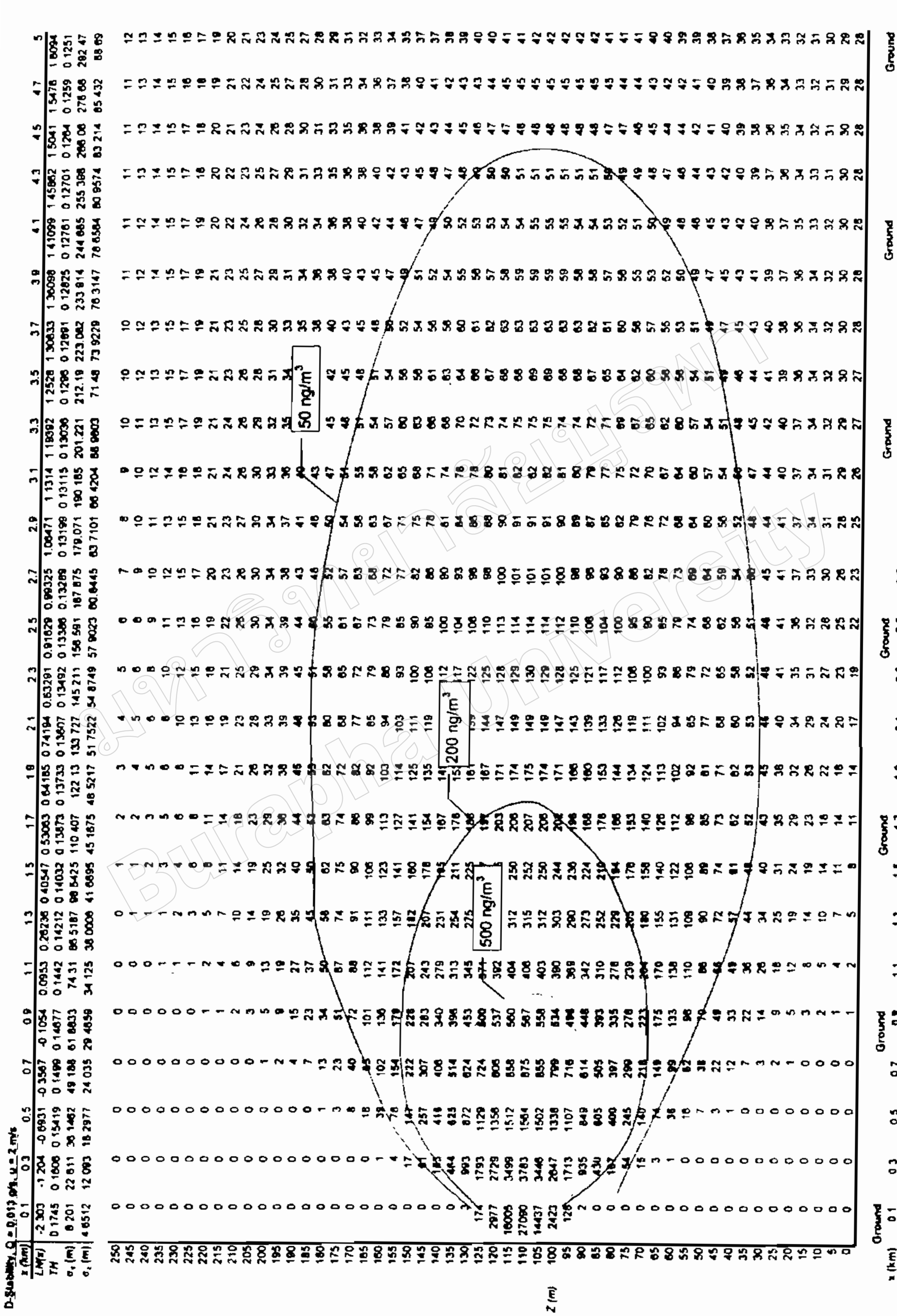

Figure 2: Estimated total mercury concentrations along x-z axis

D-Stability, Q = 0.013 m/s, u = 2 m/s

x (km)	0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	5
LN(x)	-2.3026	-1.204	-0.6931	-0.3567	-0.1054	0.0953	0.2624	0.4055	0.5306	0.6419	0.7419	0.8329	0.9163	0.99325	1.06471	1.1314	1.19392	1.25276	1.3083	1.36098	1.411	1.4586	1.5041	1.5476	1.60944
TH	0.1745	0.1606	0.1542	0.14994	0.14677	0.1442	0.1421	0.1403	0.1387	0.1373	0.1361	0.1349	0.1339	0.13289	0.13199	0.1311	0.13036	0.12961	0.1289	0.12825	0.1276	0.127	0.1264	0.1259	0.12511
σ_y (m)	8.201	22.611	36.146	49.1882	61.8833	74.31	86.519	98.542	110.41	122.13	133.73	145.21	156.59	167.875	179.071	190.18	201.221	212.186	223.08	233.914	244.69	255.4	266.06	276.66	292.472
σ_z (m)	4.6512	12.093	18.298	24.0351	29.4659	34.125	38.001	41.67	45.168	48.522	51.752	54.875	57.902	60.8445	63.7101	66.42	68.9803	71.4795	73.923	76.3147	78.658	80.957	83.214	85.432	88.6902
-250	0	0	0	0	0	1	5	10	16	21	26	29	32	33	34	35	34	34	33	33	32	31	30	29	28
-240	0	0	0	0	0	2	7	13	20	25	30	33	35	36	37	37	37	36	35	34	33	32	31	30	28
-230	0	0	0	0	1	3	9	17	24	30	34	37	39	40	40	39	39	38	37	36	35	33	32	31	29
-220	0	0	0	0	1	5	12	21	28	34	39	41	43	43	43	42	41	40	39	37	36	35	33	32	30
-210	0	0	0	0	2	8	17	26	34	40	44	46	46	46	46	45	43	42	40	39	37	36	34	33	31
-200	0	0	0	0	3	11	22	32	40	46	49	50	50	50	49	47	45	44	42	[illegible]	[illegible]	37	35	34	32
-190	0	0	0	1	5	16	28	39	47	52	54	55	55	53	52	50	48	46	44	[illegible]	[illegible]	38	36	35	32
-180	0	0	0	1	8	22	36	48	55	59	60	60	59	57	55	52	50	48	45	43	41	39	37	35	33
-170	0	0	0	2	13	30	46	57	63	66	67	65	63	61	58	55	52	49	47	45	42	40	38	36	34
-160	0	0	0	4	20	40	57	67	73	74	73	71	68	64	61	57	54	51	49	46	43	41	39	37	34
-150	0	0	0	8	30	53	70	79	82	82	80	76	72	68	64	60	56	53	50	47	45	42	40	38	35
-140	0	0	1	15	44	69	85	92	93	90	86	82	77	[illegible]	[illegible]	62	59	55	52	48	46	43	41	39	36
-130	0	0	2	27	62	88	102	106	104	99	93	87	81	[illegible]	[illegible]	65	60	57	53	50	47	44	41	39	36
-120	0	0	6	45	87	111	120	120	115	108	100	92	85	[illegible]	[illegible]	67	62	58	54	51	48	45	42	40	37
-110	0	0	15	72	117	136	140	135	126	116	107	97	89	82	75	69	64	60	56	52	49	46	43	40	37
100	0	0	34	111	154	165	161	151	138	125	113	102	93	85	78	71	66	61	57	53	49	46	44	41	38
110	0	0	15	72	117	136	140	135	126	116	107	97	89	82	75	69	64	60	56	52	49	46	43	40	37
120	0	0	6	45	87	111	120	120	115	108	100	92	85	78	72	67	62	58	54	51	48	45	42	40	37
130	0	0	2	27	62	88	102	106	104	99	93	87	81	75	70	65	60	57	53	50	47	44	41	39	36
140	0	0	1	15	44	69	85	92	93	90	86	82	77	72	67	62	59	55	52	48	46	43	41	39	36
150	0	0	0	8	30	53	70	79	82	82	80	76	72	68	64	60	56	53	50	47	45	42	40	38	35
160	0	0	0	4	20	40	57	67	73	74	73	71	68	64	61	57	54	51	49	46	43	41	39	37	34
170	0	0	0	2	13	30	46	57	63	66	67	65	63	61	58	55	52	49	47	45	42	40	38	36	34
180	0	0	0	1	8	22	36	48	55	59	60	60	59	57	55	52	50	48	45	43	41	39	37	35	33
190	0	0	0	1	5	16	28	39	47	52	54	55	55	53	52	50	48	46	44	42	40	38	36	35	32
200	0	0	0	0	3	11	22	32	40	46	49	50	50	60	49	47	45	44	42	40	38	37	35	34	32
210	0	0	0	0	2	8	17	26	34	40	[illegible]	[illegible]	46	46	46	45	43	42	40	39	37	36	34	33	31
220	0	0	0	0	1	5	12	21	28	34	[illegible]	[illegible]	43	43	43	42	41	40	39	37	36	35	33	32	30
230	0	0	0	0	1	3	9	17	24	30	34	37	39	40	40	39	39	38	37	36	35	33	32	31	29
240	0	0	0	0	0	2	7	13	20	25	30	33	35	36	37	37	37	36	35	34	33	32	31	30	28
250	0	0	0	0	0	1	5	10	16	21	26	29	32	33	34	35	34	34	33	33	32	31	30	29	28
	Ground				Ground				Ground				Ground				Ground				Ground				Ground
x (km)	0.1	0.3	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	5

Y (m)

100 ng/m3

50 ng/m3

20 ng/m3

Figure 3: Estimated total mercury concentrations along x-y axis