

# Modeling Mercury in Lake Champlain

Eric Miller, Ecosystems Research Group, Ltd.

Ning Gao, St Lawrence Univ.

James B. Shanley, USGS-VT

Neil Kamman, VTDEC

Celia Chen, Dartmouth

Andrea Lini, UVM

Tom Holsen, Clarkson Univ.

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- Lake Champlain is relatively poorly studied in regards to Hg
- LC Segments are highly varied in trophic state and mixing characteristics
- Balance of Hg sources to LC poorly understood.
- Hg studies all around Lake Champlain provide the data to model Hg fate and transport in the lake.

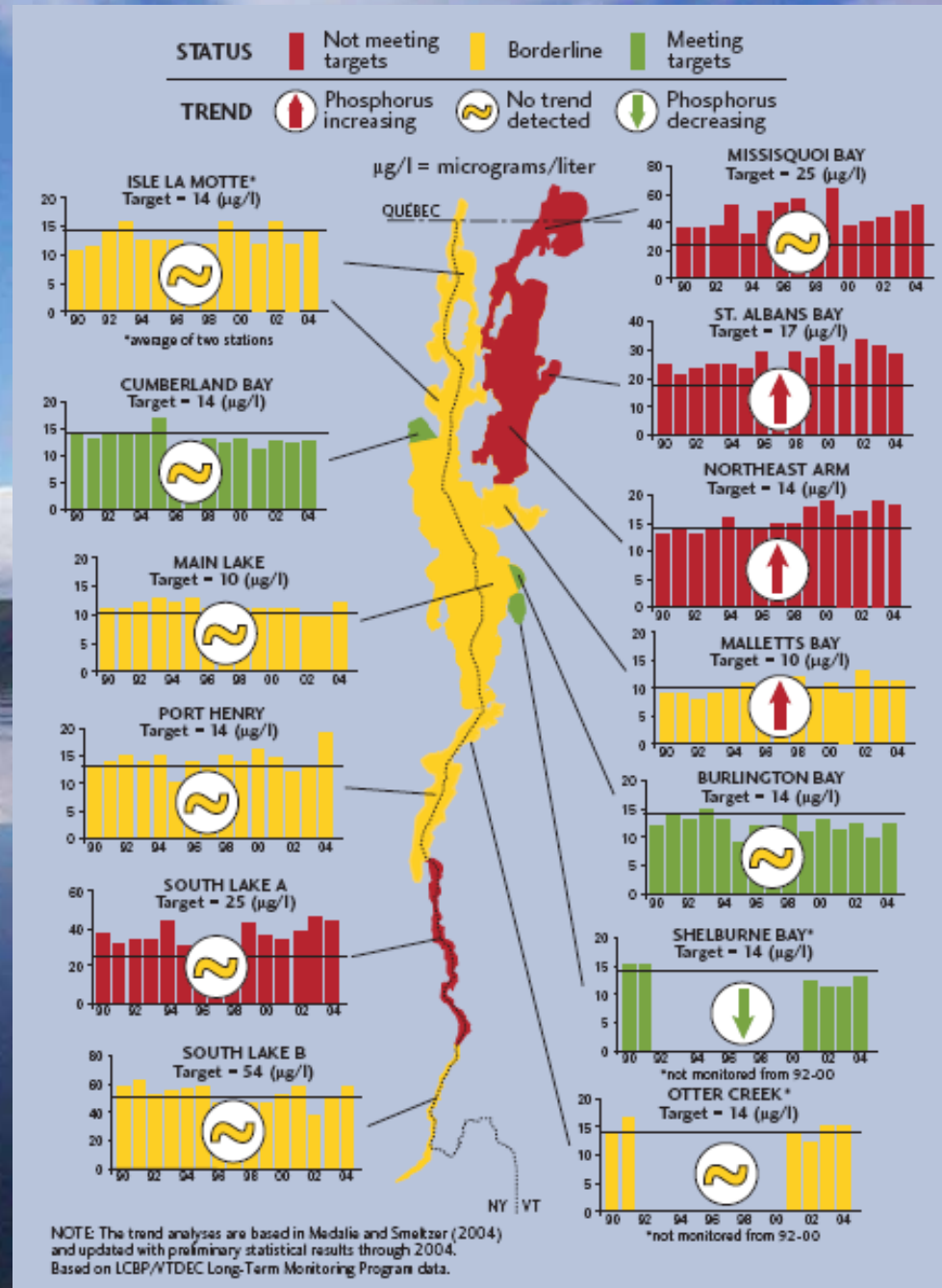
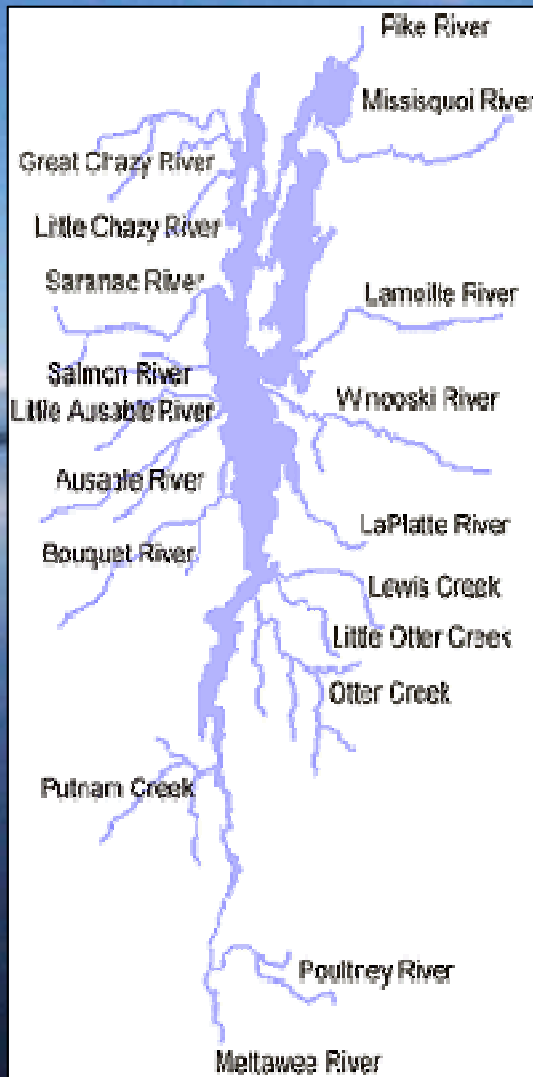
## Context



## Objectives

- Perform a mass balance accounting of sources and sinks for Hg in Lake Champlain 2000-2004
- Infer potential source sectors for Hg that is deposited to Lake Champlain 2002-2004
- To develop a biotic compartment that extends our model to account for trophic uptake and transfer 2005-2006
- Link deposition to bio-uptake by phyto and zooplankton. 2007

# Lake Champlain Segments + Tribs



# Modeling Approach



- Sources
  - Tributary Input
  - Wet and dry atmospheric deposition – direct to lake
  - WWTF inputs
- Sinks
  - Outflow
  - Surface volatilization
  - Sedimentation loss
  - Bio-uptake?
- Stella model framework

# Tributary inputs

- Major tributaries gauged and monitored for HgT and Diss. Hg across flow regimes (2000-2003)
- Leveraged the relationship between Q and TSS, and TSS and HgT, to estimate Hg loadings
- Monitoring network captured 2/3<sup>rd</sup> of basin tributaries, and the majority of WWTF discharges
- Network also captured Richelieu R. outflow

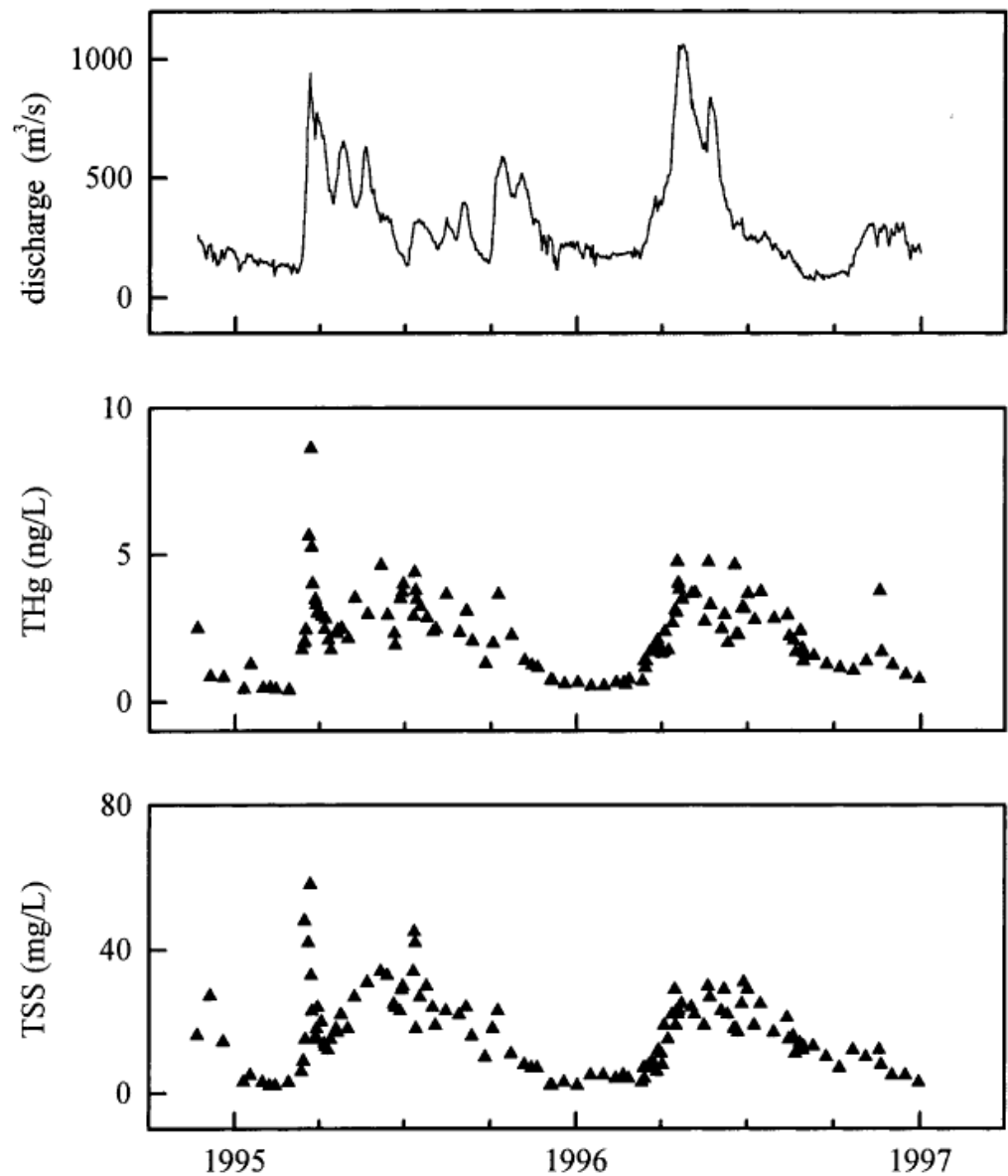
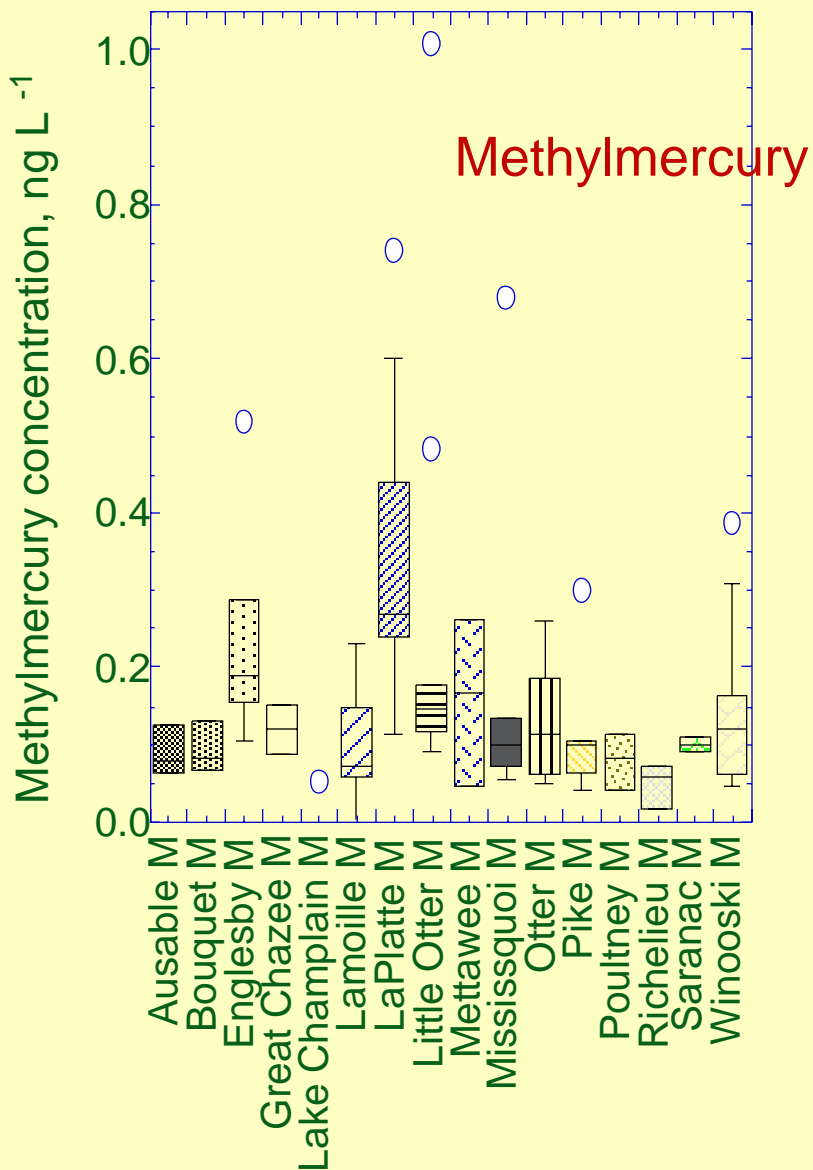
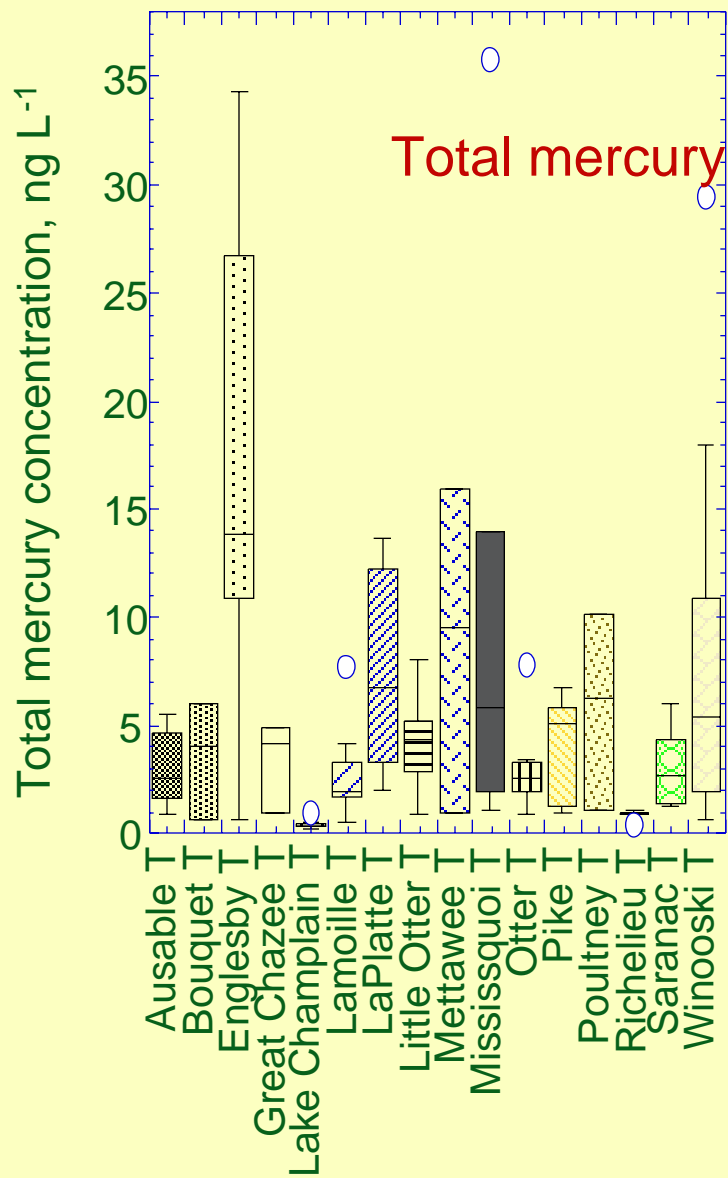


FIGURE 3. River discharge and THg and TSS concentrations at Lock and Dam 1 (km UM1364), headwater Mississippi River.

From Balogh et al., 1997, ES+T 32:4

# HgT and meHg in Champlain tributaries



Segment	Area	Volume	Trib input	Trib input
	(km <sup>2</sup> )	(km <sup>3</sup> )	(g Hg/yr)	per km <sup>2</sup>
Burlington Bay	5.51	0.063	52	9.44
St. Albans Bay	7.21	0.023	71	9.85
Port Henry	75.55	1.463	188	2.49
Shelburne Bay	9.62	0.14	213	22.14
Northeast Arm	248.25	3.38	243	0.98
South Lake A	43.27	0.125	1424	32.91
South Lake B	5.79	0.0078	2203	380.48
Cumberland Bay	10.75	0.063	2241	208.47
Missisquoi Bay	89.94	0.205	2340	26.02
Isle LaMotte	185.59	1.892	2417	13.02
Malletts Bay	55.06	0.722	3165	57.48
Otter Creek	28.49	0.955	3690	129.52
Main Lake	414.14	16.787	8216	19.84
<b>Total</b>	<b>1179.17</b>	<b>25.826</b>	<b>26463</b>	

# WWTF Inputs

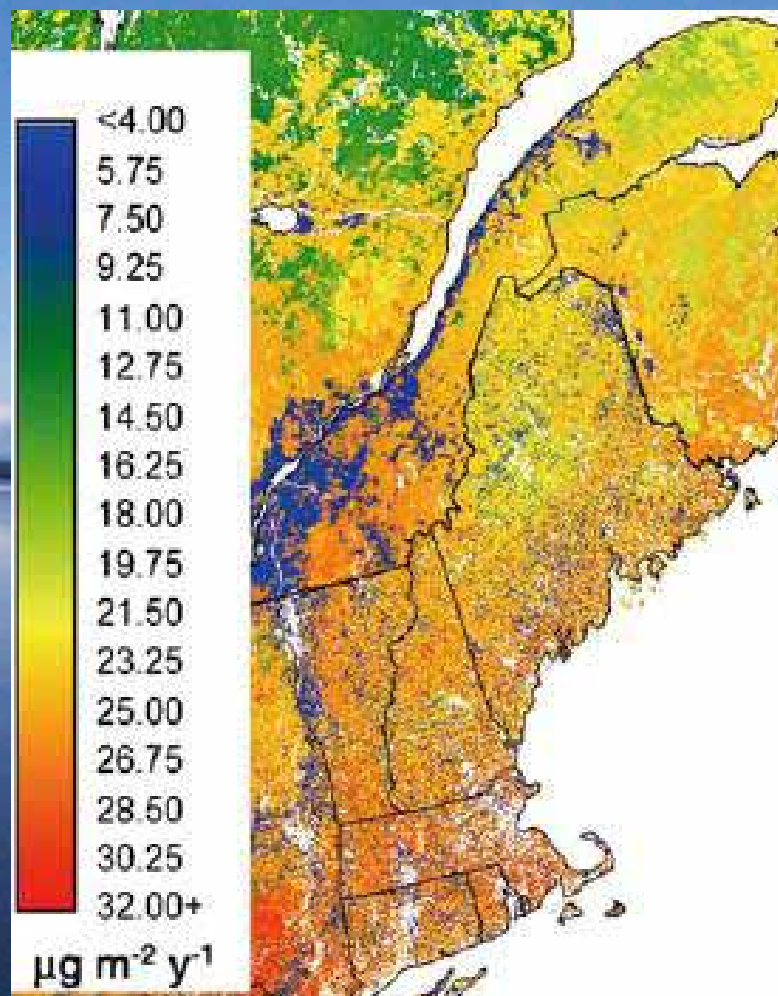
- Estimated based on literature discharges
- Direct measurements
- Application of permitted discharge flows

Segment	WWTFs (g Hg/yr)
Isle LaMotte	0
Northeast Arm	0
Malletts Bay	0
Otter Creek	2
South Lake B	2
Port Henry	3
Missisquoi Bay	3
Shelburne Bay	3
St. Albans Bay	9
Main Lake	13
Burlington Bay	38
Cumberland Bay	80
South Lake A	2524
<b>Total</b>	<b>2677</b>

# Wet and dry deposition to lake

- Wet and dry deposition based on Miller et al. 2005 *Ecotoxicology*.
- Dry deposition modeled using a model describing turbulent transfer across the air-water interface
- Dependent on HgP, RGM in air, and DGM in water, as well as temperature, turbulence, and fetch
- Assumption that  $DGM = 20\% \text{ HgT}$  in water

# Wet and dry dep.

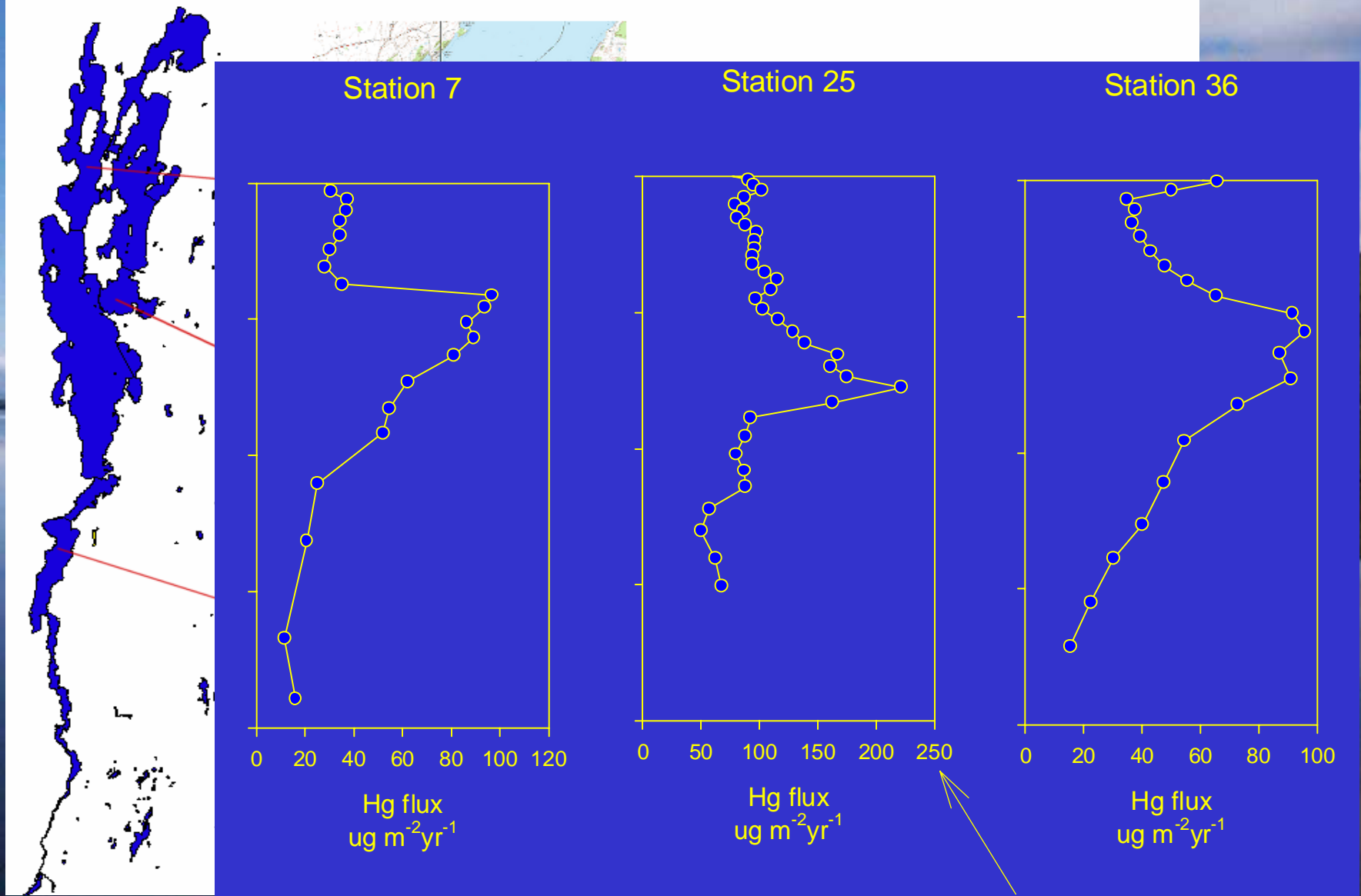


Segment	Wet Dep (g Hg/yr)	Dry Dep (g Hg/yr)
South Lake B	47	21
Burlington Bay	44	39
St. Albans Bay	57	50
Shelburne Bay	77	69
Otter Creek	229	101
Cumberland Bay	84	115
South Lake A	353	160
Port Henry	605	278
Malletts Bay	433	426
Missisquoi Bay	738	699
Isle LaMotte	1455	1581
Northeast Arm	1959	1884
Main Lake	3255	3077
<b>Total</b>	<b>9336</b>	<b>8479</b>

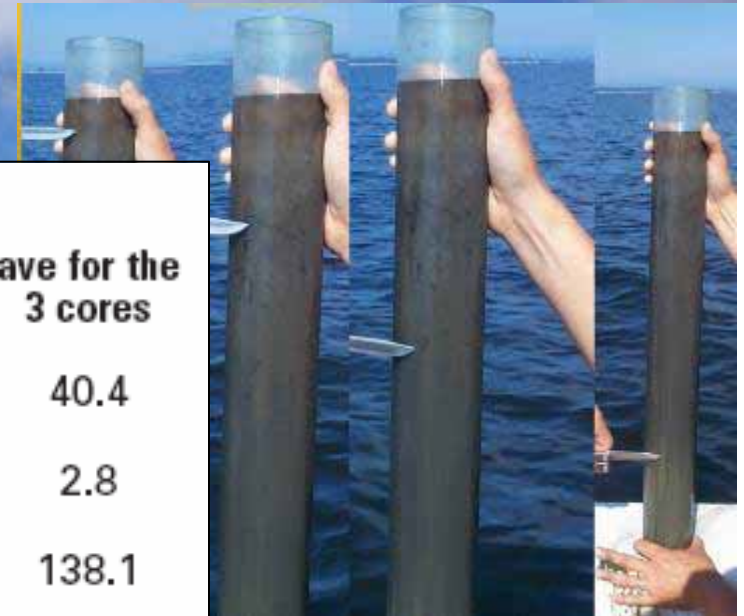
# Losses

- Loss to Richelieu River – 23% of tributary influx
- Hg volatilization loss – highly complex interaction of HgT, DGM, RGM, fetch and temperature.
- Estimated volatilization loss ranged from <0.1 to 3.6 kg/yr as DGM lost.
- Sedimentation estimated by sediment cores

# Sedimentation history



# Sedimentation losses



flux values:	site			ave for the 3 cores
	Cole Bay	Malletts Bay	Point au Roche	
modern mean (1994–present)	19.4	54.4	47.4	40.4
ratio: modern mean/baseline	2.3	3.9	2.4	2.8
peak	96.8	221.7	95.7	138.1
year of peak	1959	1922	1944	
ratio: peak/baseline	6.9	9.8	4.2	7.0



- Sedimentation applied to integrated lake bottom areas
- Losses ranged from 0.2 to 7.4 kg/yr

# Mass Balance Assessment

- **Basis:** Law of mass conservation

$$[\text{Hg}]_t = [\text{Hg}]_{t-dt} + [\Sigma(\text{Input}) / \text{Vol} - \Sigma(\text{Output}) / \text{Vol} + \Sigma(\text{Internal Conversion}) / \text{Vol}] * dt$$

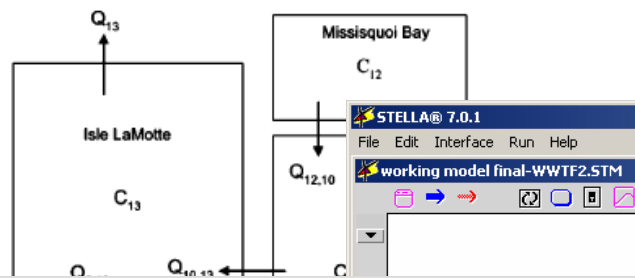
## **Where:**

**Inputs:** tributary input, advective flow from up-stream lake segment, wastewater treatment facility discharge (and municipal discharge), atmospheric dry deposition, atmospheric wet deposition, etc.

**Outputs:** tributary outflow, volatilization, sedimentation, etc.

**Internal conversions:** methylation and biota uptake, segment exchange (dispersion), etc.

# Stella model



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working model final-WWTF2.STM

STELLA® 7.0.1  
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working model final-WWTF2.STM

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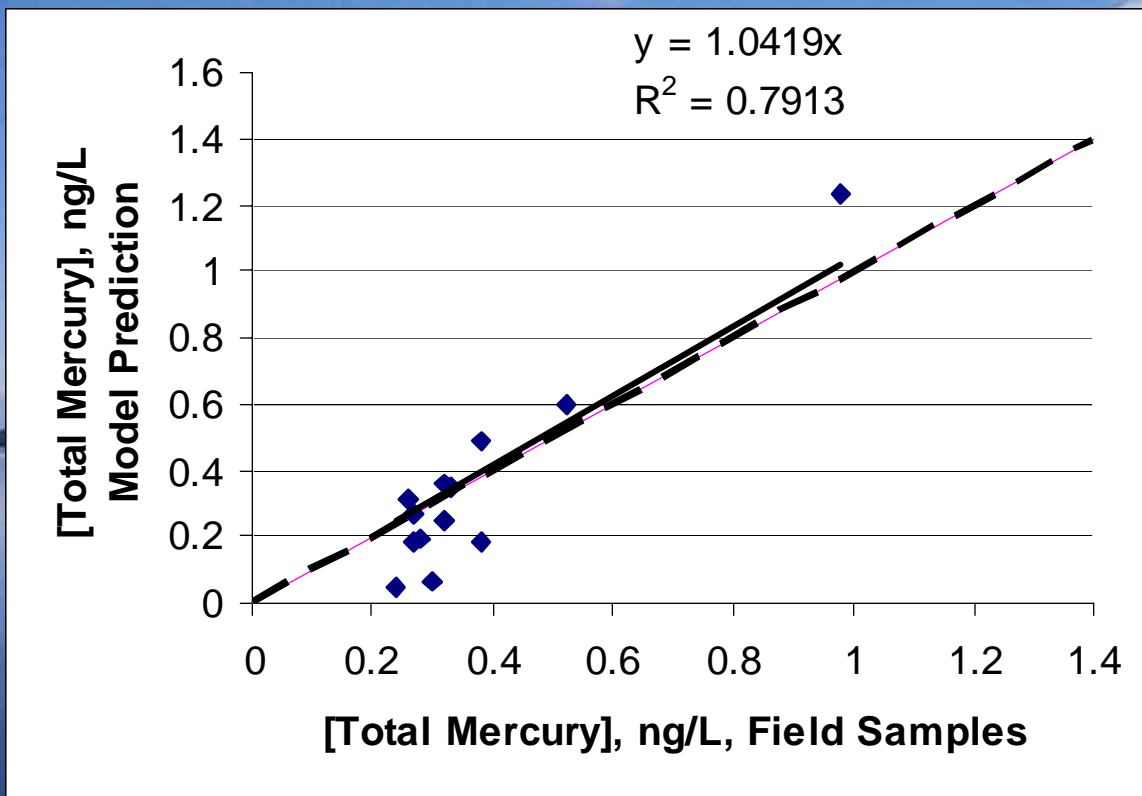
select a section of the lake to simulate the change in Hg overtime.

Run

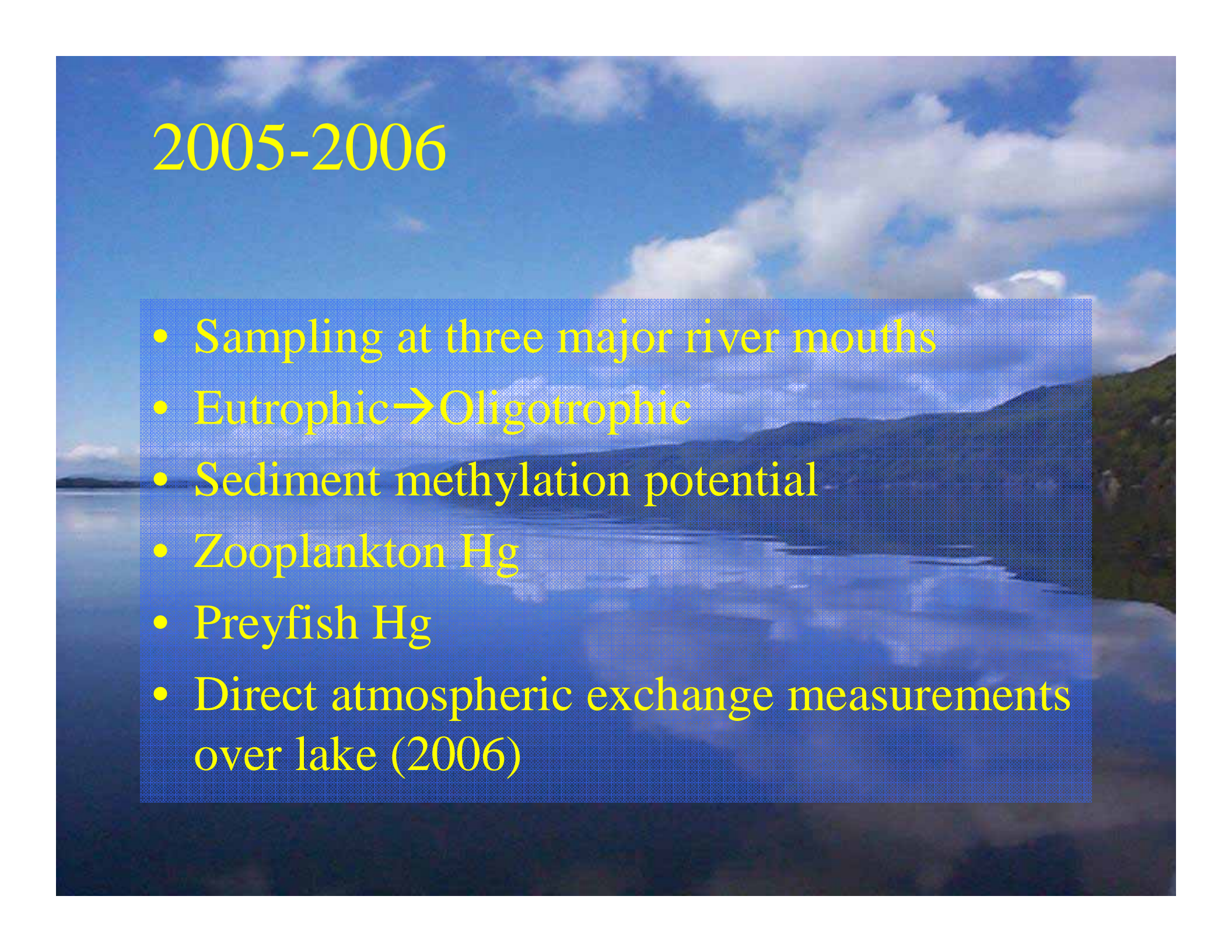
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# Modeled vs. observed and results



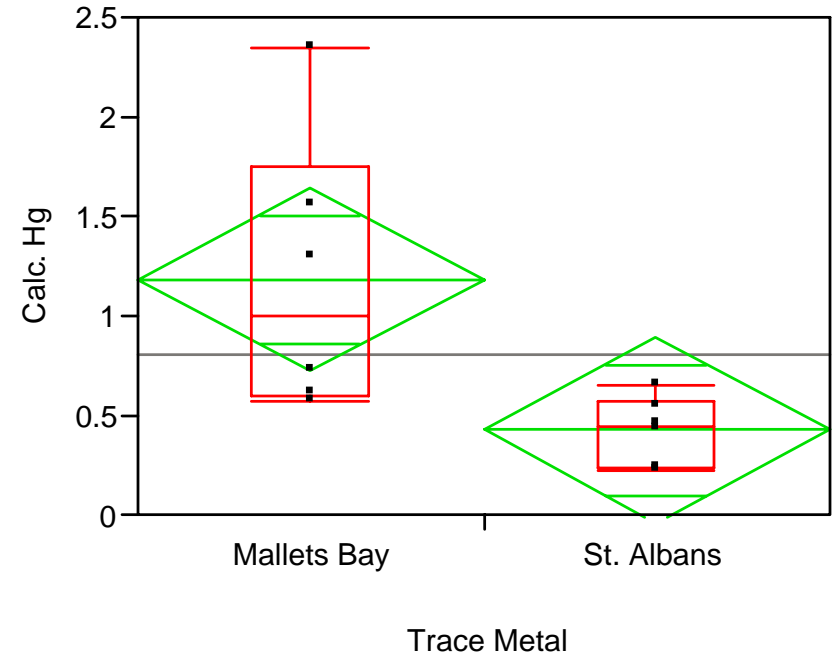
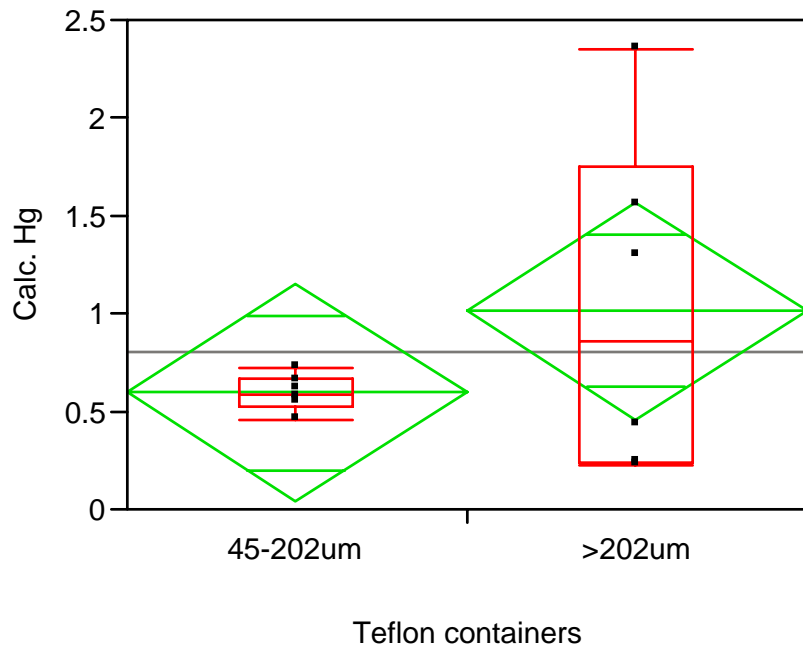
- 56% of inputs are from watershed
- 36% of inputs are direct to lake
- Sedimentation loss 2.8x historical baseline



# 2005-2006

- Sampling at three major river mouths
- Eutrophic → Oligotrophic
- Sediment methylation potential
- Zooplankton Hg
- Preyfish Hg
- Direct atmospheric exchange measurements over lake (2006)

# Hg in zooplankton – trial data



# 2006 and Proposed for 2007

- Direct flux measurements will be used to better quantify atmospheric deposition and volatile loss.
- In-lake DGM measurements will be made co-incident with flux measurements.
- Measurements at Underhill show importance of “extreme” wet and dry deposition events.
- HYSPLIT models show the most probable source regions of these events.
- Biweekly sampling (2007) of HgT and meHg in water and plankton across lake will be used to assess incremental enhancement of Hg in lake and biota.