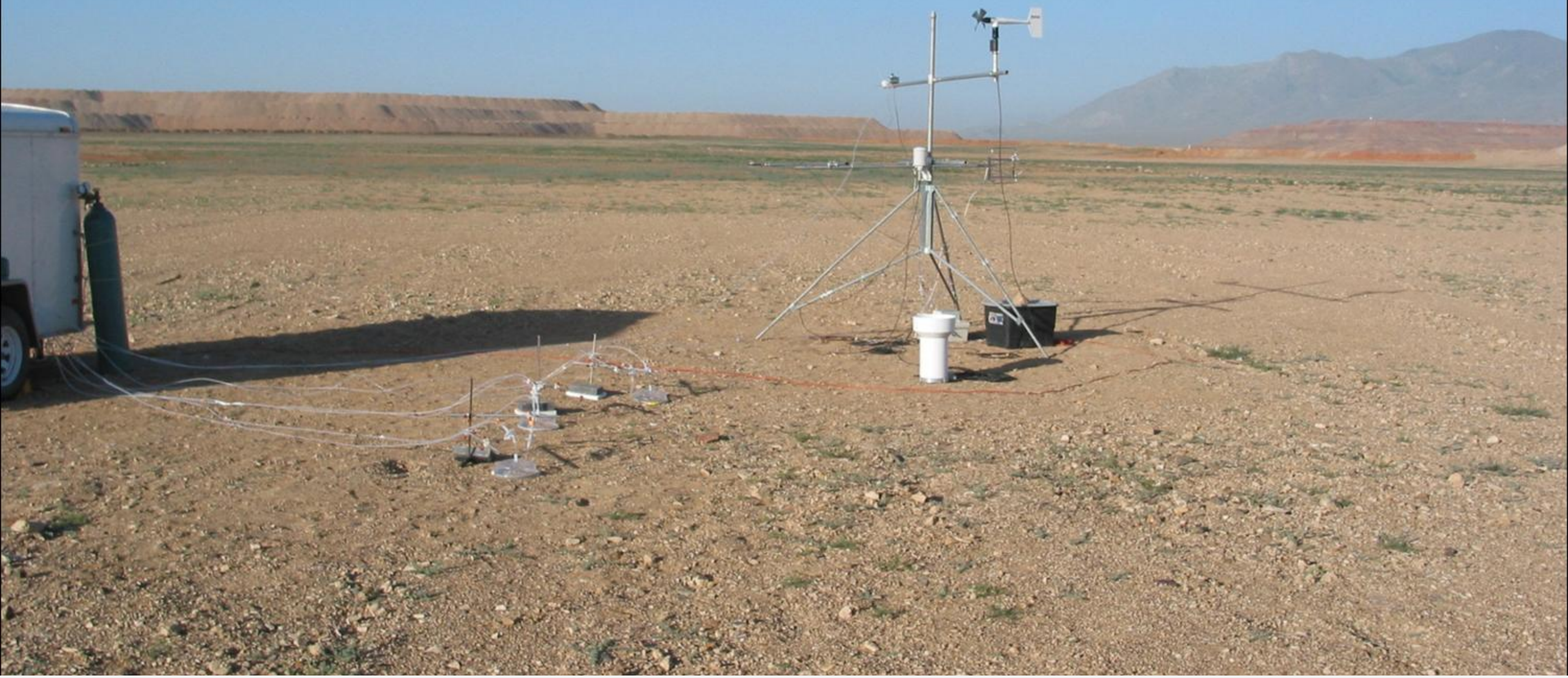
Mercury Flux Measurements Methods in Nevada, USA

Eckley, C.S[a]., Gustin, M[a]., Lin, C.-J.[b], Li, X.[c] , Miller, M.B.[a]



[a]Department of Natural Resources & Environmental Science, University of Nevada, Reno, NV USA
[b]Department of Civil Engineering, Lamar University, USA
[c]Department of Mechanical Engineering, Lamar University, USA

Presentation Outline

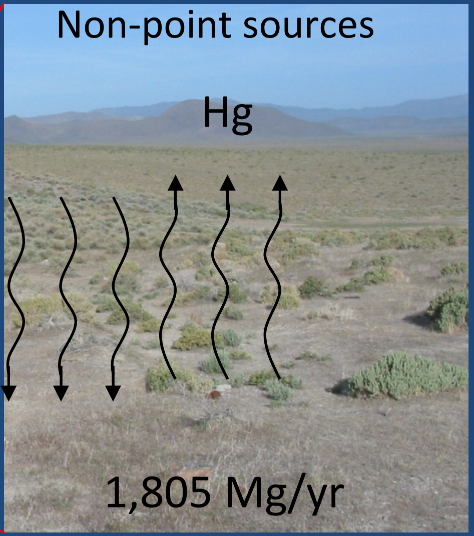
- Introduction to surface-air fluxes
- Measurements
  - Equipment
  - Site conditions
  - Data interpretation
- Flux chamber design experiments

Introduction: surface-air fluxes

Terrestrial non-point source emissions are an important component of the global Hg cycle

Table 1.28 -Total mercury emissions by source category.

Region	Hg emission in atmosphere (Mg y^{-1})	Reference year	Reference
Natural			
Oceans	2682	2008	Mason, 2008
Lakes	96	2008	Mason, 2008
Forest	342	2008	Mason, 2008
Tundra/Grassland/Savannah/Prairie/Chaparral	448	2008	Mason, 2008
Desert/Metalliferrous/ Non-vegetated Zones	546	2008	Mason, 2008
Agricultural areas	128	2008	Mason, 2008
Evasion after mercury depletion events	200	2008	Mason, 2008
Biomass burning	675	2008	Friedli et al., 2008
Volcanoes and geothermal areas	90	2008	Mason, 2008
Total (Natural)	**5207**		
Anthropogenic			
Coal combustion, oil combustion	1422	2000	Pacyna et al., 2006b
Pig iron and steel production	31	2000	Pacyna et al., 2006b
Non-ferrous metal production	156	2007	USGS, 2004
Caustic soda production	65	2000	Pacyna et al., 2006b
Cement production	140	2000	Pacyna et al., 2006b
Coal bed fires	6	2007	This work
Waste disposal	166	2007	This work
Mercury production	50	2007	This work
Artisanal gold mining production	400	2007	Telmer and Veiga, 2008
Other	65	2007	This work
Total (Anthropogenic)	**2503**		
Total (Natural + Anthropogenic)	**7710**		



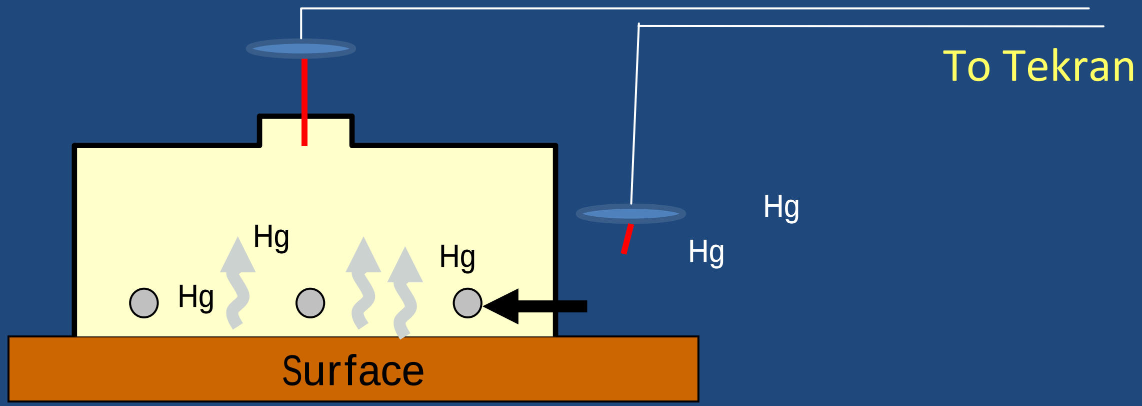
Source: UNEP Global Hg Partnership Interim Report, 2008

Introduction: surface-air fluxes

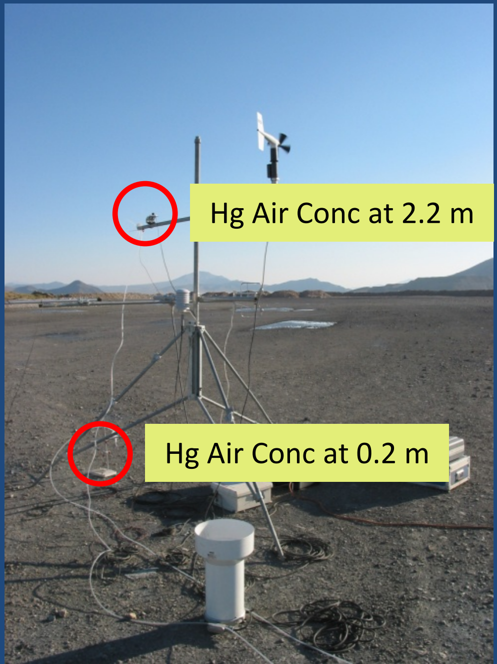
2 main methods used to measure surface-air Hg flux:

1) Dynamic Flux Chambers (DFC)

Flux = $(C_{inside} - C_{outside}) * (Q/A)$



2) Micrometeorological Gradient Method



Set-up: Equipment

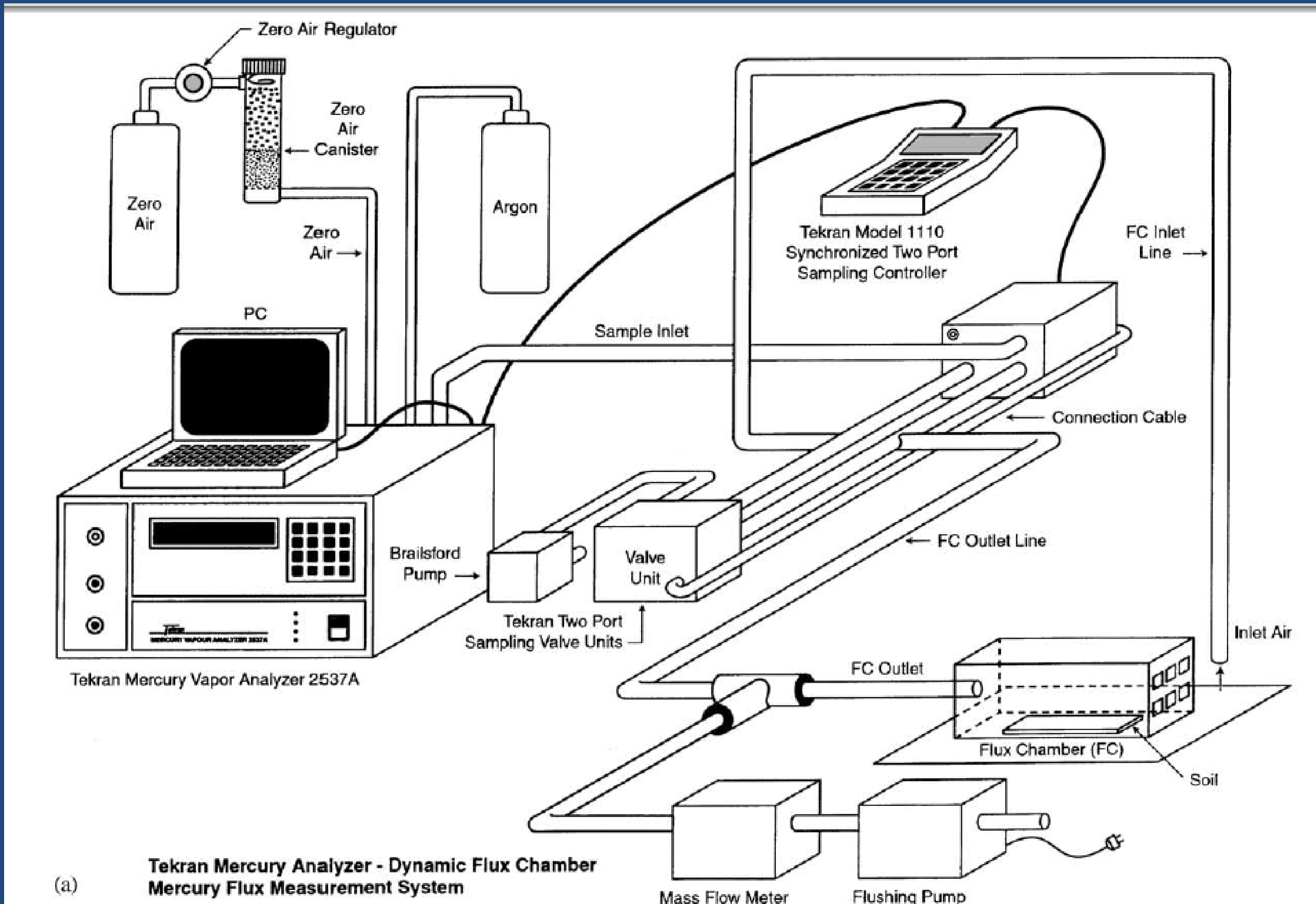


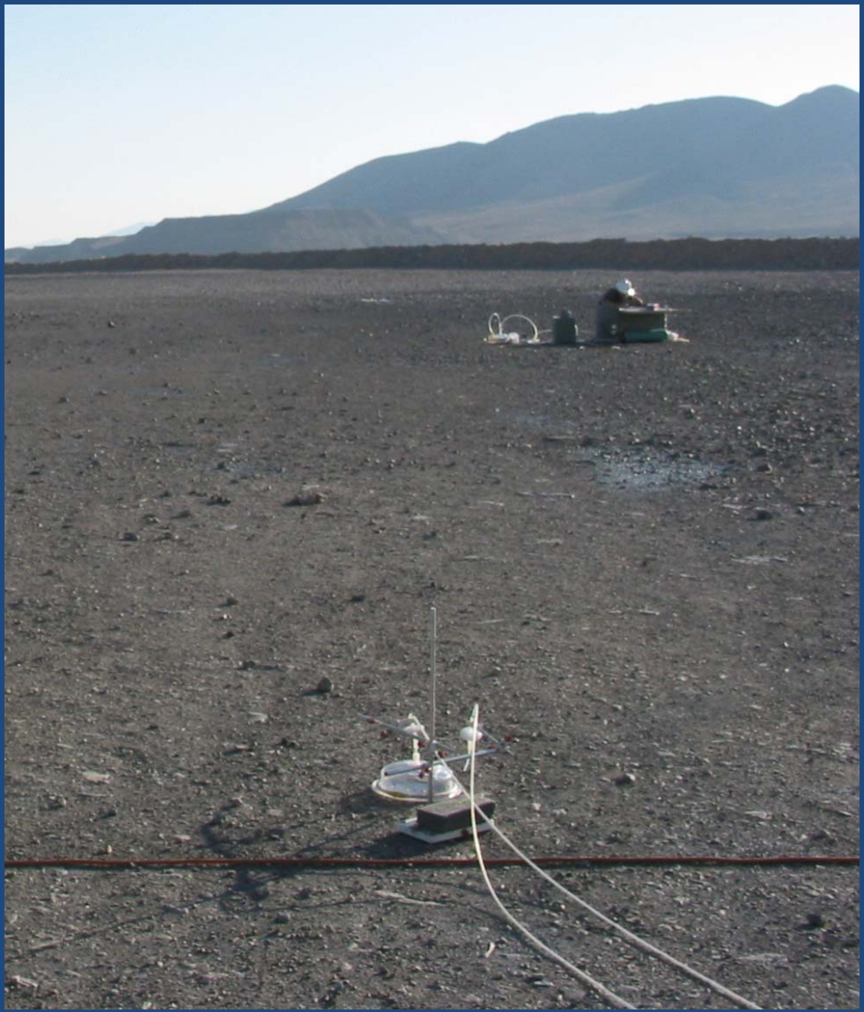
Figure from Lindberg et al., 2002

Set-up: Equipment

- Tekran 2537A/B Mercury Vapour Analyzer
- Tekran Model 1110 Synchronized Two Port Sampling System (TADS)
- Tekran 2505 Mercury Vapour Calibration Unit
- Generator (Honda EU2000iA)
- Line conditioner (Tripp Lite Line Conditioner)
- Surge protector
- Argon gas
- Flush pump(s)
- Flow meter
- Teflon tubing (insulation)
- Teflon tape
- Silicon tubing connectors
- Soda lime traps
- Air filters (0.22 µm;PTFE)
- Fan/heaters
- Laptop computer
- Dynamic Flux Chamber

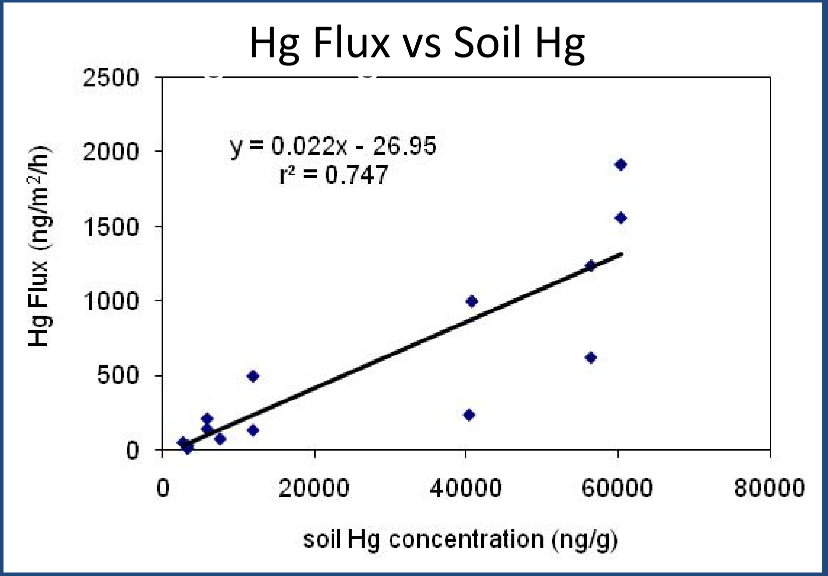
Set-up: Equipment

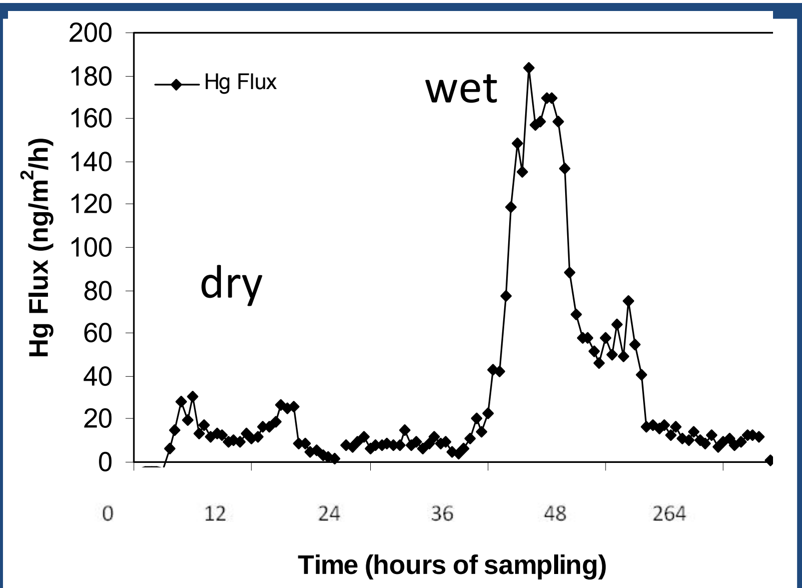
Set-up: Equipment



Set-up: Equipment

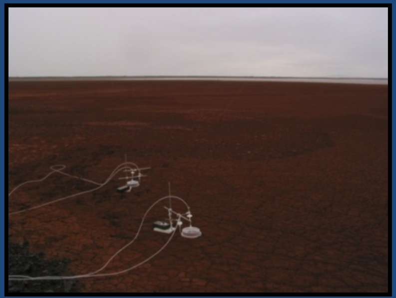
- Ancillary data:
  - Meteorological Measurements
    - Solar radiation
    - Temperature
    - Relative humidity
    - Wind speed/direction
    - Precipitation (tipping bucket)
  - Soil moisture content
  - Soil Hg conc. under chamber





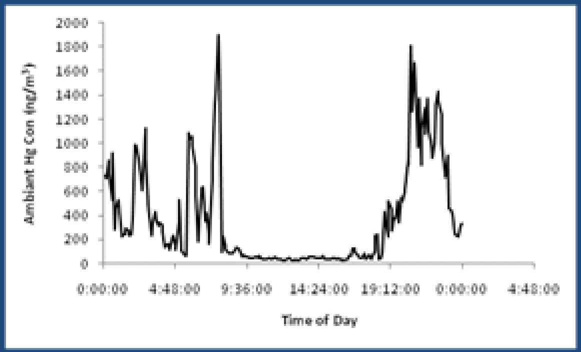
Set-up: Sampling Considerations

- Location
  - —Surface variability (important for scaling)
  - – Stable ambient air concentrations

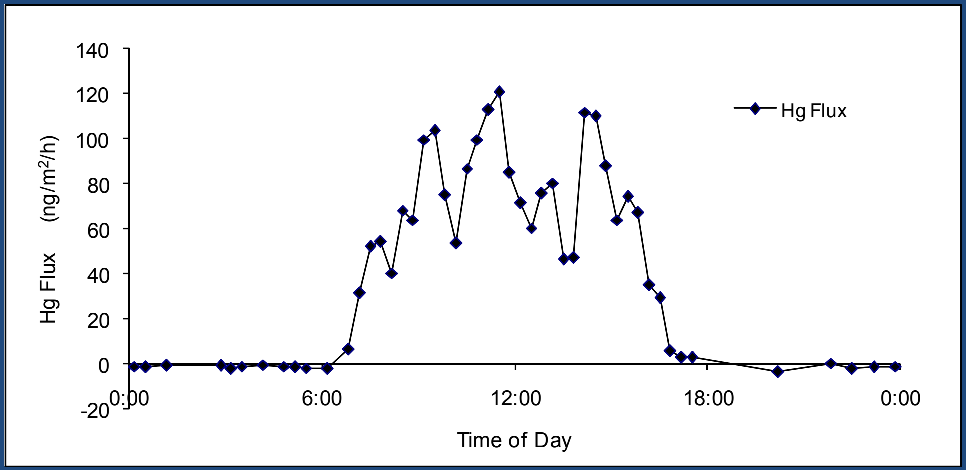


- 24 hour measurements
- Seasonal measurements

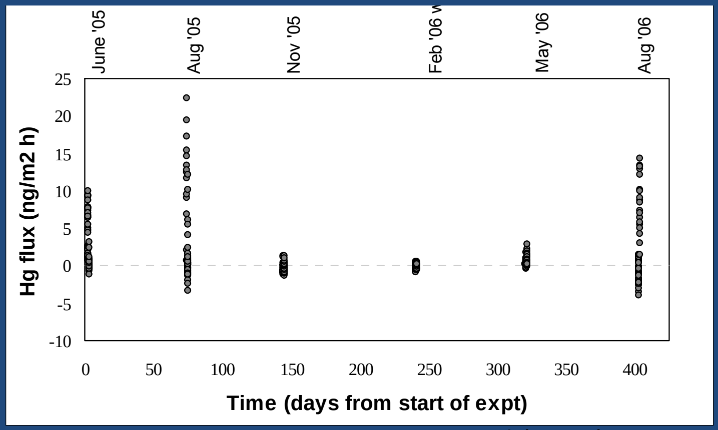
Variable Hg Air Concentrations



24 hour Flux Data



Seasonal Hg Flux

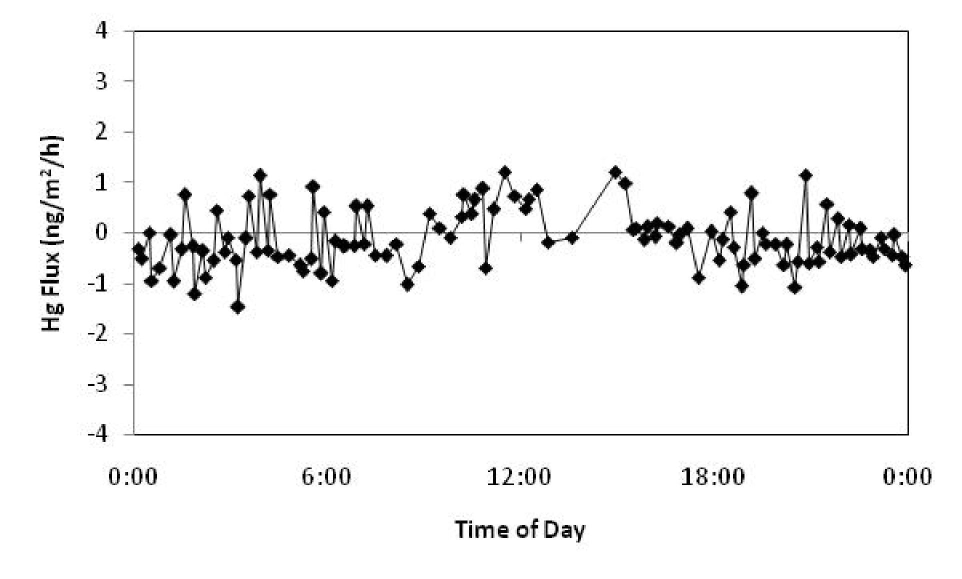


Gustin et al (2008) JAWMA

Set-up: Equipment

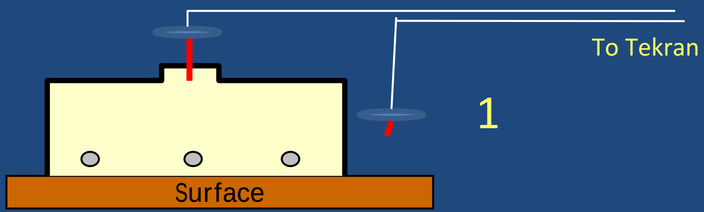
- Chamber blanks

Blank chamber: similar conditions to sampling



Sample Results—Good Data

$$\text{Flux} = (C_{inside} - C_{outside}) * (Q/A)$$

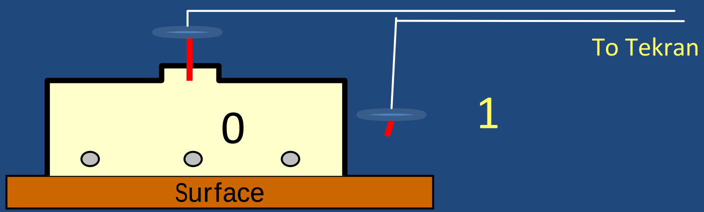


Inlet Air

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Area:	0.0363	m^2		Flow Rate:		0.17	m^3/h									
2											..	Air Hg		Hg Flux			Hg Flux
3	Date	Time	C	St	at	AdTim	Vol	Bl	BlDev	MaxV	Area	ng/m^3	Delta C	$ng/m^2/h$	IF 1	IF 2	$ng/m^2/h$
4	11/08/2009	00:40:00	B	OK	1	300	7.52	0.1	0.069	0.085	95612	3					
5	11/08/2009	00:45:00	A	OK	1	300	7.51	0.1	0.055	0.076	82893	2					
6	11/08/2009	00:50:00	B	OK	0	300	7.51	0.1	0.05	0.309	887154	25	22	106	106	106	106
7	11/08/2009	00:55:00	A	OK	0	300	7.5	0.1	0.053	0.264	861989	25					
8	11/08/2009	01:00:00	B	OK	1	300	7.52	0.1	0.047	0.085	95413	3					
9	11/08/2009	01:05:00	A	OK	1	300	7.5	0.1	0.075	0.075	81567	2					
10	11/08/2009	01:10:00	B	OK	0	300	7.51	0.1	0.085	0.314	915034	26	23	108	108	108	108
11	11/08/2009	01:15:00	A	OK	0	300	7.5	0.1	0.049	0.263	870156	25					
12	11/08/2009	01:20:00	B	OK	1	300	7.52	0.1	0.042	0.09	113395	3					
13	11/08/2009	01:25:00	A	OK	1	300	7.51	0.1	0.049	0.083	108953	3					
14	11/08/2009	01:30:00	B	OK	0	300	7.51	0.1	0.059	0.299	853990	24	21	102	102	102	102
15	11/08/2009	01:35:00	A	OK	0	300	7.5	0.1	0.051	0.261	861292	25					
16	11/08/2009	01:40:00	B	OK	1	300	7.52	0.1	0.061	0.086	103240	3					
17	11/08/2009	01:45:00	A	OK	1	300	7.5	0.1	0.058	0.076	78507	2					
18	11/08/2009	01:50:00	B	OK	0	300	7.51	0.1	0.061	0.31	885222	25	23	108	108	108	108
19	11/08/2009	01:55:00	A	OK	0	300	7.5	0.1	0.058	0.273	904459	26					
20	11/08/2009	02:00:00	B	OK	1	300	7.52	0.1	0.095	0.088	113083	3					
21	11/08/2009	02:05:00	A	OK	1	300	7.51	0.1	0.054	0.076	81343	2					
22	11/08/2009	02:10:00	B	OK	0	300	7.51	0.1	0.054	0.283	784360	22	20	97	97	97	97
23	11/08/2009	02:15:00	A	OK	0	300	7.5	0.1	0.06	0.257	834566	24					
24	11/08/2009	02:20:00	B	OK	1	300	7.52	0.1	0.056	0.084	99419	3					
25	11/08/2009	02:25:00	A	OK	1	300	7.5	0.1	0.068	0.076	78537	2					
26	11/08/2009	02:30:00	B	OK	0	300	7.51	0.1	0.044	0.323	912577	26	23	111	111	111	111
27	11/08/2009	02:35:00	A	OK	0	300	7.5	0.1	0.047	0.276	913834	26					
28	11/08/2009	02:40:00	B	OK	1	300	7.52	0.1	0.055	0.087	109512	3					
29	11/08/2009	02:45:00	A	OK	1	300	7.51	0.1	0.049	0.079	96339	3					
30	11/08/2009	02:50:00	B	OK	0	300	7.51	0.1	0.051	0.313	895404	25	22	106	106	106	106

Sample Results—Good Data

$$\text{Flux} = (C_{inside} - C_{outside}) * (Q/A)$$



Outlet Air

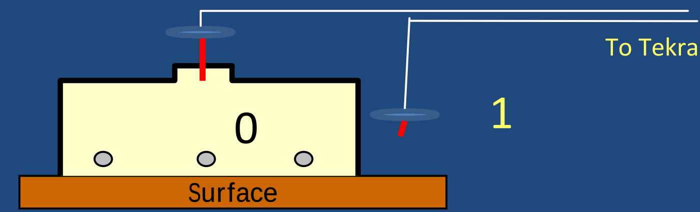
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Area:	0.0363	m^2		Flow Rate:		0.17	m^3/h									
2											..	Air Hg		Hg Flux			Hg Flux
3	Date	Time	C	St	at	AdTim	Vol	Bl	BlDev	MaxV	Area	ng/m^3	Delta C	$ng/m^2/h$	IF 1	IF 2	$ng/m^2/h$
4	11/08/2009	00:40:00	B	OK		300	7.52	0.1	0.069	0.085	95612	3					
5	11/08/2009	00:45:00	A	OK		300	7.51	0.1	0.055	0.076	82893	2					
6	11/08/2009	00:50:00	B	OK	0	300	7.51	0.1	0.05	0.309	887154	25	22	106	106	106	106
7	11/08/2009	00:55:00	A	OK	0	300	7.5	0.1	0.053	0.264	861989	25					
8	11/08/2009	01:00:00	B	OK	1	300	7.52	0.1	0.047	0.085	95413	3					
9	11/08/2009	01:05:00	A	OK	1	300	7.5	0.1	0.075	0.075	81567	2					
10	11/08/2009	01:10:00	B	OK	0	300	7.51	0.1	0.085	0.314	915034	26	23	108	108	108	108
11	11/08/2009	01:15:00	A	OK	0	300	7.5	0.1	0.049	0.263	870156	25					
12	11/08/2009	01:20:00	B	OK	1	300	7.52	0.1	0.042	0.09	113395	3					
13	11/08/2009	01:25:00	A	OK	1	300	7.51	0.1	0.049	0.083	108953	3					
14	11/08/2009	01:30:00	B	OK	0	300	7.51	0.1	0.059	0.299	853990	24	21	102	102	102	102
15	11/08/2009	01:35:00	A	OK	0	300	7.5	0.1	0.051	0.261	861292	25					
16	11/08/2009	01:40:00	B	OK	1	300	7.52	0.1	0.061	0.086	103240	3					
17	11/08/2009	01:45:00	A	OK	1	300	7.5	0.1	0.058	0.076	78507	2					
18	11/08/2009	01:50:00	B	OK	0	300	7.51	0.1	0.061	0.31	885222	25	23	108	108	108	108
19	11/08/2009	01:55:00	A	OK	0	300	7.5	0.1	0.058	0.273	904459	26					
20	11/08/2009	02:00:00	B	OK	1	300	7.52	0.1	0.095	0.088	113083	3					
21	11/08/2009	02:05:00	A	OK	1	300	7.51	0.1	0.054	0.076	81343	2					
22	11/08/2009	02:10:00	B	OK	0	300	7.51	0.1	0.054	0.283	784360	22	20	97	97	97	97
23	11/08/2009	02:15:00	A	OK	0	300	7.5	0.1	0.06	0.257	834566	24					
24	11/08/2009	02:20:00	B	OK	1	300	7.52	0.1	0.056	0.084	99419	3					
25	11/08/2009	02:25:00	A	OK	1	300	7.5	0.1	0.068	0.076	78537	2					
26	11/08/2009	02:30:00	B	OK	0	300	7.51	0.1	0.044	0.323	912577	26	23	111	111	111	111
27	11/08/2009	02:35:00	A	OK	0	300	7.5	0.1	0.047	0.276	913834	26					
28	11/08/2009	02:40:00	B	OK	1	300	7.52	0.1	0.055	0.087	109512	3					
29	11/08/2009	02:45:00	A	OK	1	300	7.51	0.1	0.049	0.079	96339	3					
30	11/08/2009	02:50:00	B	OK	0	300	7.51	0.1	0.051	0.313	895404	25	22	106	106	106	106

Sample Results—Good Data

Delta C

AVE (25, 25)- AVE(2,3) = 22 (ng/m^3)

Flux = $(C_{inside}-C_{outside})*(Q/A)$



Flux Calculation

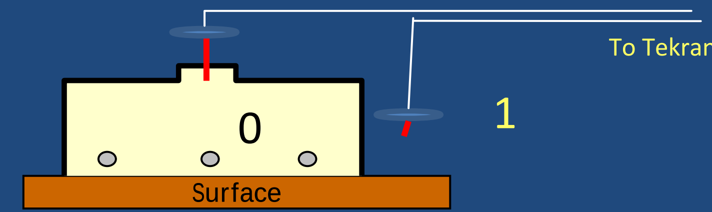
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Area:	0.0363	m^2		Flow Rate:		0.17	m^3/h									
2											..	Air Hg		Hg Flux			Hg Flux
3	Date	Time	C	St	at	AdTim	Vol	Bl	BlDev	MaxV	Area	ng/m^3	Delta C	ng/m^2/h	IF 1	IF 2	ng/m^2/h
4	11/08/2009	00:40:00	B	OK	1	300	7.52	0.1	0.069	0.085	95612	3					
5	11/08/2009	00:45:00	A	OK	1	300	7.51	0.1	0.055	0.076	82893	2					
6	11/08/2009	00:50:00	B	OK	0	300	7.51	0.1	0.05	0.309	887154	25	22	106	106	106	106
7	11/08/2009	00:55:00	A	OK	0	300	7.5	0.1	0.053	0.264	861989	25					
8	11/08/2009	01:00:00	B	OK	1	300	7.52	0.1	0.047	0.085	95413	3					
9	11/08/2009	01:05:00	A	OK	1	300	7.5	0.1	0.075	0.075	81567	2					
10	11/08/2009	01:10:00	B	OK	0	300	7.51	0.1	0.085	0.314	915034	26	23	108	108	108	108
11	11/08/2009	01:15:00	A	OK	0	300	7.5	0.1	0.049	0.263	870156	25					
12	11/08/2009	01:20:00	B	OK	1	300	7.52	0.1	0.042	0.09	113395	3					
13	11/08/2009	01:25:00	A	OK	1	300	7.51	0.1	0.049	0.083	108953	3					
14	11/08/2009	01:30:00	B	OK	0	300	7.51	0.1	0.059	0.299	853990	24	21	102	102	102	102
15	11/08/2009	01:35:00	A	OK	0	300	7.5	0.1	0.051	0.261	861292	25					
16	11/08/2009	01:40:00	B	OK	1	300	7.52	0.1	0.061	0.086	103240	3					
17	11/08/2009	01:45:00	A	OK	1	300	7.5	0.1	0.058	0.076	78507	2					
18	11/08/2009	01:50:00	B	OK	0	300	7.51	0.1	0.061	0.31	885222	25	23	108	108	108	108
19	11/08/2009	01:55:00	A	OK	0	300	7.5	0.1	0.058	0.273	904459	26					
20	11/08/2009	02:00:00	B	OK	1	300	7.52	0.1	0.095	0.088	113083	3					
21	11/08/2009	02:05:00	A	OK	1	300	7.51	0.1	0.054	0.076	81343	2					
22	11/08/2009	02:10:00	B	OK	0	300	7.51	0.1	0.054	0.283	784360	22	20	97	97	97	97
23	11/08/2009	02:15:00	A	OK	0	300	7.5	0.1	0.06	0.257	834566	24					
24	11/08/2009	02:20:00	B	OK	1	300	7.52	0.1	0.056	0.084	99419	3					
25	11/08/2009	02:25:00	A	OK	1	300	7.5	0.1	0.068	0.076	78537	2					
26	11/08/2009	02:30:00	B	OK	0	300	7.51	0.1	0.044	0.323	912577	26	23	111	111	111	111
27	11/08/2009	02:35:00	A	OK	0	300	7.5	0.1	0.047	0.276	913834	26					
28	11/08/2009	02:40:00	B	OK	1	300	7.52	0.1	0.055	0.087	109512	3					
29	11/08/2009	02:45:00	A	OK	1	300	7.51	0.1	0.049	0.079	96339	3					
30	11/08/2009	02:50:00	B	OK	0	300	7.51	0.1	0.051	0.313	895404	25	22	106	106	106	106

Sample Results—Good Data

Flux

$$\text{Flux} = (C_{inside} - C_{outside}) * (Q/A)$$

$$22\ (ng/m^3) \times 0.17\ (m^3/h) \div 0.036\ (m^2) = 106\ (ng/m^2/h)$$

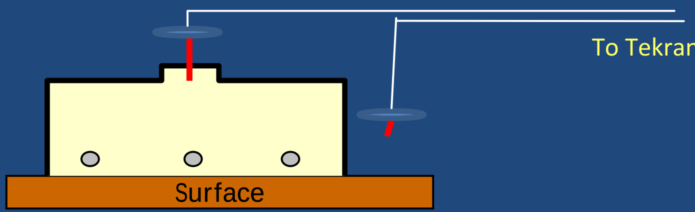


Flux Calculation

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Area:	0.0363	m^2		Flow Rate:		0.17	m^3/h									
2											..	Air Hg		Hg Flux			Hg Flux
3	Date	Time	C	St	at	AdTim	Vol	Bl	BlDev	MaxV	Area	ng/m^3	Delta C	$ng/m^2/h$	IF 1	IF 2	$ng/m^2/h$
4	11/08/2009	00:40:00	B	OK	1	300	7.52	0.1	0.069	0.085	95612	3					
5	11/08/2009	00:45:00	A	OK	1	300	7.51	0.1	0.055	0.076	82893	2					
6	11/08/2009	00:50:00	B	OK	0	300	7.51	0.1	0.05	0.309	887154	25	22	106	106	106	106
7	11/08/2009	00:55:00	A	OK	0	300	7.5	0.1	0.053	0.264	861989	25					
8	11/08/2009	01:00:00	B	OK	1	300	7.52	0.1	0.047	0.085	95413	3					
9	11/08/2009	01:05:00	A	OK	1	300	7.5	0.1	0.075	0.075	81567	2					
10	11/08/2009	01:10:00	B	OK	0	300	7.51	0.1	0.085	0.314	915034	26	23	108	108	108	108
11	11/08/2009	01:15:00	A	OK	0	300	7.5	0.1	0.049	0.263	870156	25					
12	11/08/2009	01:20:00	B	OK	1	300	7.52	0.1	0.042	0.09	113395	3					
13	11/08/2009	01:25:00	A	OK	1	300	7.51	0.1	0.049	0.083	108953	3					
14	11/08/2009	01:30:00	B	OK	0	300	7.51	0.1	0.059	0.299	853990	24	21	102	102	102	102
15	11/08/2009	01:35:00	A	OK	0	300	7.5	0.1	0.051	0.261	861292	25					
16	11/08/2009	01:40:00	B	OK	1	300	7.52	0.1	0.061	0.086	103240	3					
17	11/08/2009	01:45:00	A	OK	1	300	7.5	0.1	0.058	0.076	78507	2					
18	11/08/2009	01:50:00	B	OK	0	300	7.51	0.1	0.061	0.31	885222	25	23	108	108	108	108
19	11/08/2009	01:55:00	A	OK	0	300	7.5	0.1	0.058	0.273	904459	26					
20	11/08/2009	02:00:00	B	OK	1	300	7.52	0.1	0.095	0.088	113083	3					
21	11/08/2009	02:05:00	A	OK	1	300	7.51	0.1	0.054	0.076	81343	2					
22	11/08/2009	02:10:00	B	OK	0	300	7.51	0.1	0.054	0.283	784360	22	20	97	97	97	97
23	11/08/2009	02:15:00	A	OK	0	300	7.5	0.1	0.06	0.257	834566	24					
24	11/08/2009	02:20:00	B	OK	1	300	7.52	0.1	0.056	0.084	99419	3					
25	11/08/2009	02:25:00	A	OK	1	300	7.5	0.1	0.068	0.076	78537	2					
26	11/08/2009	02:30:00	B	OK	0	300	7.51	0.1	0.044	0.323	912577	26	23	111	111	111	111
27	11/08/2009	02:35:00	A	OK	0	300	7.5	0.1	0.047	0.276	913834	26					
28	11/08/2009	02:40:00	B	OK	1	300	7.52	0.1	0.055	0.087	109512	3					
29	11/08/2009	02:45:00	A	OK	1	300	7.51	0.1	0.049	0.079	96339	3					
30	11/08/2009	02:50:00	B	OK	0	300	7.51	0.1	0.051	0.313	895404	25	22	106	106	106	106

Sample Results—Bad Data

Flux = $(C_{inside}-C_{outside})*(Q/A)$



Criteria for accepting/rejecting a flux:

1) The delta C must be larger than the difference between the 2 inlets

16 ~~(ng/m^3) > 29 (ng/m^3)~~ Cannot Accurately Calculate Flux

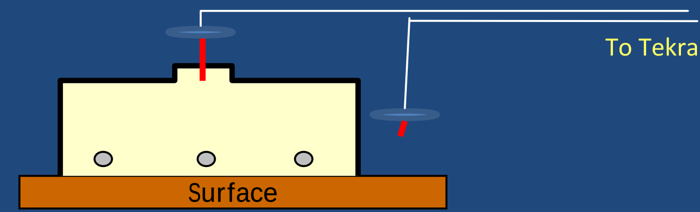
2) The difference between the 2 outlets must be smaller than the outlet average

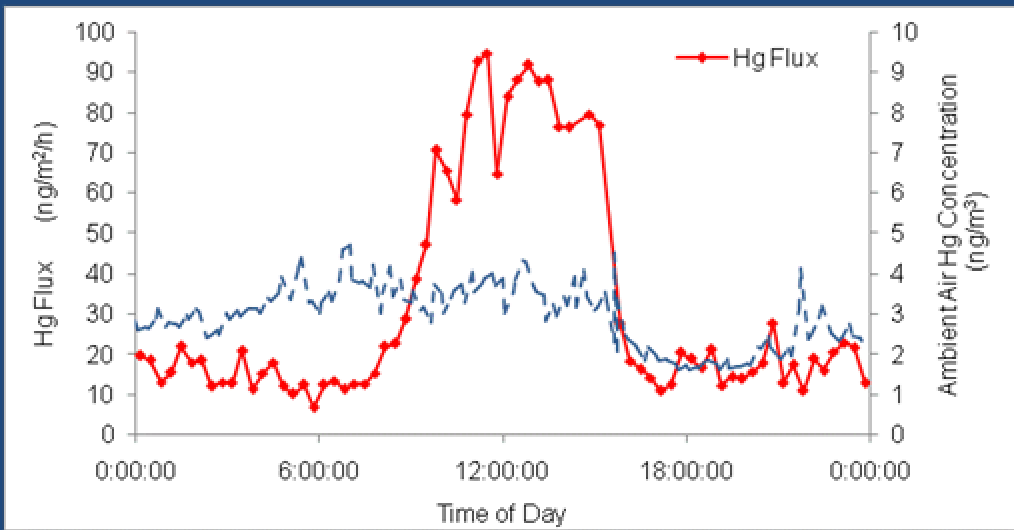
~~258-74 = **184** (ng/m^3) < AVE(258,74) = **166** (ng/m^3)~~ Cannot Accurately Calculate Flux

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Area:	0.0363	m^2			Flow:	0.13	m^3/h									
2																	
3												Air Hg		Hg Flux			Hg Flux
4	Date	Time	C	St	at	AdTim	Vol	Bl	BlDev	MaxV	Area	ng/m^3	Delta C	$ng/m^2/h$	IF 1	IF 2	$ng/m^2/h$
5	08/08/2016	16:46:09	B	OK	1	200	5.01	0.1	0.123	0.957	3210060	121					
6	08/08/2016	16:49:29	A	OK	1	200	4.99	0.1	0.09	0.815	2501217	93					
7	08/08/2016	16:52:49	B	OK	0	200	5.01	0.1	0.136	0.77	2485235	93	16	57	0	57	0
8	08/08/2016	16:56:09	A	OK	0	200	4.97	0.1	0.089	0.827	2554109	95					
9	08/08/2016	16:59:29	B	OK	1	200	5.01	0.1	0.123	0.571	1708969	64					
10	08/08/2016	17:02:49	A	OK	1	200	4.99	0.1	0.104	0.462	1267019	47					
11	08/08/2016	17:06:09	B	OK	0	200	5.01	0.1	0.09	0.455	1289769	48	6	22	0	22	0
12	08/08/2016	17:09:29	A	OK	0	200	4.96	0.1	0.045	0.486	1348077	50					
13	08/08/2016	17:12:49	B	OK	1	200	5.01	0.1	0.107	0.387	1055121	40					
14	08/08/2016	17:16:09	A	OK	1	200	4.98	0.1	0.067	0.441	1179188	44					
15	08/08/2016	17:19:29	B	OK	0	200	5.01	0.1	0.099	0.427	1183827	45	7	25	0	25	0
16	08/08/2016	17:22:49	A	OK	0	200	4.96	0.1	0.073	0.818	2520397	94					
17	08/08/2016	17:26:09	B	OK	1	200	5.01	0.1	0.141	0.691	2156632	81					
18	08/08/2016	17:42:49	A	OK	1	200	4.98	0.1	0.07	0.612	1786474	66					
19	08/08/2016	17:46:09	B	OK	0	200	5.01	0.1	0.111	1.938	6861453	258	119	430	430	0	0
20	08/08/2016	17:49:29	A	OK	0	200	4.96	0.1	0.15	0.668	1964540	73					
21	08/08/2016	17:52:49	B	OK	1	200	5.01	0.1	0.151	0.297	709723	27					
22	08/08/2016	17:56:09	A	OK	1	200	4.98	0.1	0.065	0.441	1197234	45					

Sample Results—Good & Bad Data

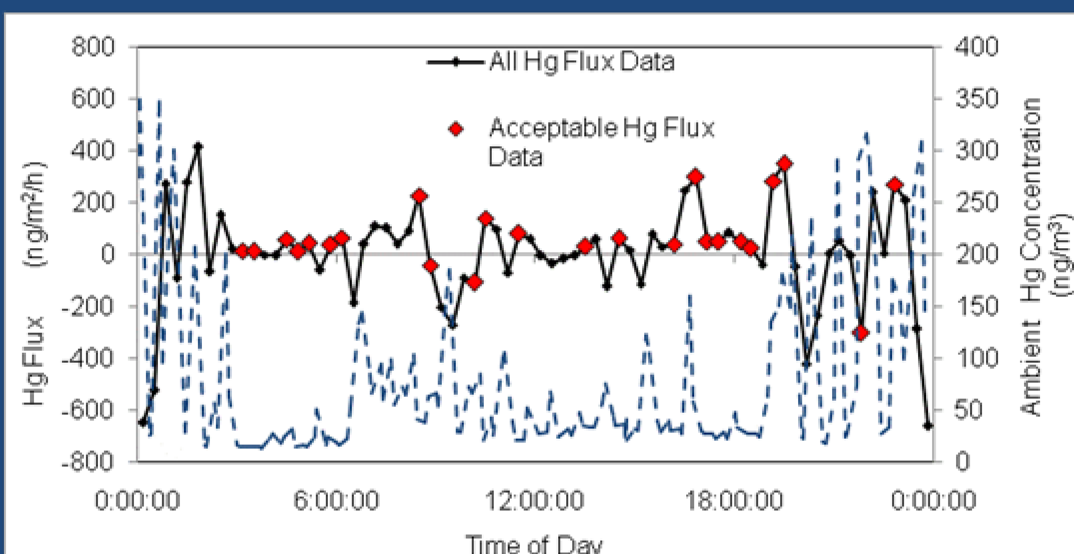
Flux = $(C_{inside}-C_{outside}) * (Q/A)$





<u>Ideal Flux Sampling Conditions</u>:
Stable Ambient Air Concentration:
1.6 to 4.7 ng/m^3

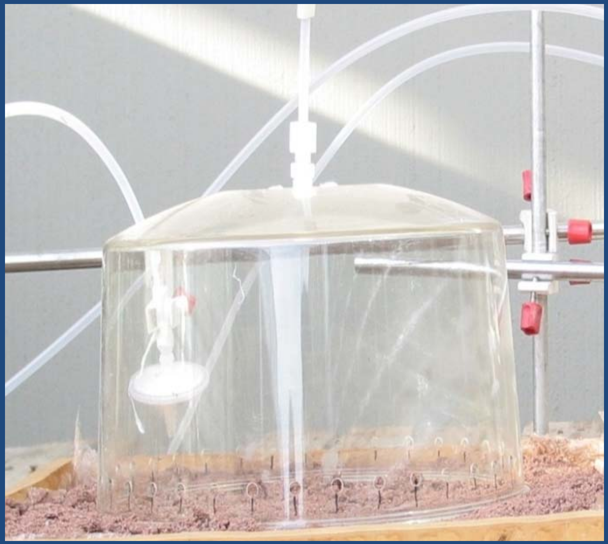
All flux data was acceptable



<u>Poor Flux Sampling Conditions</u>:
Unstable Ambient Air Concentration:
15 to 350 ng/m^3

33 % of flux data was acceptable

Dynamic Flux Chamber Design:






DFC Design:

Large diversity of DFC designs and flow rates

Area (m^2)	Volume (L)	Flow (L/min)	TOT (min)	Material	Researcher
0.16	32	2.0	16	Stainless steel	Schroeder et al. 1989
0.13	25	1.8	13.9	Teflon	He et al., 1998
0.12	24	3.2	7.5	Acrylic	Magarelli & Fostier, 2005
0.073	11.2	1.5	7.5	Polycarbonate	Kuiken et al., 2008
0.13	10	1.5	6.7	Stainless steel/Teflon	Poissant & Casimir, 1998
0.12	24	5	4.8	Teflon	Carpi and Lindberg, 1998
0.12	24	6	4	Plexiglass	Ferrara & Mazzolai, 1998
0.12	24	6	4	Teflon	Zhang et al., 2001
0.03	2.2	1.5	1.5	Teflon	Zhang et al., 2008
0.063	3	2.3	1.3	Polycarbonate	Eckley & Branfireun, 2008
0.036	1.5	1.5	1	Polycarbonate	Ericksen and Gustin, 2006
0.06	4.7	15	0.31	Quartz	Wang et al., 2005
NA	2	6.7	0.30	Polycarbonate	Gustin & Stamenkovic, 2005
0.031	1	6.5	0.15	Polycarbonate	Nacht & Gustin , 2004
0.031	1	10	0.10	Polycarbonate	Engle et al., 2001

Question: How does flux chamber design influence the quantification of Hg emissions?

Research Objectives:

Compare DFCs with different:

1) materials
2) volumes
3) port placements
4) flow rates

Introduction:

Several studies address the influence of these variables:

Flushing Flow Rate (& Chamber Volume)

Wallschlager et al., 1999
Flux increases with flow; high flows recommended

Gillis & Miller, 2000
No flow recommendations—they felt their flows (1-10 lpm) were below optimal

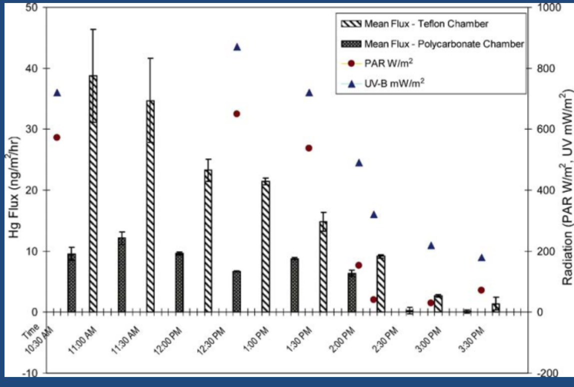
Zhang et al., 2002 & Lindberg et al., 2002
Low flows may underestimate fluxes—recommend high flow: 15 to 40 lpm

Engle et al, 2006
Optimal flow rate may vary with magnitude of surface emissions

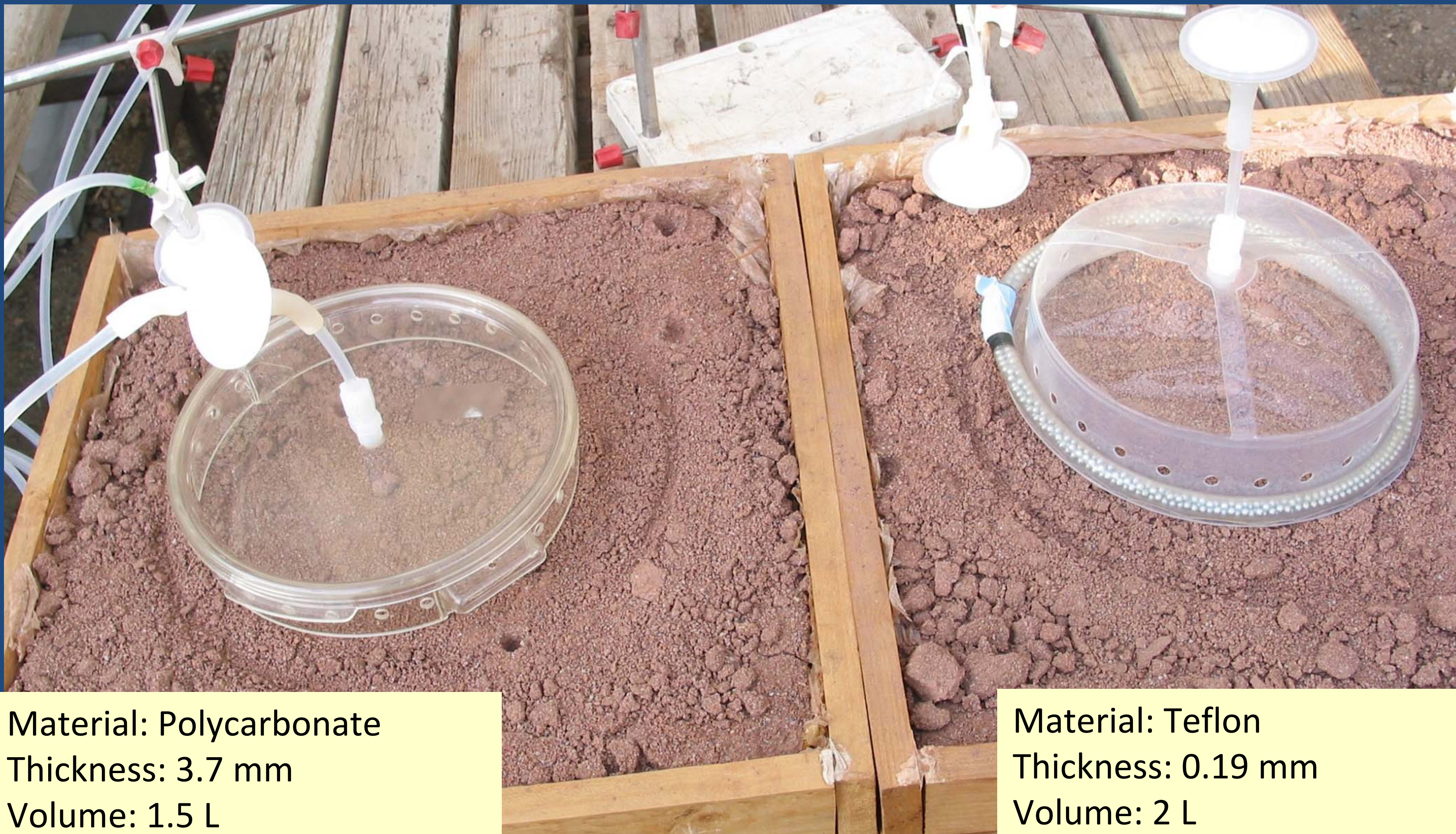
Chamber Material

Carpi et al., 2007

Polycarbonate chambers may underestimate flux relative to Teflon



DFC: Chamber Material



Material: Polycarbonate
Thickness: 3.7 mm
Volume: 1.5 L
Area:0.038 m^2
Flow (TOT): 1.13 lpm (1.32)

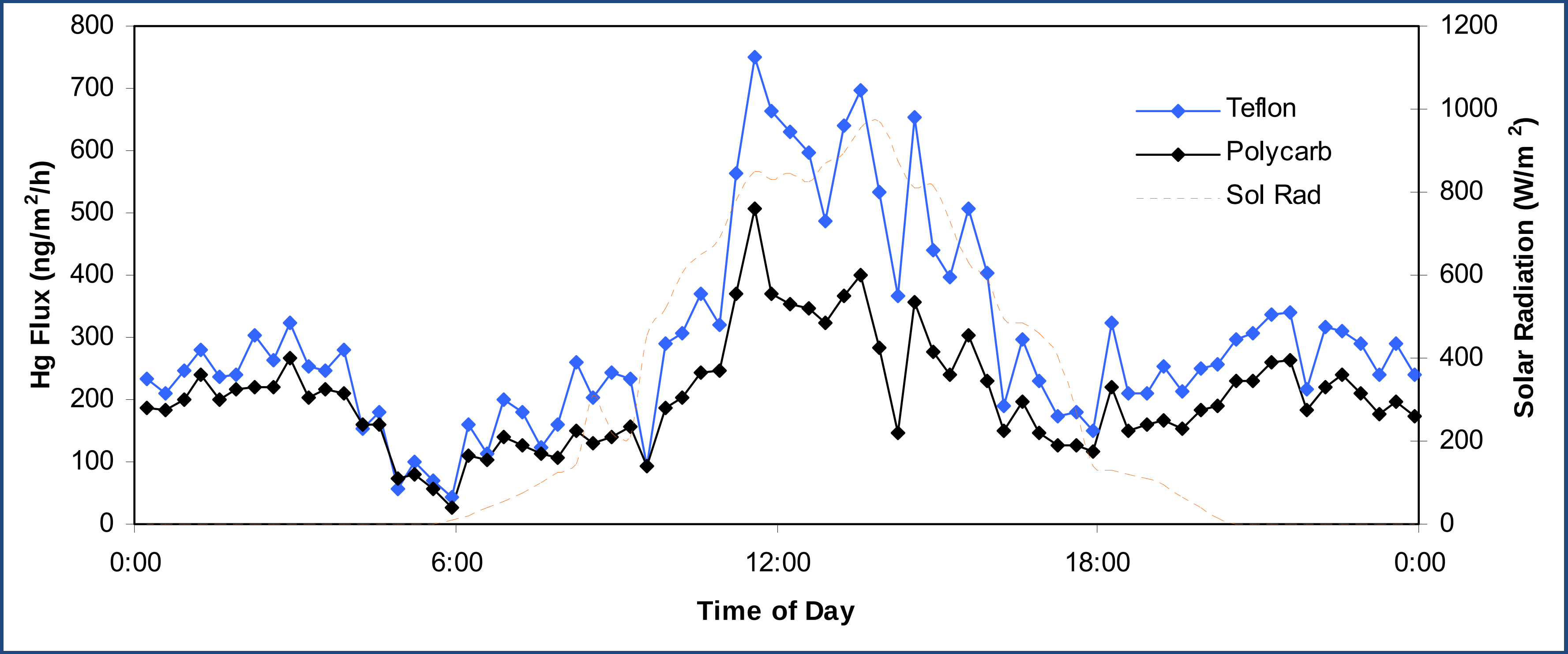
Material: Teflon
Thickness: 0.19 mm
Volume: 2 L
Area: 0.036 m^2
Flow (TOT): 1.5 lpm (1.36)

DFC: Chamber Material

Surface Material: Mine Tailings (30.1 µg/g)

Teflon Flux:	298 ng/m²/h
Polyc. Flux:	204 ng/m²/h

($p < 0.001$)



DFC: Chamber Material

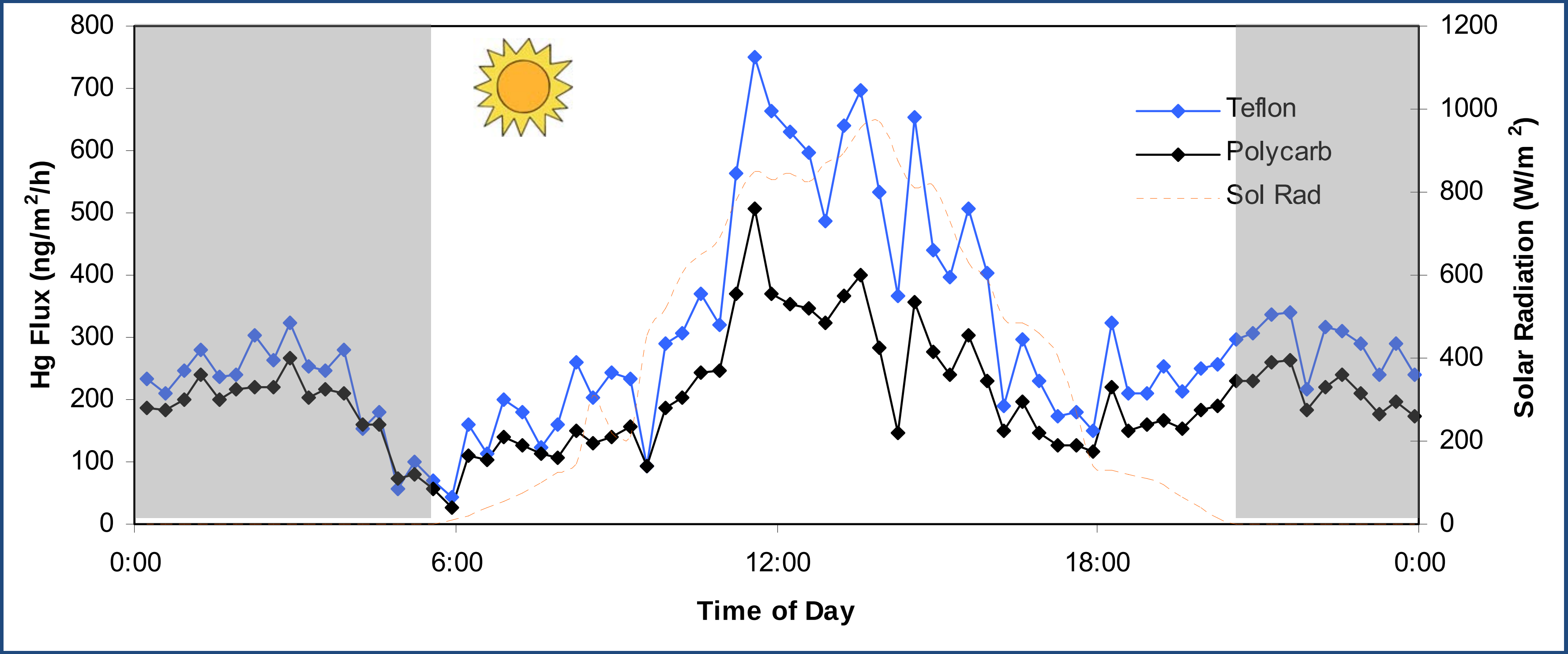
Surface Material: Mine Tailings (30.1 µg/g)

Sunlight Hours Flux

Teflon Flux: 325 $ng/m^2/h$

(p < 0.001)

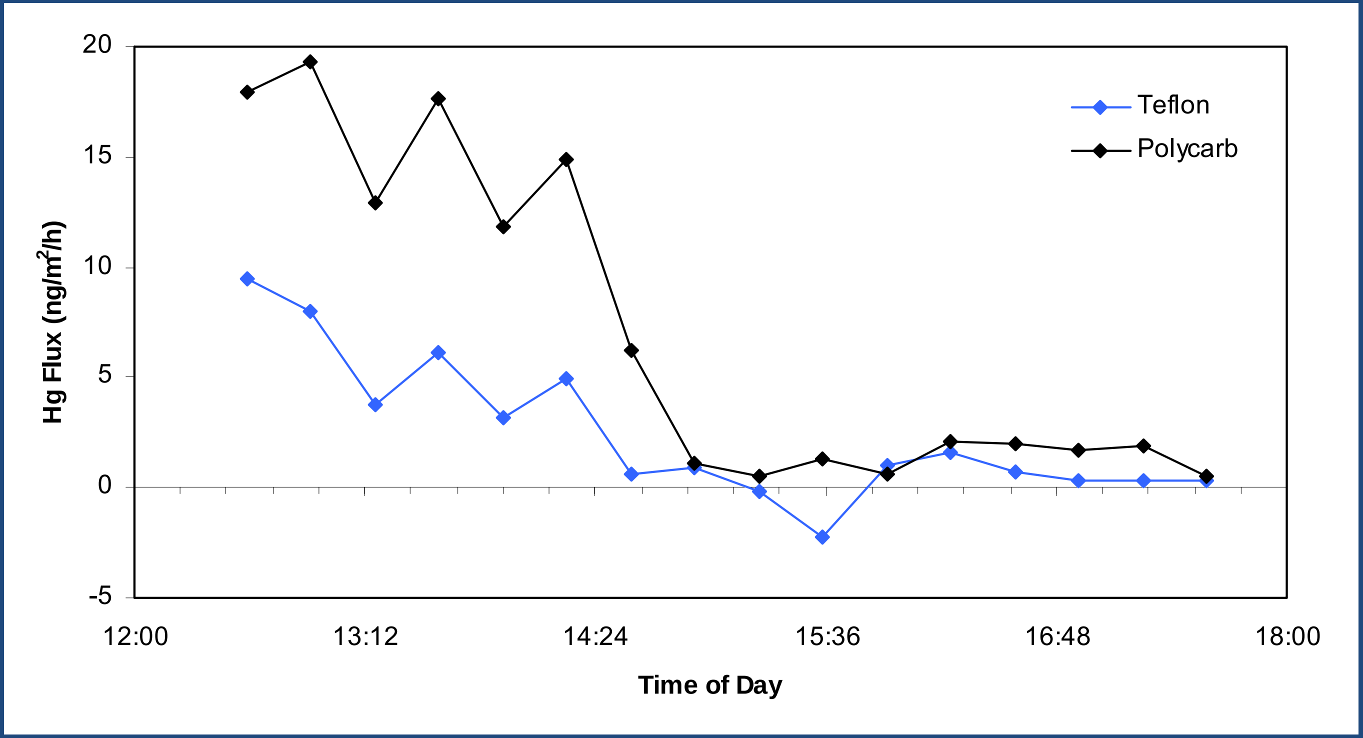
Polyc. Flux: 207 $ng/m^2/h$



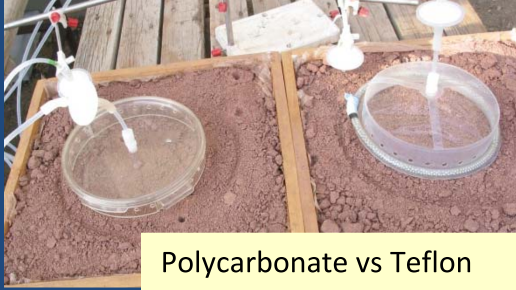
DFC: Chamber Material

Chamber Blanks (post-sampling w/o acid cleaning)

Teflon Flux:	2.4 $ng/m^2/h$	($p = 0.001$)
Polyc. Flux:	7.0 $ng/m^2/h$	



DFC: Chamber Material


Polycarbonate vs Teflon

Conclusion:

- Teflon DFC blanks were lower than polycarbonate (with & without acid cleaning)

- Teflon DFC Hg fluxes were higher than polycarbonate for 2 of 3 substrates--

Daily average relative difference: 46 ±12 %

Hourly maximum relative difference: 107%

DFC: Chamber Volume

<u>Large DFC</u>
Material: Polycarbonate
Thickness: 3.7 mm
Volume: 10.00 L
Area: 0.071 m^2
Flow: 1.5 - 9.9 lpm

Surface Material: 1.3 µg/g

<u>Small DFC</u>
Material: Polycarbonate
Thickness: 3.7 mm
Volume: 4.05 L
Area:0.063 m^2
Flow: 1.5 – 4.1 lpm

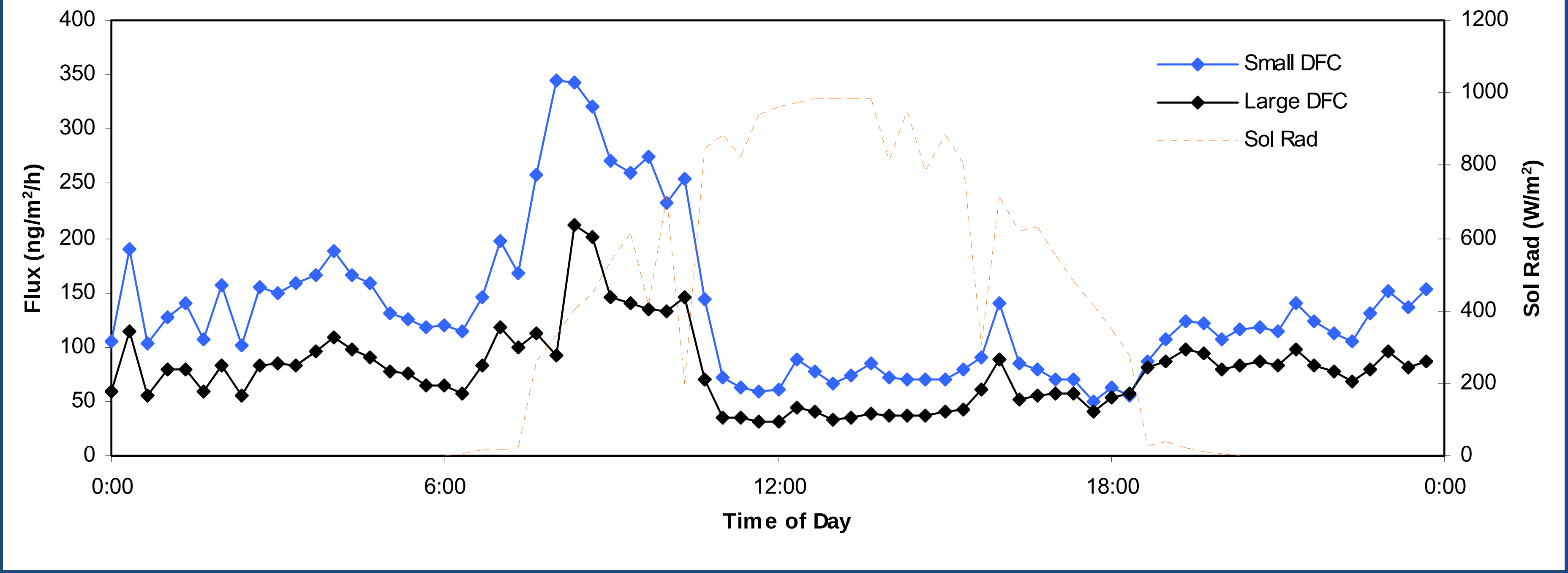
DFC: Chamber Volume

Same Flow Rate

Small DFC Flow: 1.5 L/min	TOT: 2.2
Large DFC Flow: 1.5 L/min	TOT: 6.7

Air-stream velocity: 5.0 m/h
2.0 m/h

Small DFC Flux: 134 $ng/m^2/h$
Large DFC Flux: 78 $ng/m^2/h$



DFC: Chamber Volume

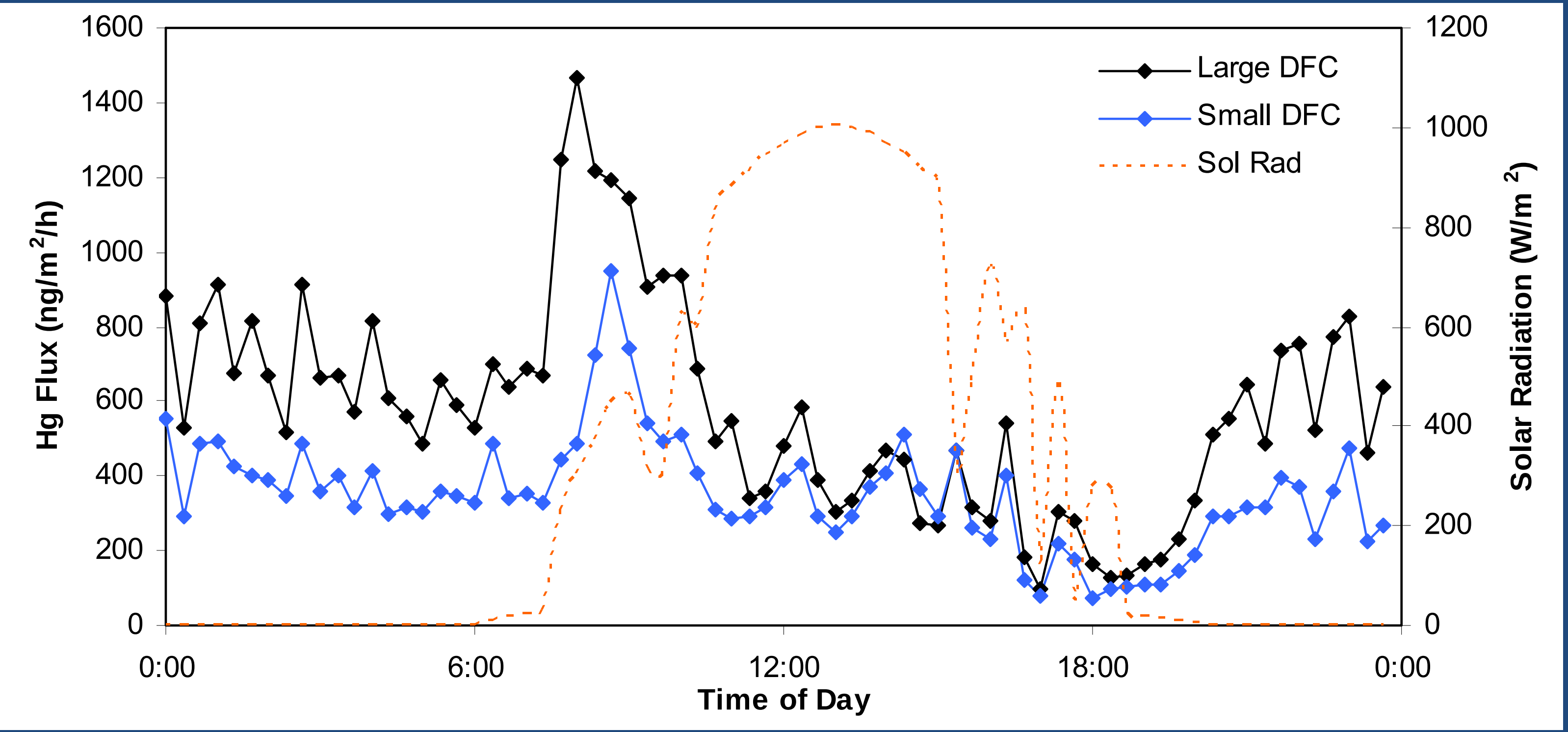
Same TOT

Small DFC Flow: 4.1 L/min	TOT: 1.1
Large DFC Flow: 9.9 L/min	TOT: 1.0

Air-stream velocity: 13.4 m/h
13.2 m/h

Small DFC Flux: 351 ng/m^2/h
Large DFC Flux: 579 ng/m^2/h

Small DFC Δ C: 91 ng/m^3
Large DFC Δ C: 68 ng/m^3



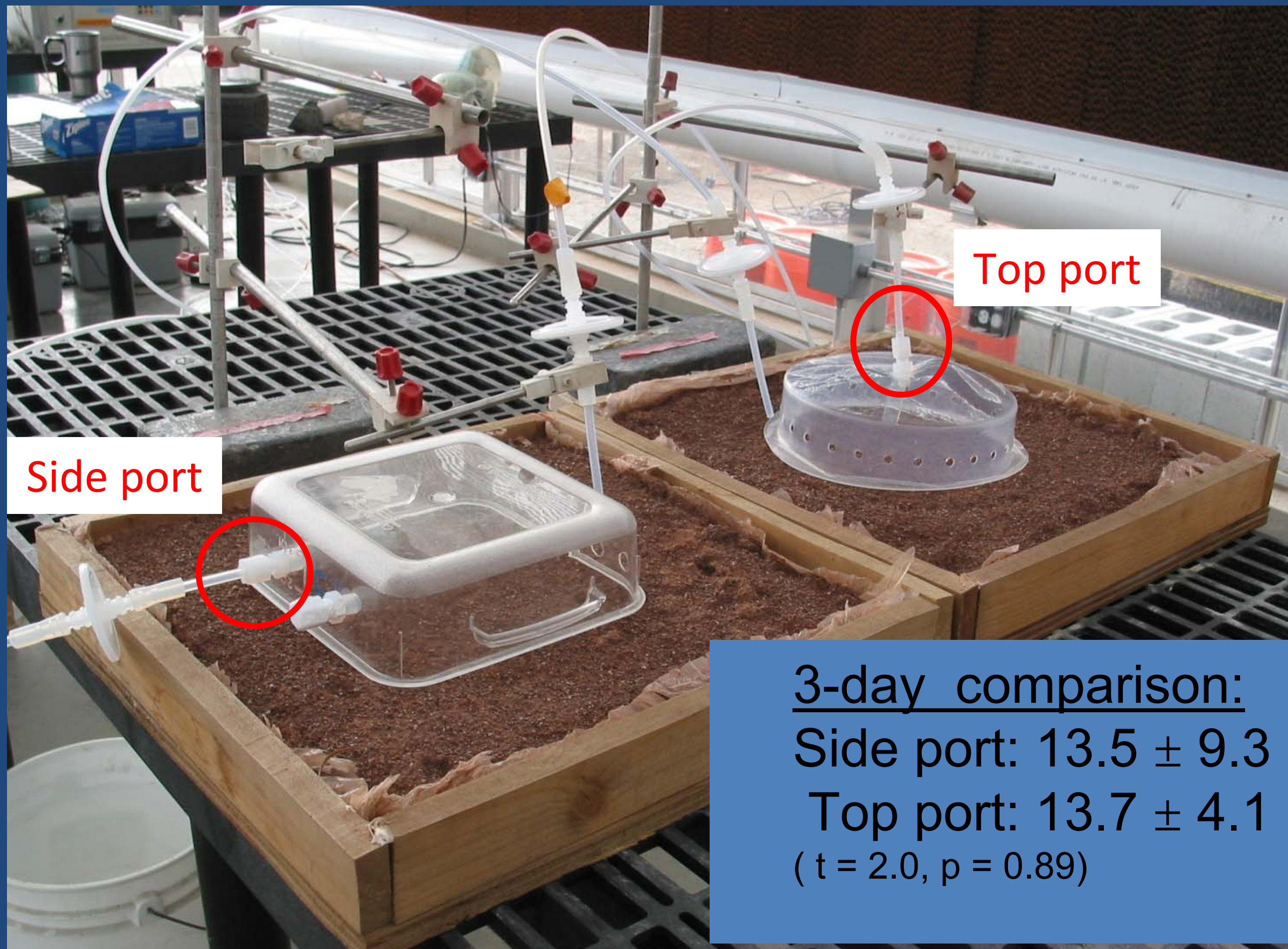
DFC: Chamber Volume

Conclusion:

- At the same flow, the smaller chamber has a higher air-stream velocity over the surface which may enhance emissions

- At the same TOT (& velocity), the larger chamber has a greater Hg emission potential due to a lower chamber air concentration and/or a higher flushing flow rate promoting release of Hg from the surface

DFC: Port Placement

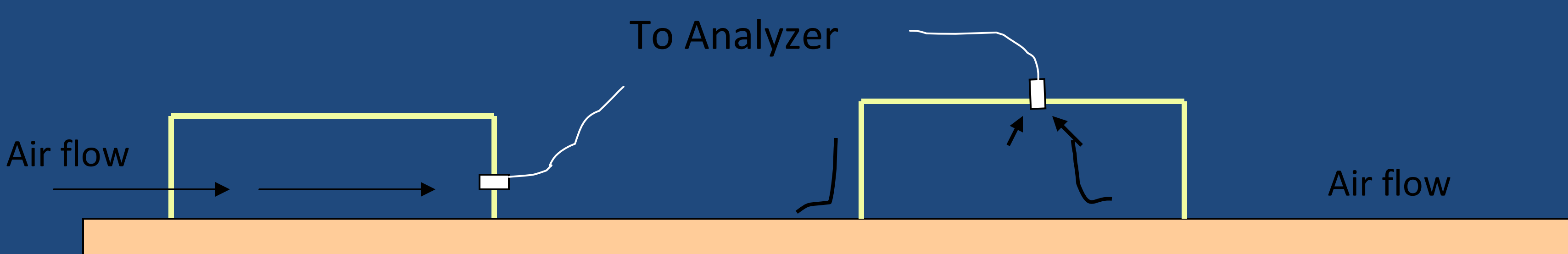


3-day comparison:

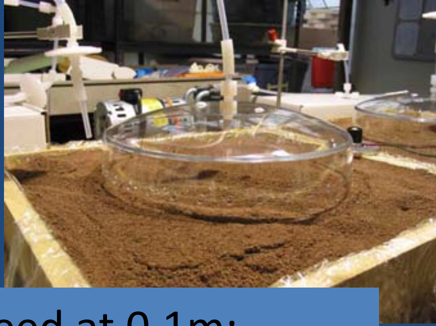
Side port: 13.5 ± 9.3 ng m^{-2} h^{-1}

Top port: 13.7 ± 4.1 ng m^{-2} h^{-1}

($t = 2.0$, $p = 0.89$)



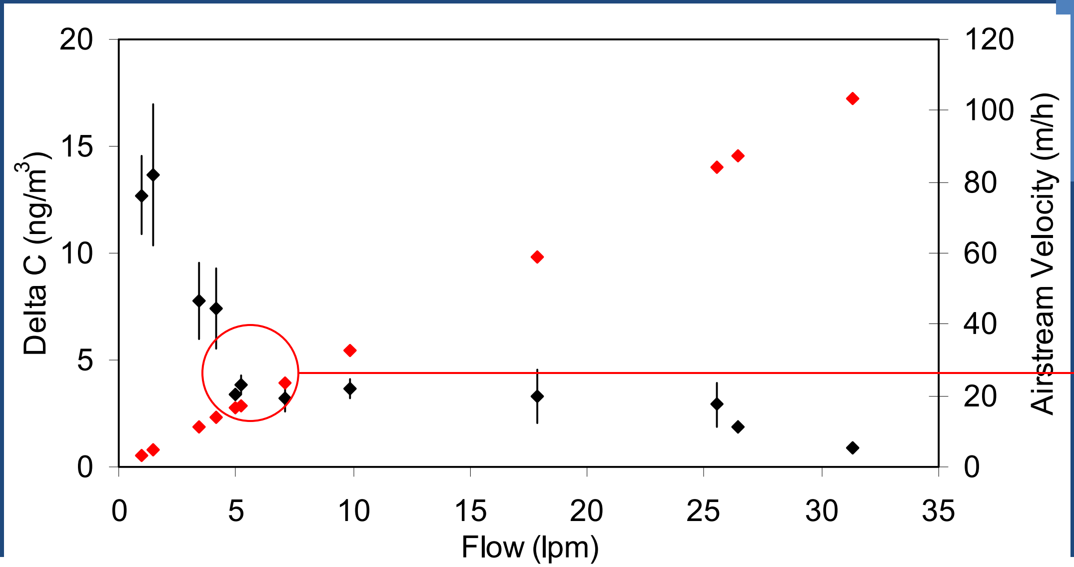
DFC: Chamber Flushing Flow



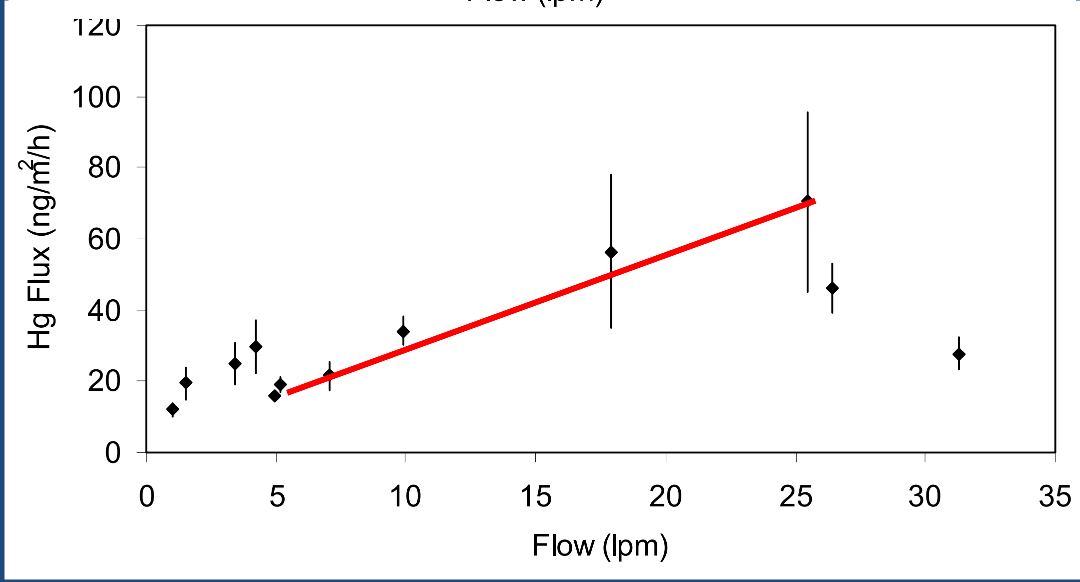
Surface Material:
Alluvium (0.5 µg/g)

Flux = $(C_{inside} - C_{outside}) * (Q/A)$

Typical wind speed at 0.1m:
0 to 70 m/h
(depending on surface roughness)



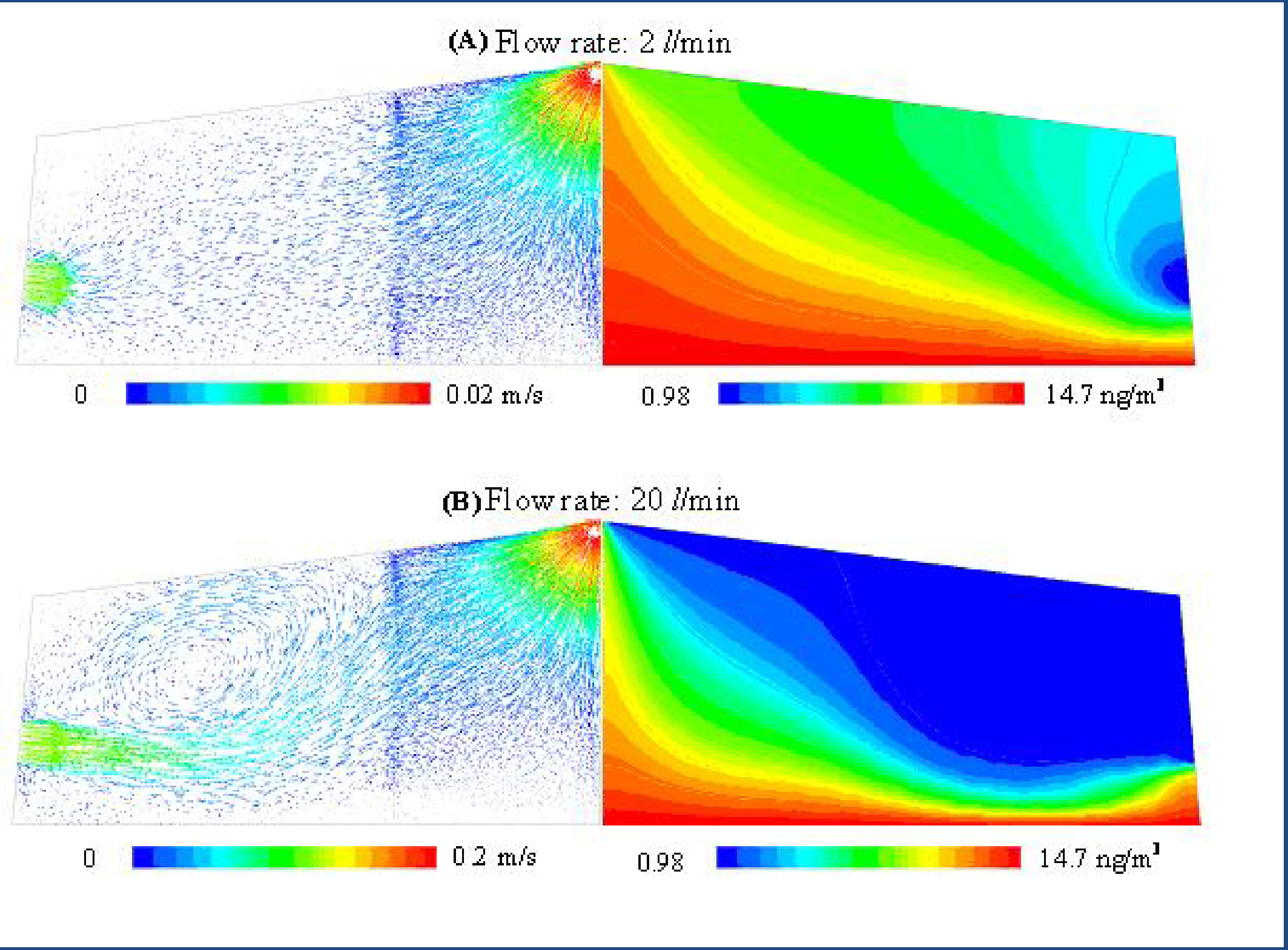
Target zone for measuring flux



DFC: Chamber Flushing Flow

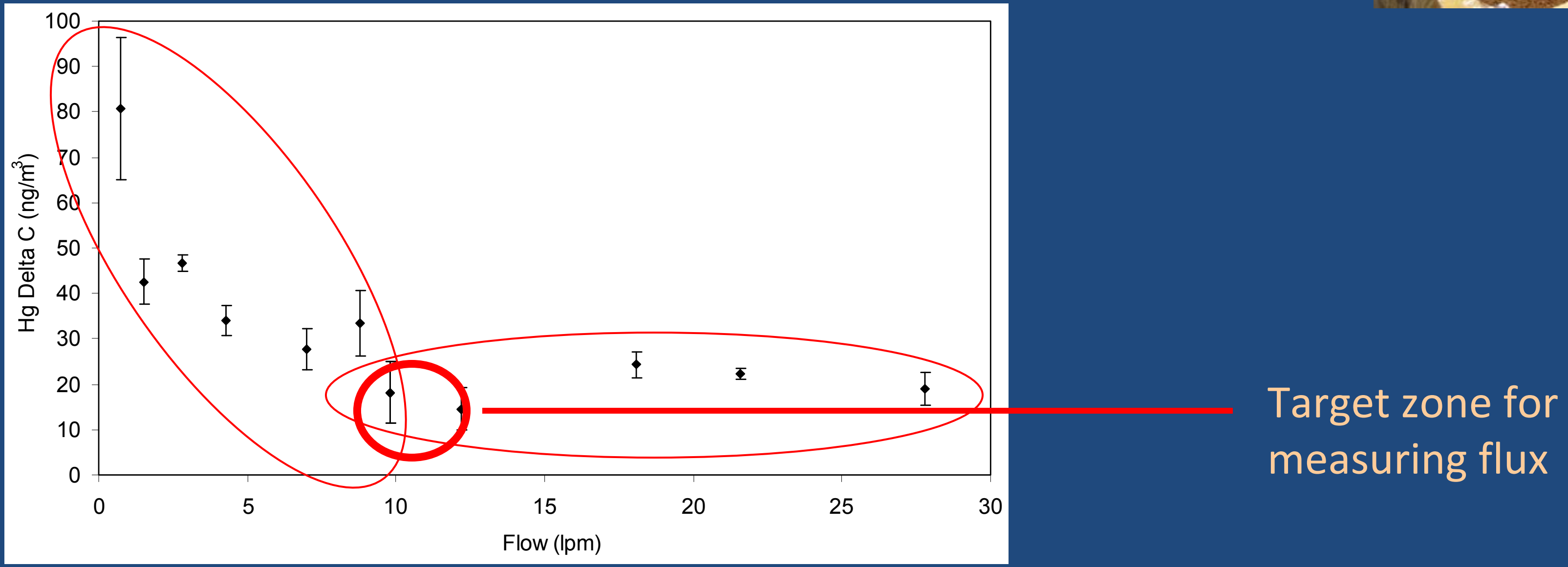
Ideal flow rate would create conditions inside the chamber similar to those outside the chamber

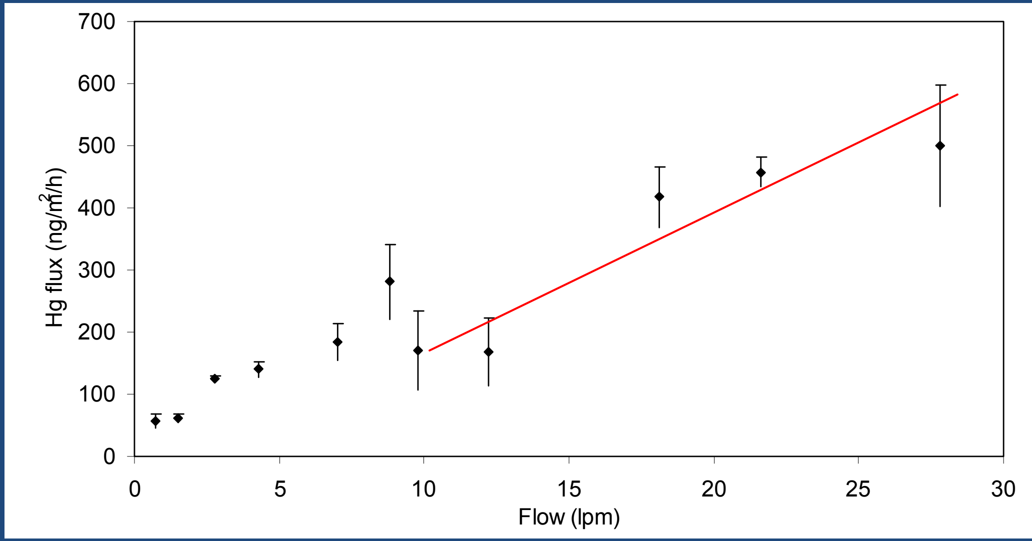
Competing criteria: similar air flow *vs* similar air Hg concentration gradient



DFC: Chamber Flushing Flow

Surface Material:
Mine Tailings (30.1 µg/g)





DFC: Chamber Flushing Flow

Conclusion:

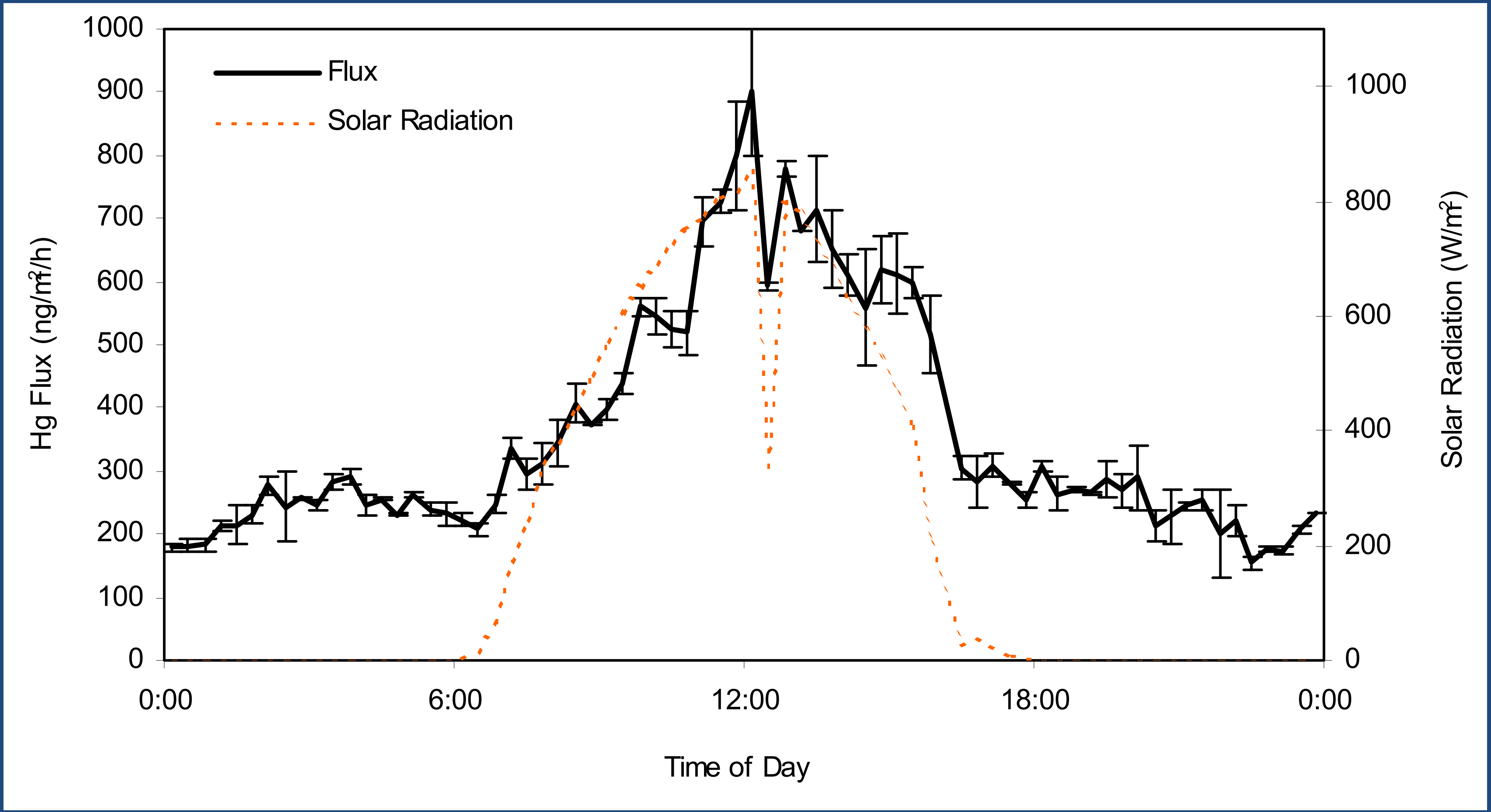
Flow rates can have a larger influence on calculated Hg emissions

Ideal flow rate and TOT vary with the strength of the emission

Substrate	Hg Conc. (µg g^{-1})	Stable period ΔC (ng m^{-3})	Optimal Flow in l min^{-1} (TOT minute)
Alluvium	0.25	3.4 ± 0.3	5.0 (0.82)
Low-grade ore	13	3.0 ± 0.7	4.9 (0.84)
Tailings	85	19 ± 3.7	9.3 (0.44)
High-grade ore	60	690 ± 54	7.0 (0.29)

DFC: Chamber Flushing Flow

Flux changes on diel cycle—therefore sometimes TOT will be less than ideal



Overall Conclusions

Question: How does flux chamber design influence the quantification of Hg emissions?

1) materials	< 1-fold difference
2) volumes	< 1-fold difference
3) port placements	No difference
4) flow rates	**> 7-fold difference**

Questions: ceckley@cabnr.unr.edu