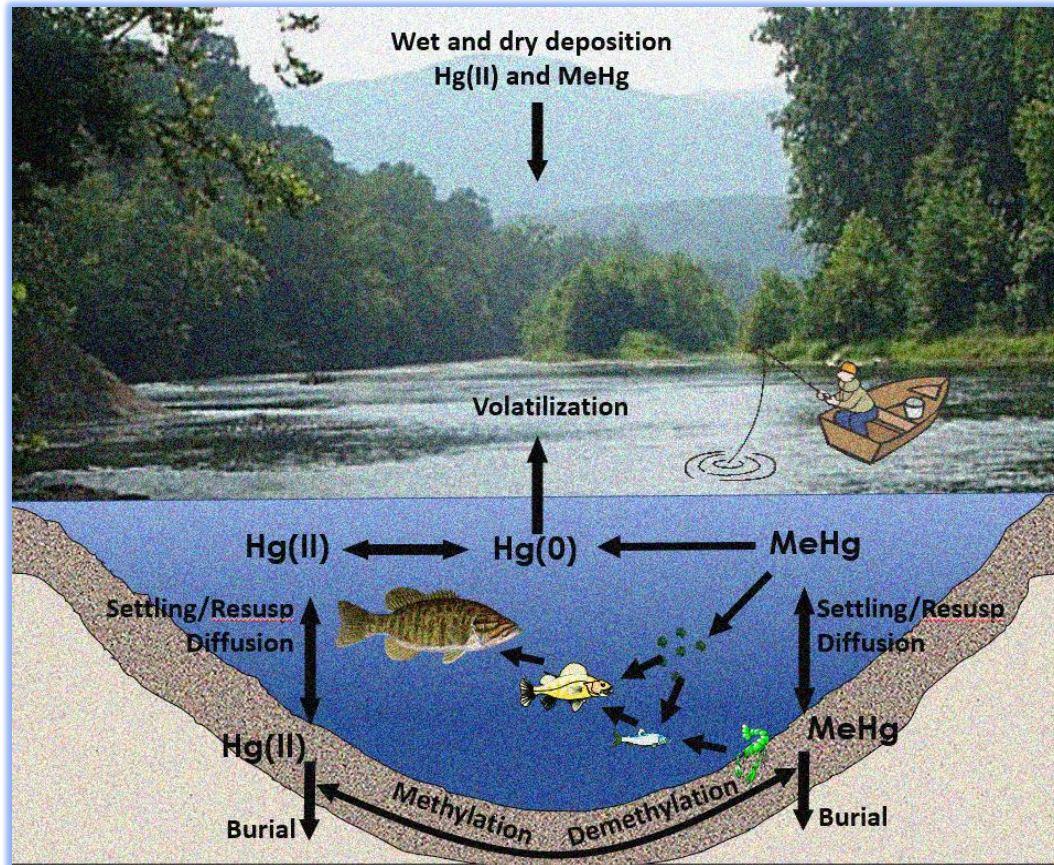


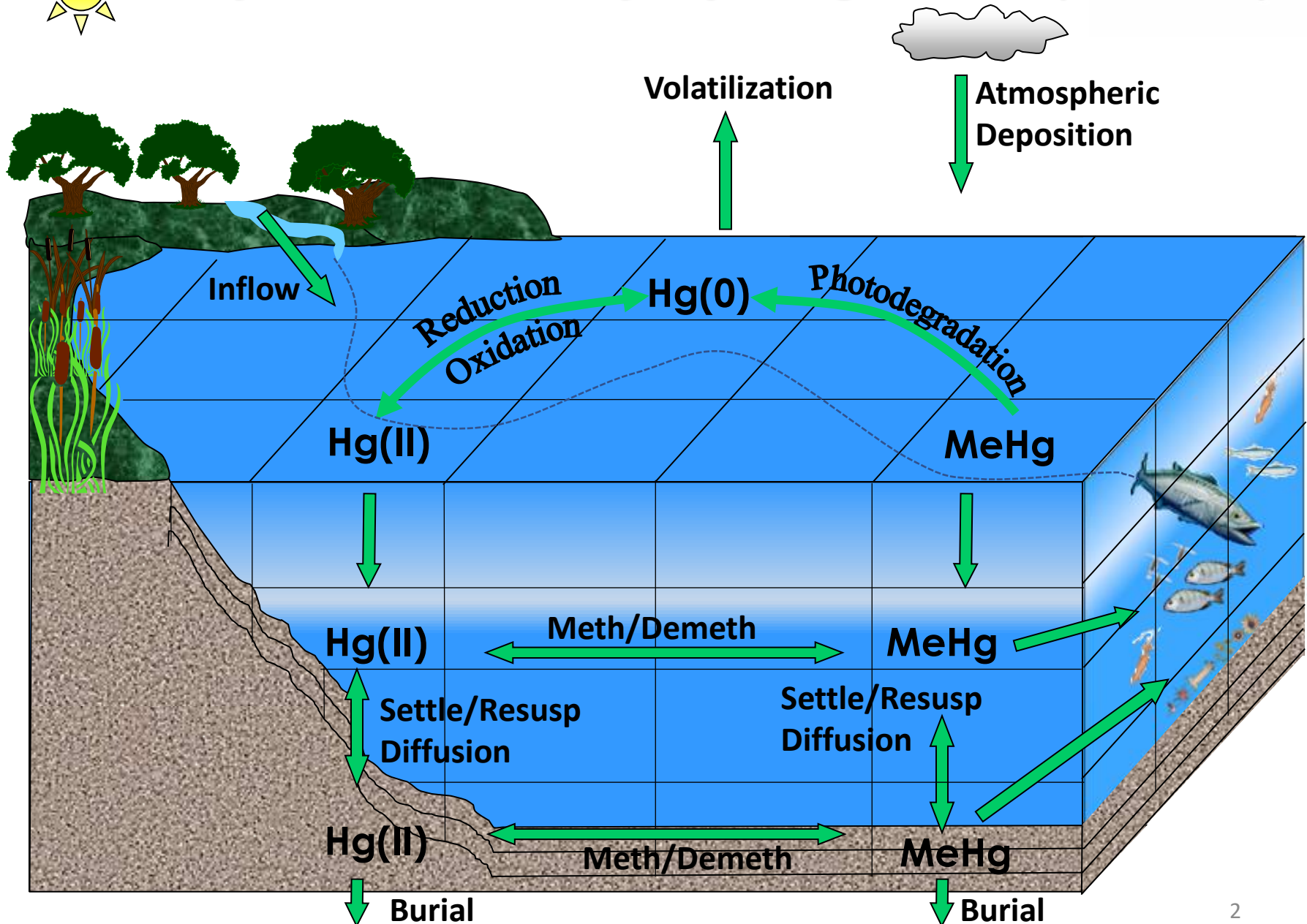
Mechanistic Mercury Model Application to the South River, VA

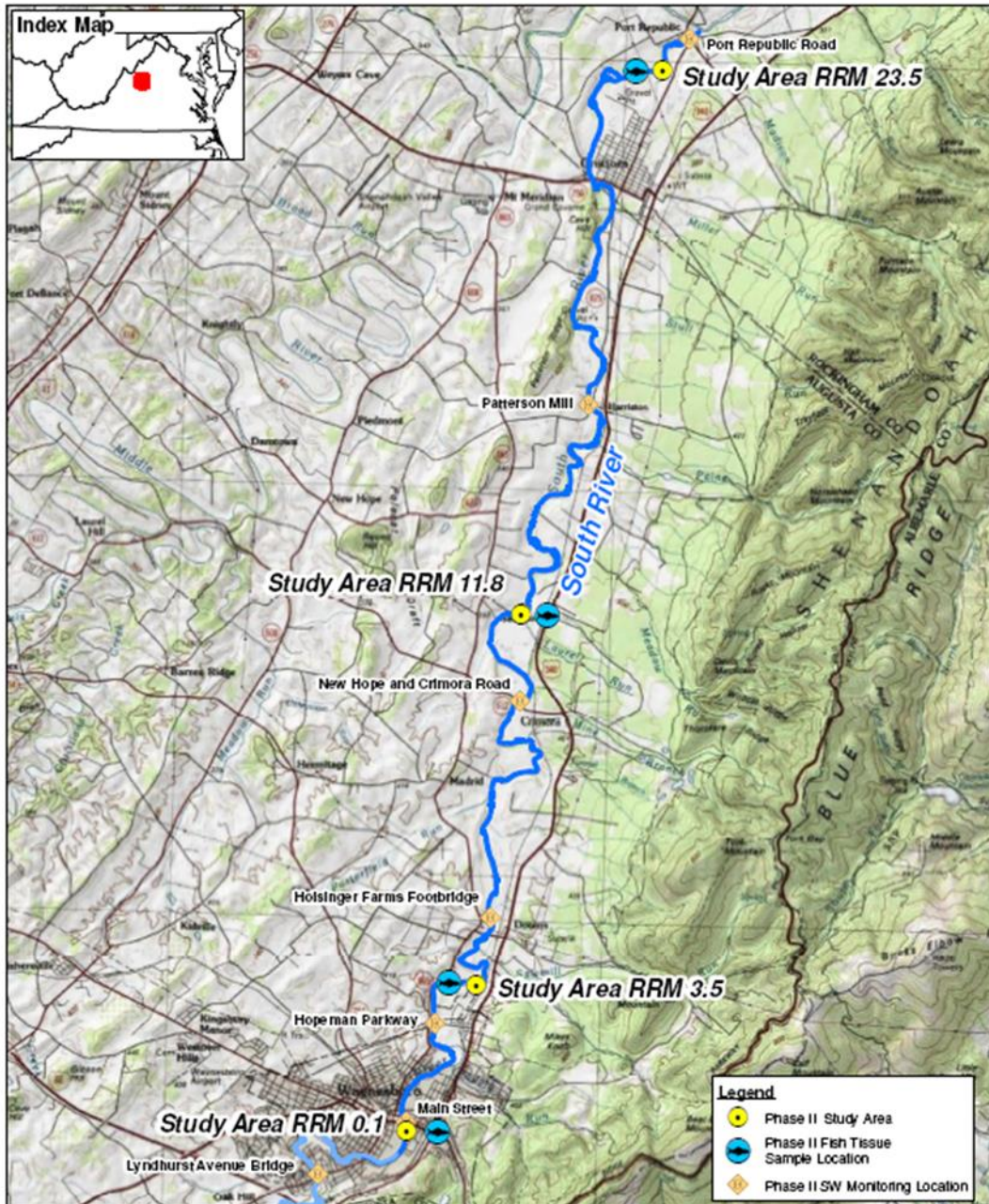


Reed Harris, David Hutchinson and Don Beals
Reed Harris Environmental Ltd.
April 24, 2020



Dynamic Mercury Cycling Model (D-MCM)





Model setup

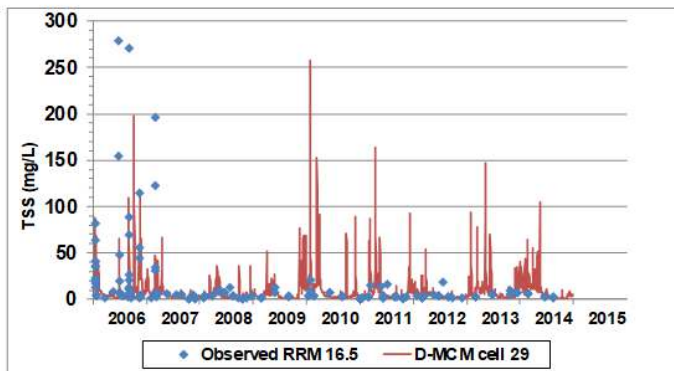
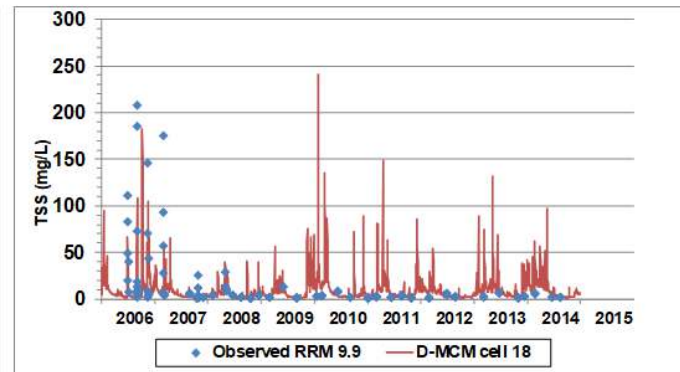
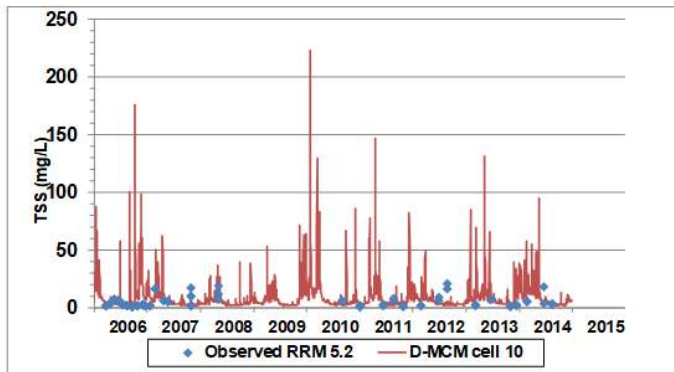
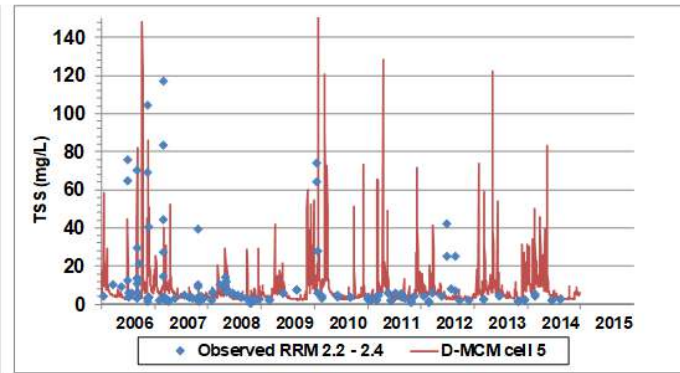
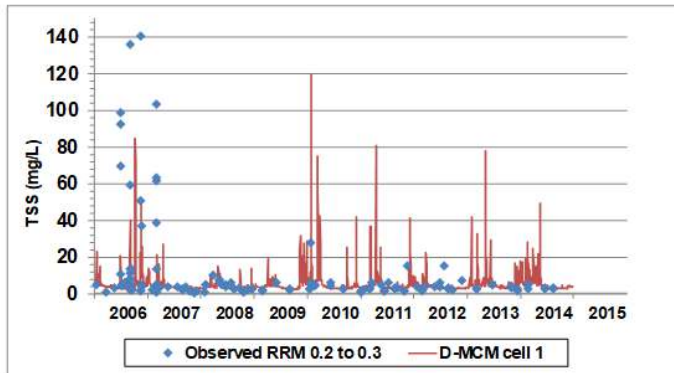
Set of
connected 46
cells

RRM 0-27

Simulated
2006-2014

Particle dynamics

Predicted and observed TSS vs time at different locations



Don't know if the model overestimated spikes in TSS, or the field data miss those short term events....

**TSS is highly variable, even at a given flow rate
(model used black line)**

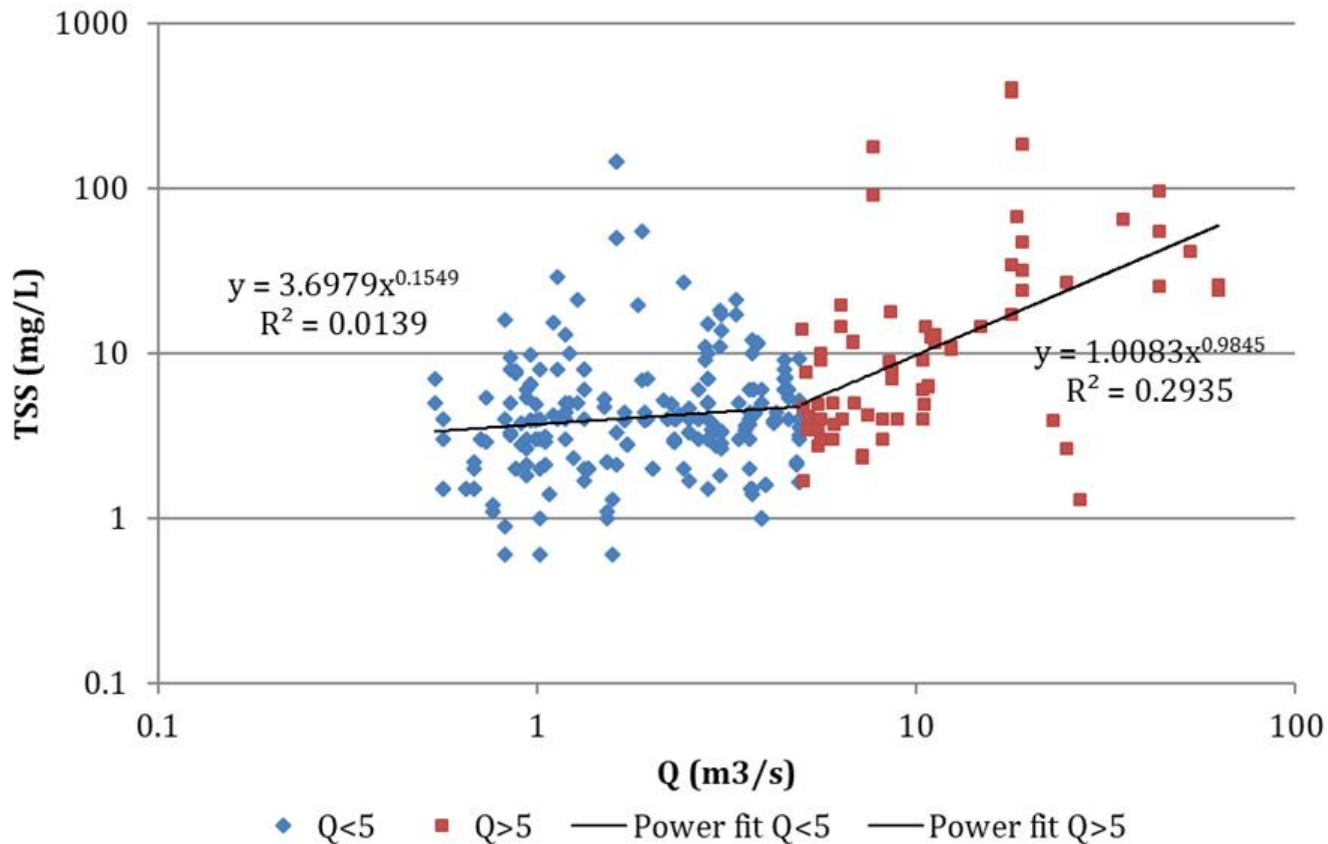
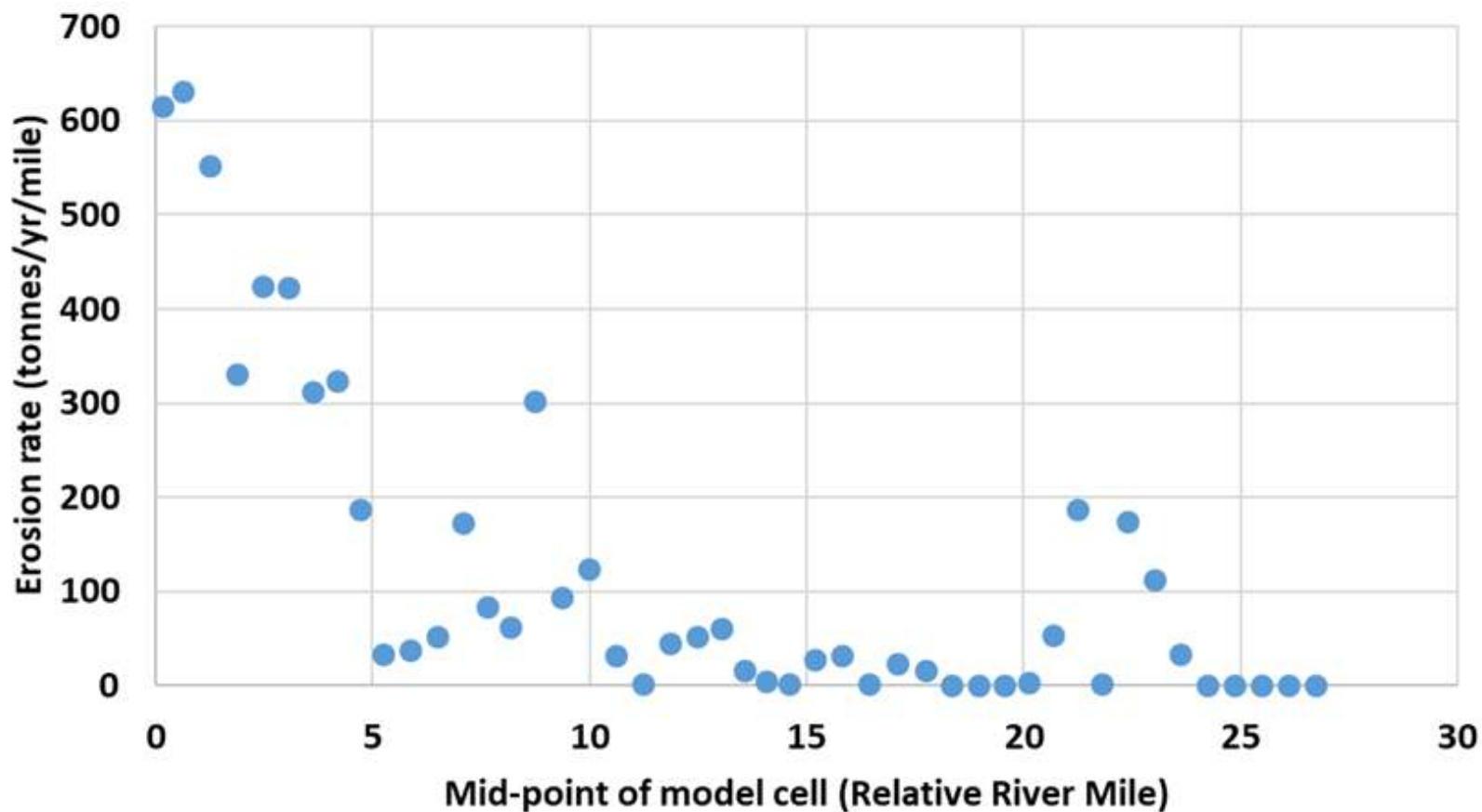
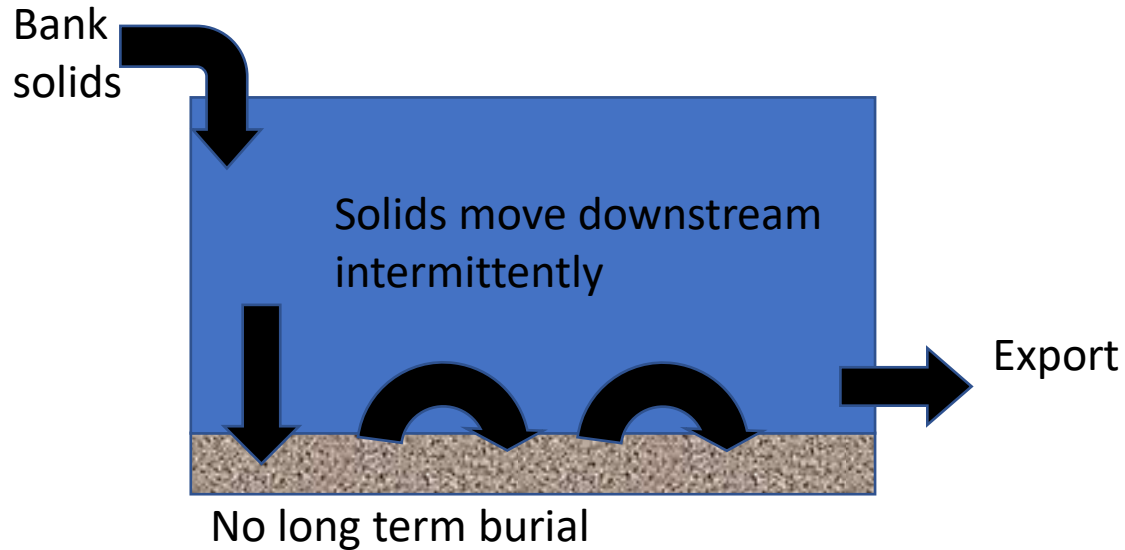


Figure 31. Suspended solids concentrations in the South River as a function of flow for RRM -2.8 to 0. Data from 1999-2014, n=312. Data source: Flanders (2016).

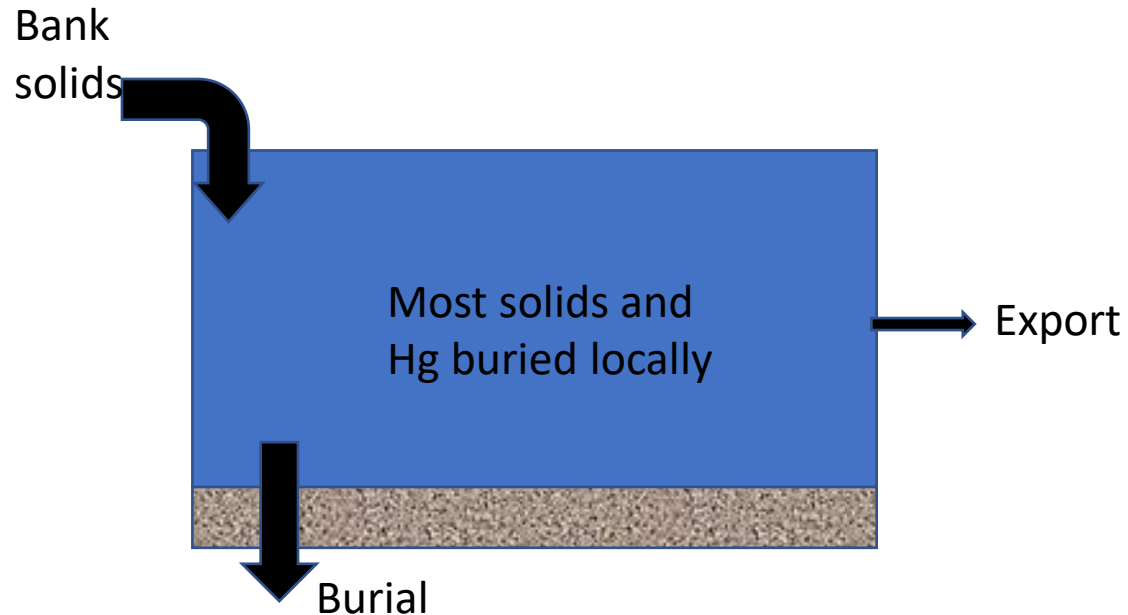
Average Solids Load Estimates to Model Cells 2006-2014



Are solids buried or moving downstream?



a) More feedback from sediments to water.

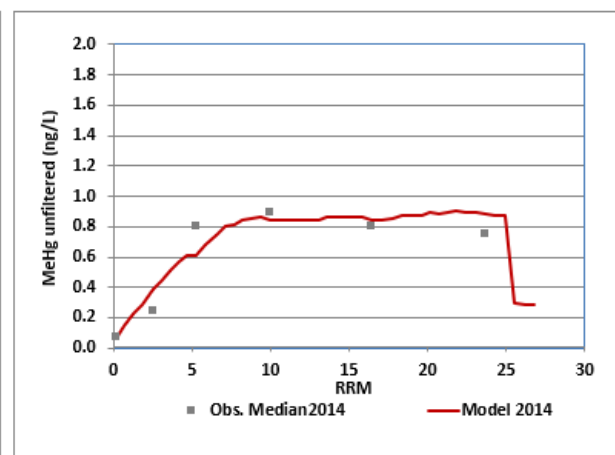
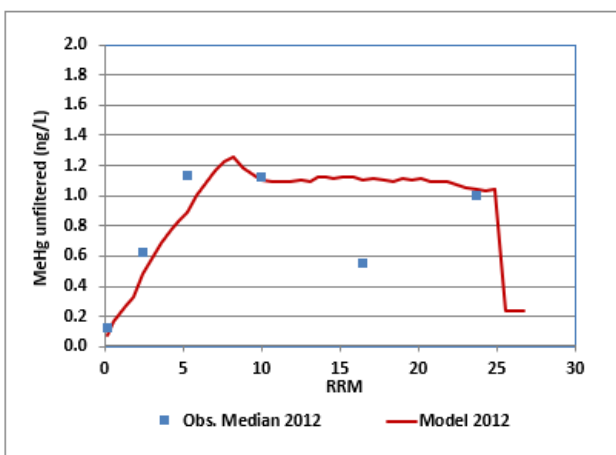
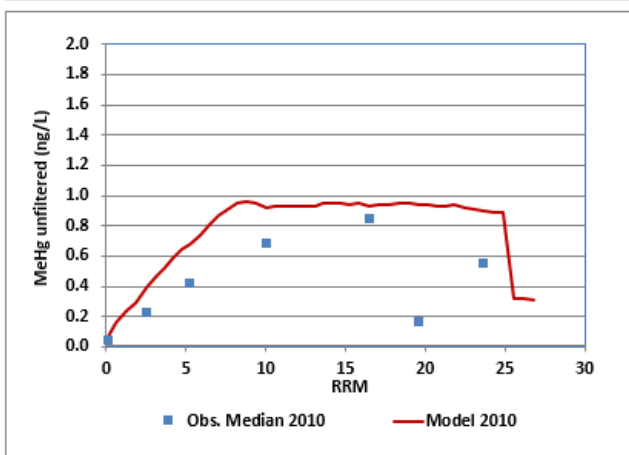
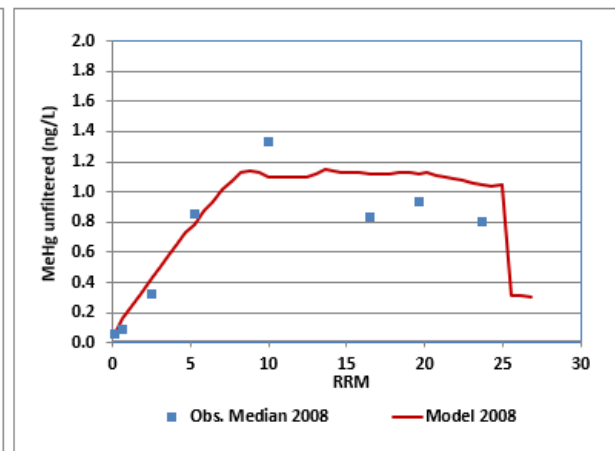
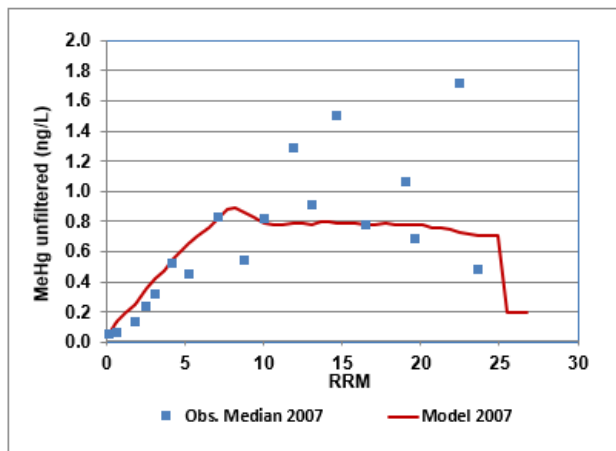
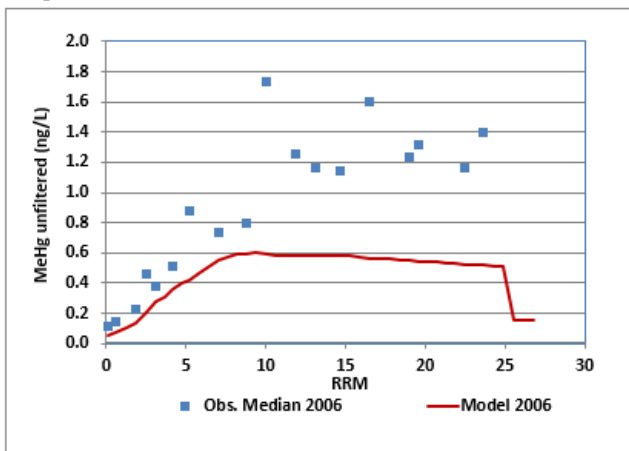


b) Less feedback from sediments to water.

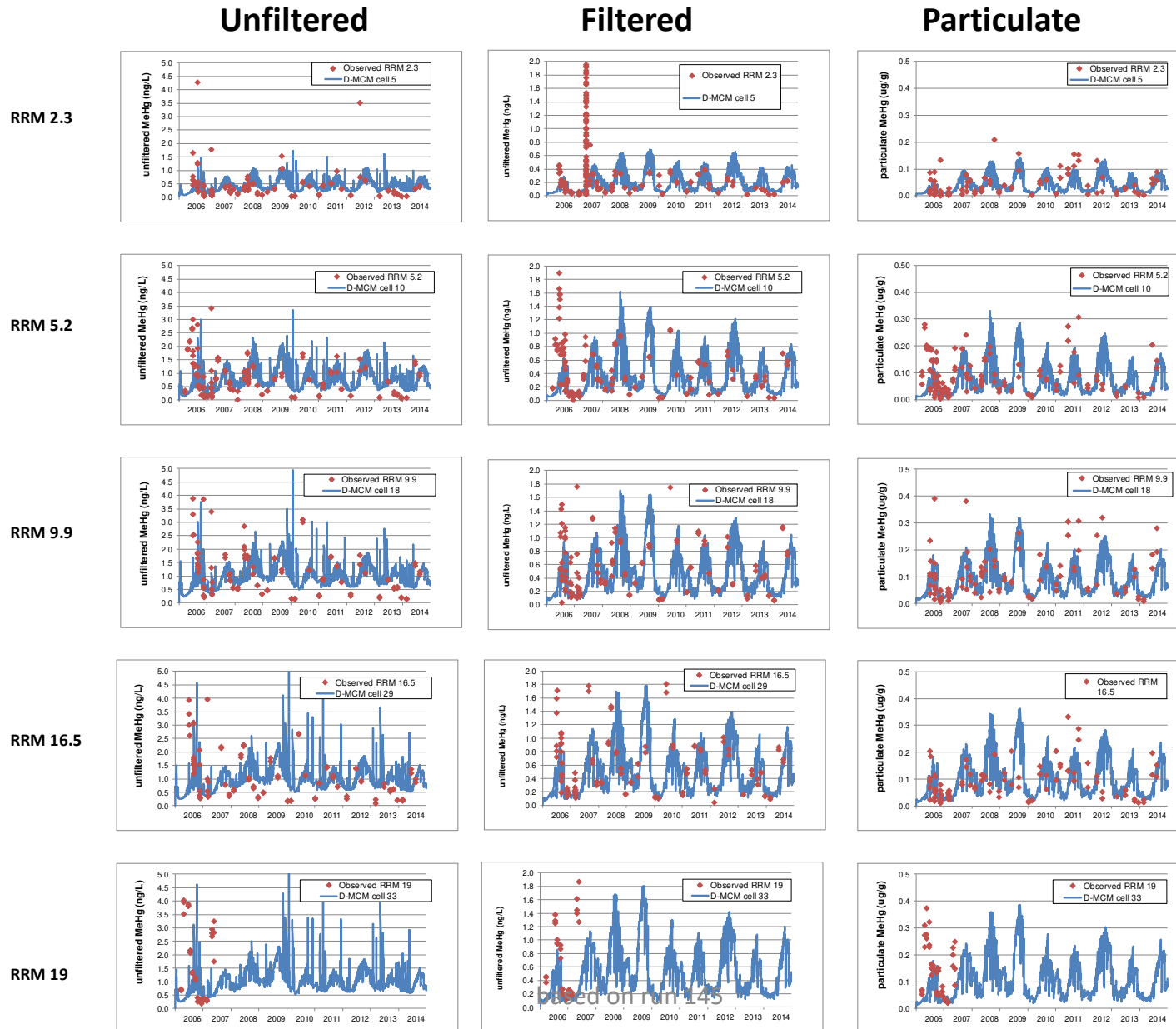
Mercury Calibration

Model Calibration – Bulk Methylmercury in water (ng/L unfiltered)

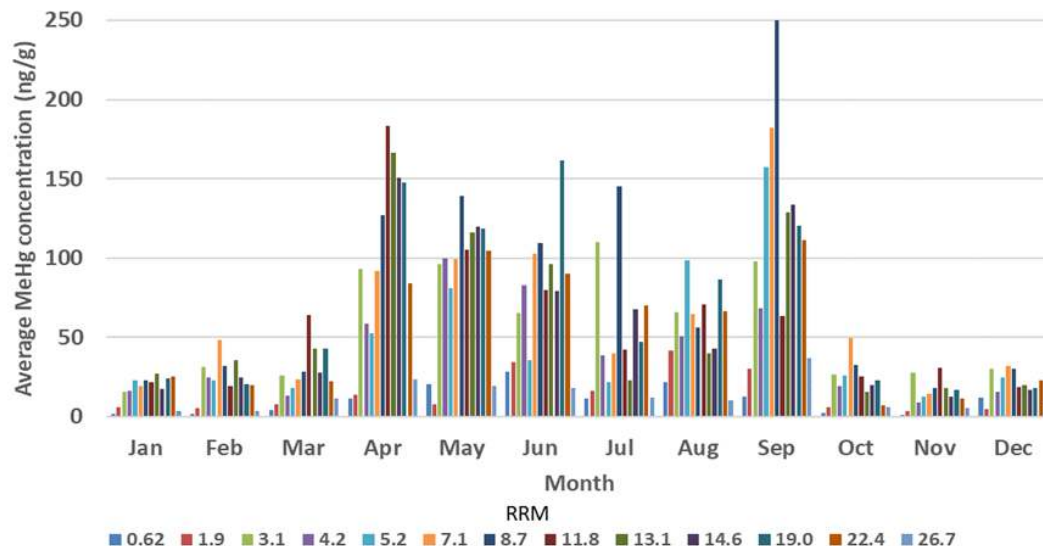
MeHg unfiltered (ng/L)



Model Calibration – MeHg concentration in water vs time at different locations

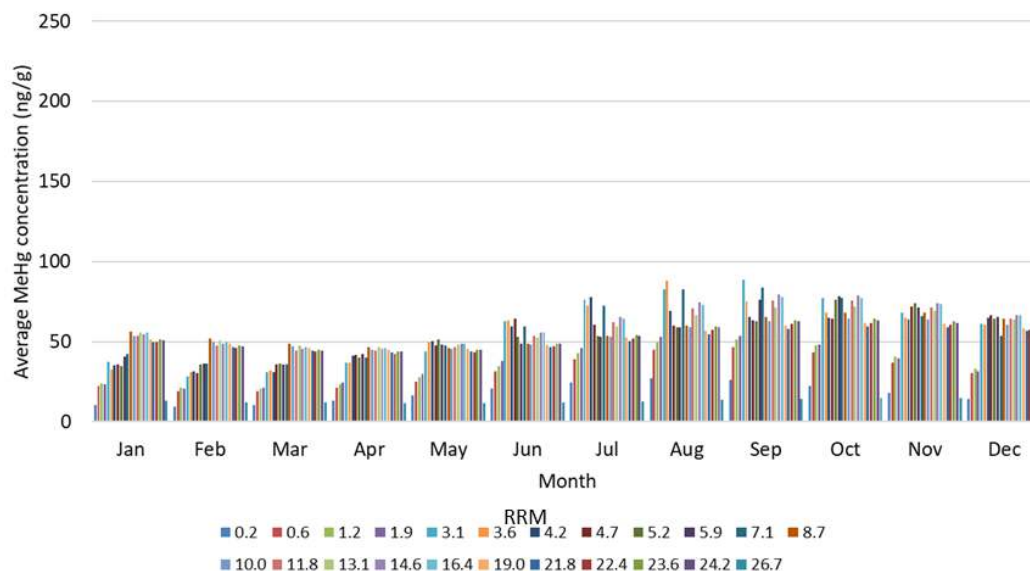


a) Field data



**MeHg concentrations
in sediments,
averaged by river
mile from 2006-2014**

b) Simulated

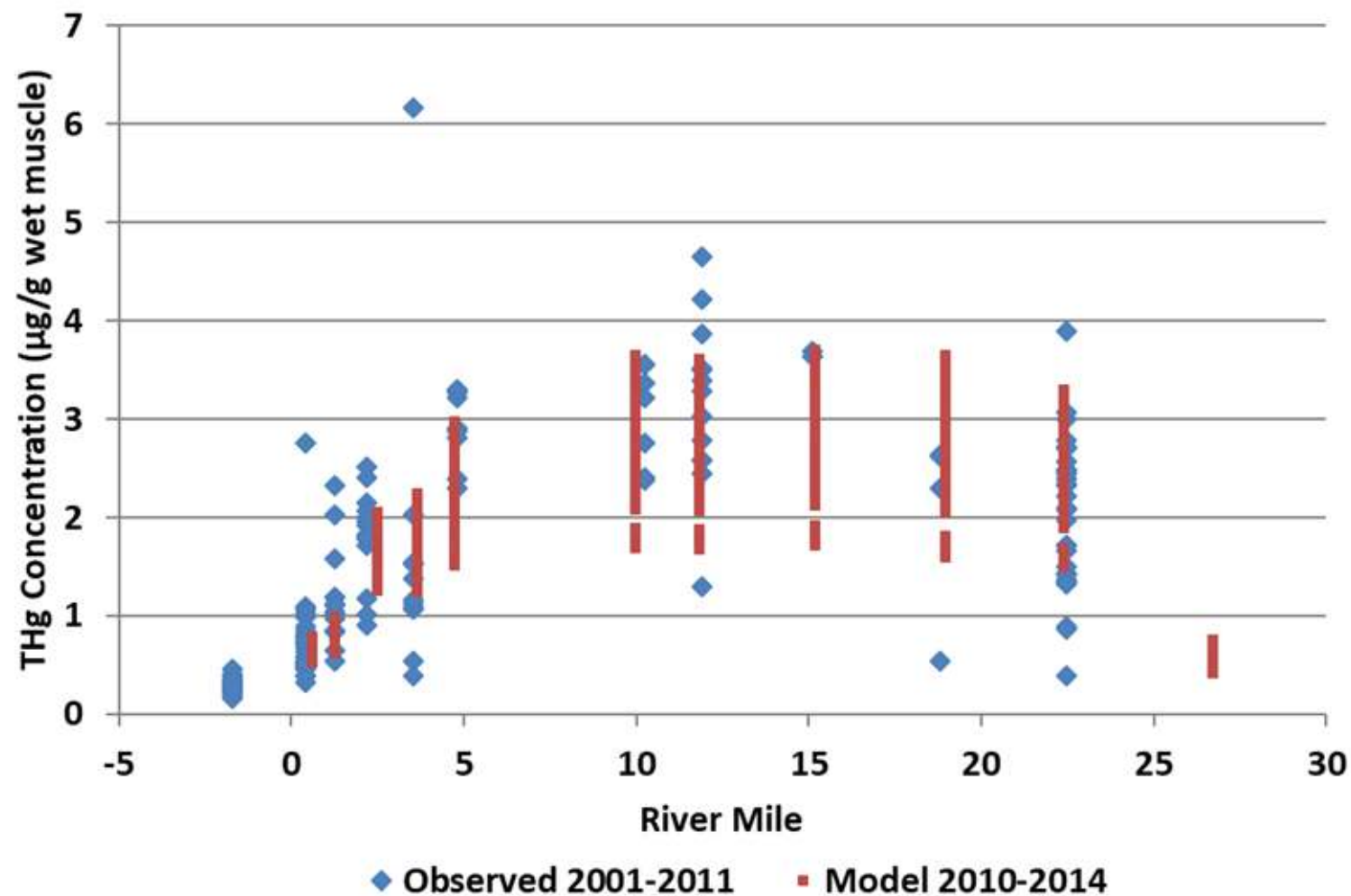


Some factor other
than temperature is
causing MeHg in
increase in Spring.....

Pulse of:

- organics?
- sulfate?
- Bioavailable Hg?

Model Calibration – MeHg in 250-300 mm Smallmouth Bass (µg/g)



Model Calibration – MeHg in 250-300 mm Smallmouth Bass ($\mu\text{g/g}$)

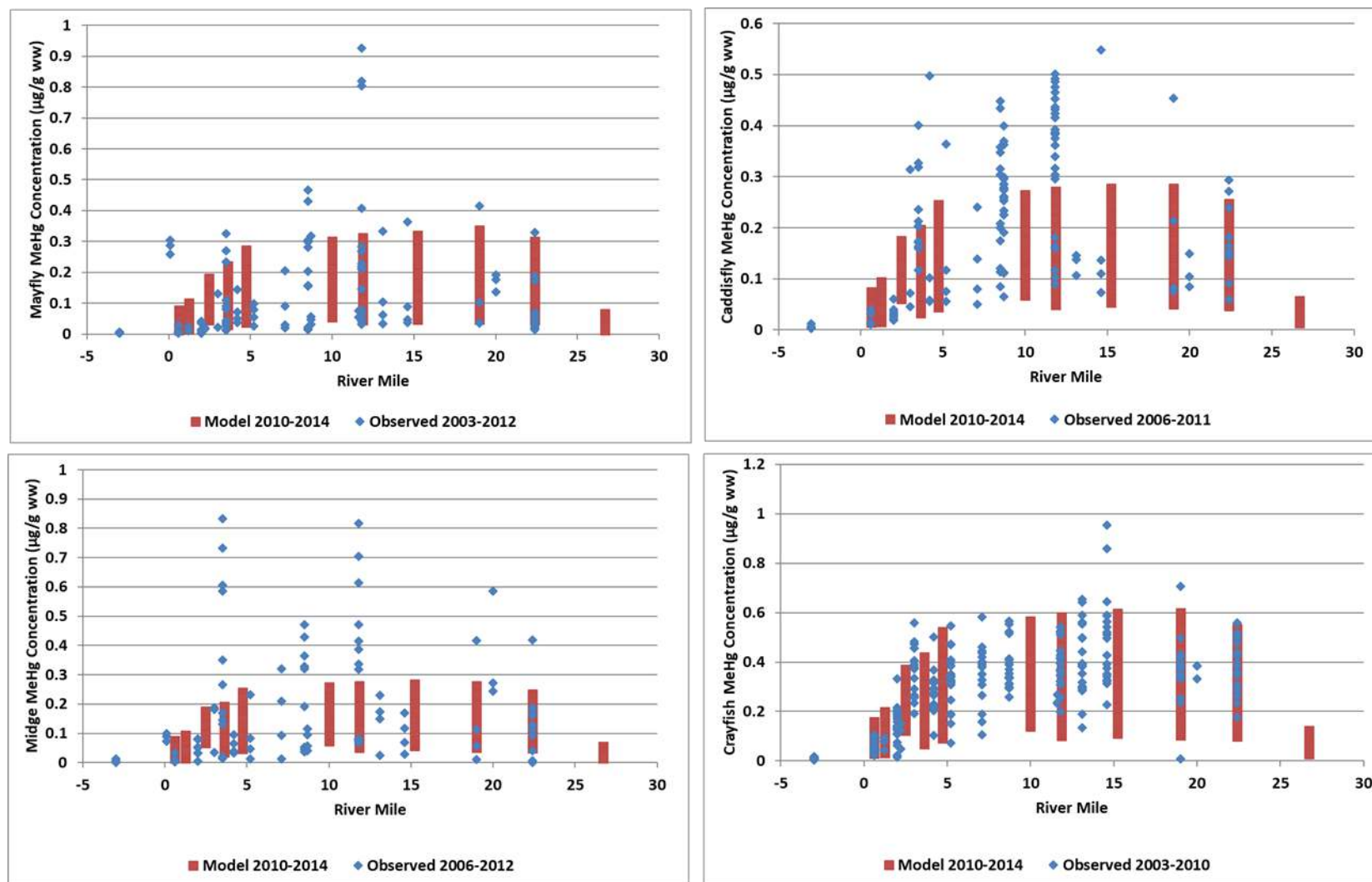


Figure 63. Simulated and observed MeHg concentrations in mayfly, caddisfly, midge and crayfish. Blue diamonds are individual samples. Red squares are simulated values for biota from 2012-2014. Data from Collins (2016b).

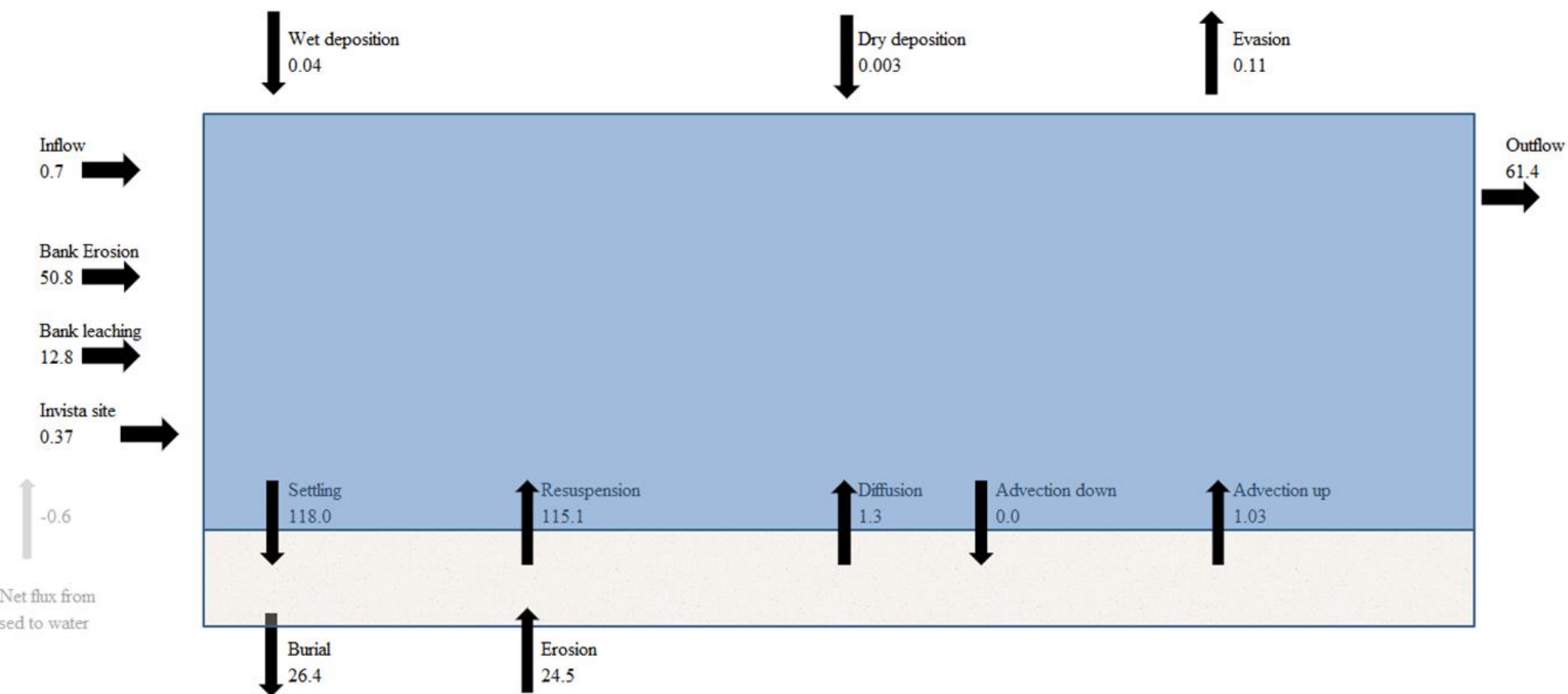
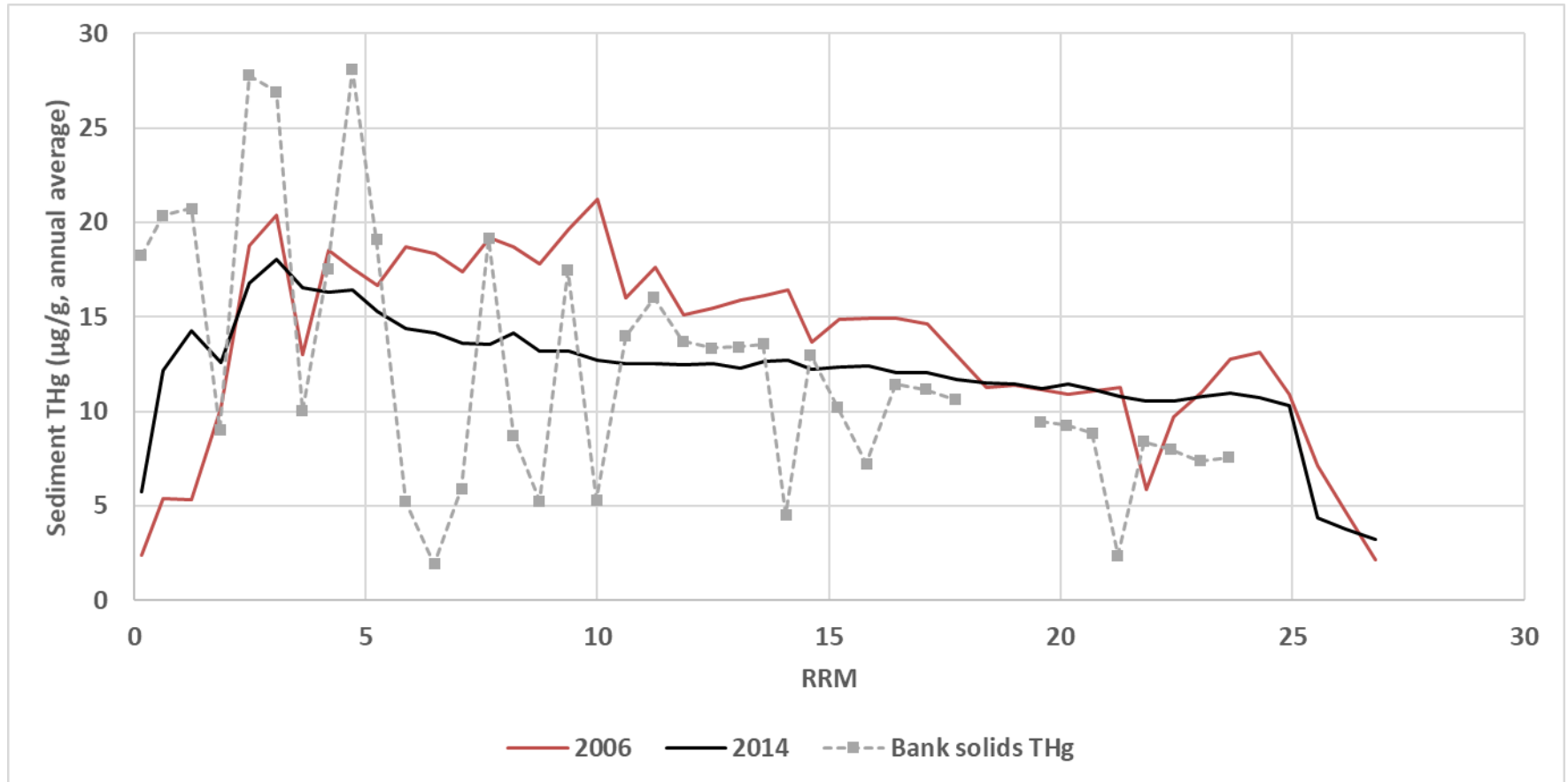


Figure 1. Model mass balance for inorganic Hg in the water column and surface sediments (0-2 cm), averaged from the former DuPont facility site to the confluence with the North River, for 2006-2014 (kg/yr)

Are sediment Hg concentrations stabilizing at levels based on Hg supplied from a mix of bank solids and inflowing solids from upstream?



Relationship between MeHg and THg

Is the relationship between MeHg and THg linear? (probably no..)

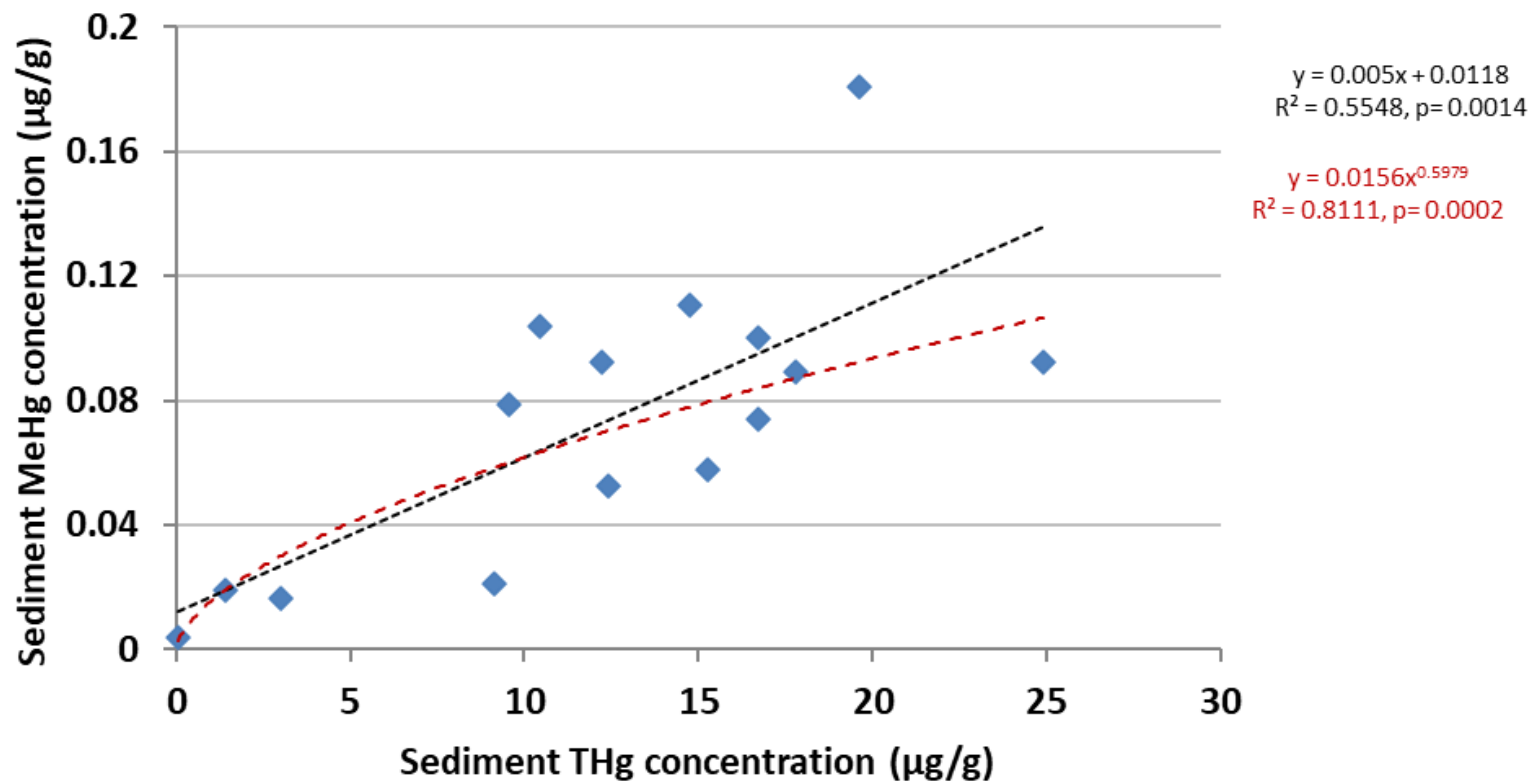


Figure 1. Relationship between MeHg and THg in South River surface sediments (<3 cm) using average concentrations for each sampling location (RRM 0.6 to 26). Each location used paired data from March-September 2006). Derived from (Collins, 2018a).

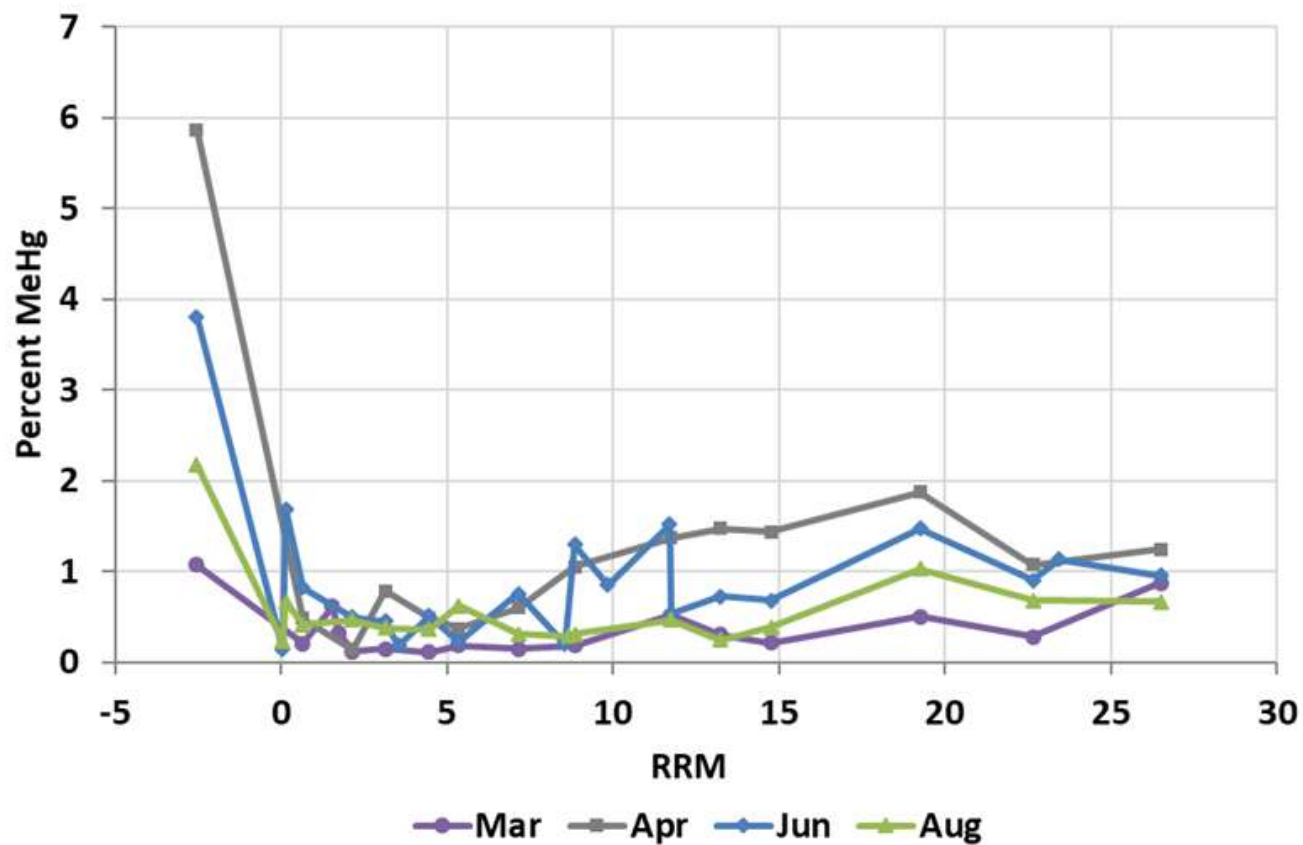
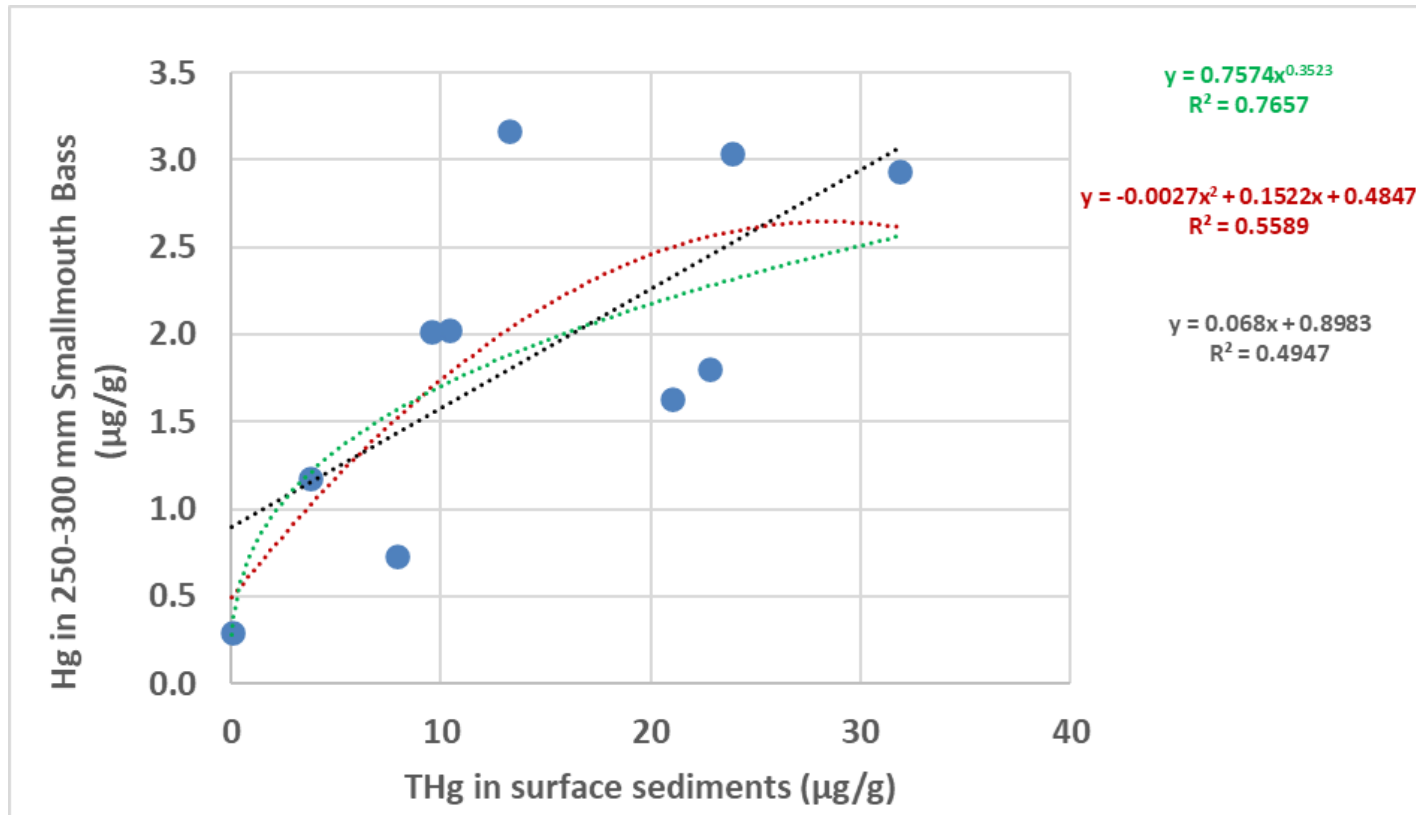


Figure 1. Percent MeHg in South River surface sediments (<3 cm) from RRM -2.5 to 26.4. Paired data from samples collected from 2005-2012. Derived by D. Hutchinson from (Collins, 2018a).

Relationship between Hg in Smallmouth Bass and Sediments - Data paired by RRM



Remediation Scenarios

Predicted response to Phase 1 and 2 remediation

Table 4. Solids and mercury loads associated with base case and Phase 1 remediation for RRM 0-2 (model cells 1-4).

Derived from Grosso (2018).

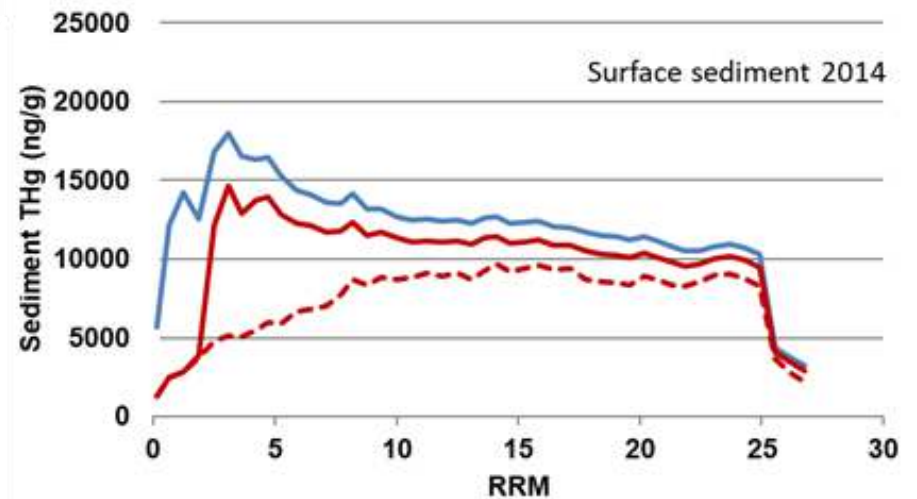
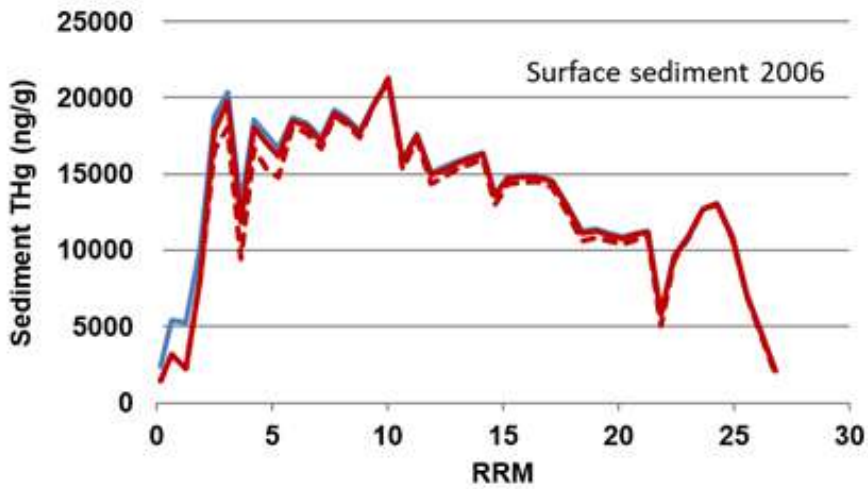
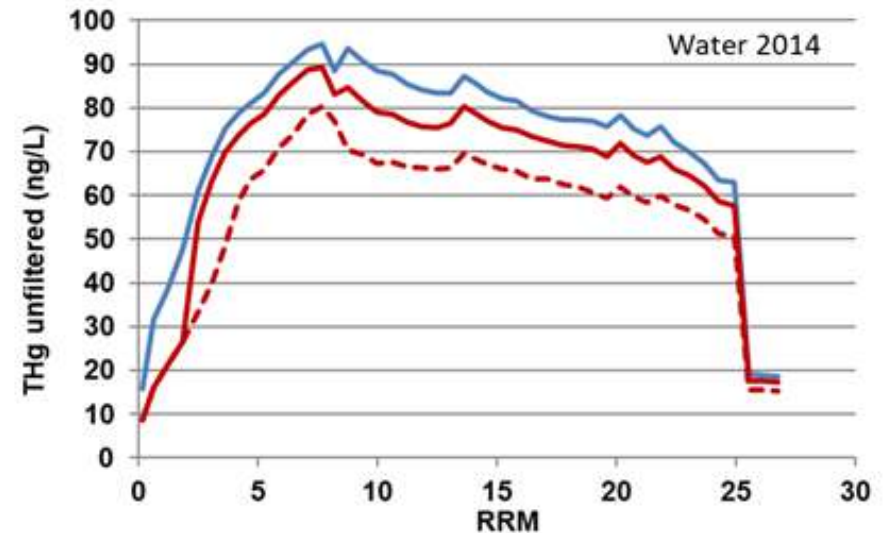
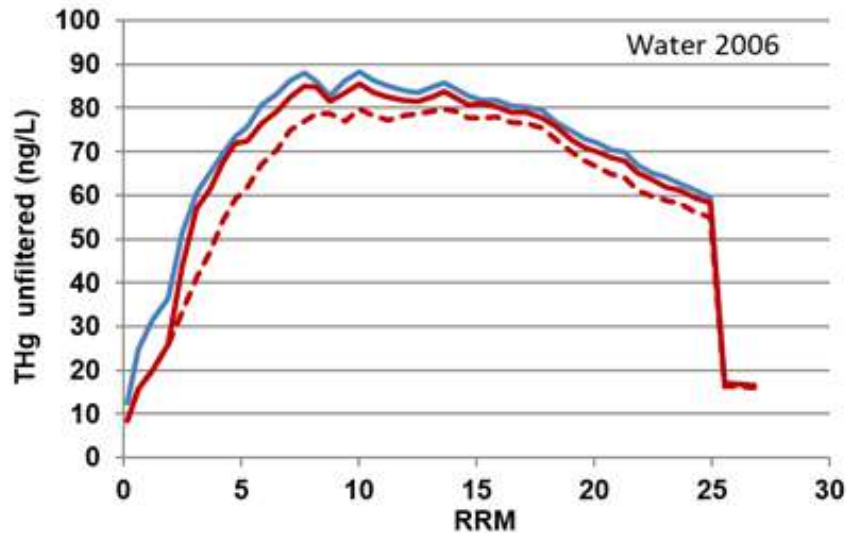
Model Cell	Solids load (kg/yr)			THg load (kg/yr)			THg concentration (µg/g)		
	Base Case	Remediation	% Reduction	Base Case	Remediation	% Reduction	Base Case	Remediation	% Reduction
1	190,768	119,915	37	3.48	0.17	95	18.24	1.45	92
2	391,166	216,696	45	7.97	0.67	92	20.39	3.08	85
3	342,694	138,069	60	7.10	0.51	93	20.72	3.71	82
4	205,282	181,897	11	1.86	0.66	64	9.04	3.62	60
Total	1,129,910	656,578	42	20.41	2.01	90			

Table 5. Solids and mercury loads associated with base case and Phase 2 remediation for RRM 2-5 (model cells 5-9).

Derived from Grosso (2018).

Model Cell	Solids load (kg/yr)			THg load (kg/yr)			THg concentration (µg/g)		
	Base Case	Remediation	% Reduction	Base Case	Remediation	% reduction	Base Case	Remediation	% Reduction
5	263,090	103,000	61	7.31	0.58	92	27.79	5.68	80
6	236,166	49,806	79	6.36	0.39	94	26.91	7.83	71
7	173,861	111,256	36	1.74	0.64	63	10.02	5.75	43
8	180,450	79,373	56	3.17	0.42	87	17.56	5.32	70
9	92,777	28,171	70	2.61	0.32	88	28.08	11.51	59
Total	946,344	371,606	61	21.18	2.36	89			

Predicted Effects of Phase 1 and 2 Remediation (imposed January 1, 2006)



— Base Case — Phase 1 remediation - - - Phase 2 remediation

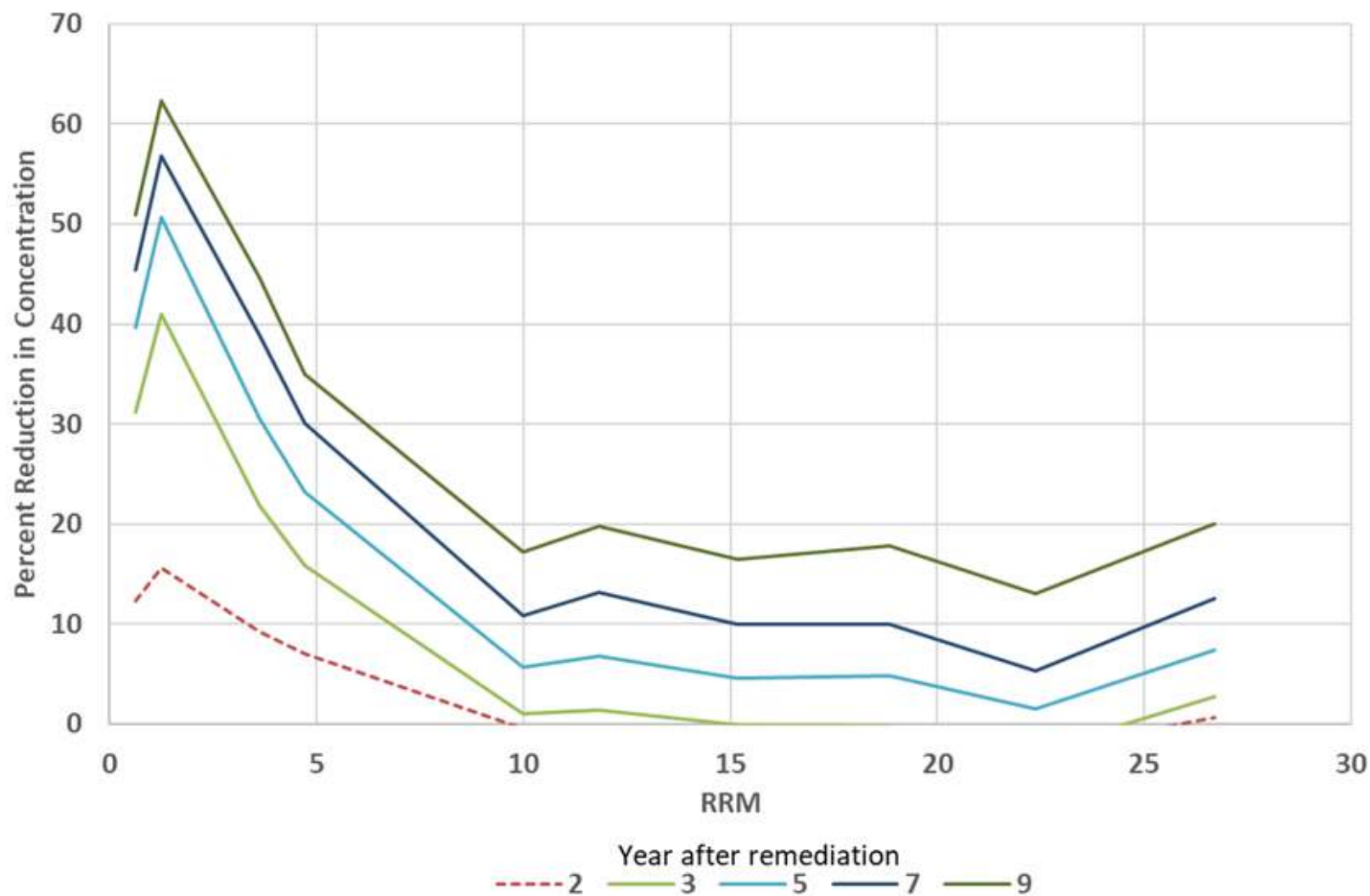


Figure 71. Predicted percent reduction in MeHg concentrations in 250-300 mm smallmouth bass from 2006-2014 due to Phase 1 plus Phase 2 remediation.

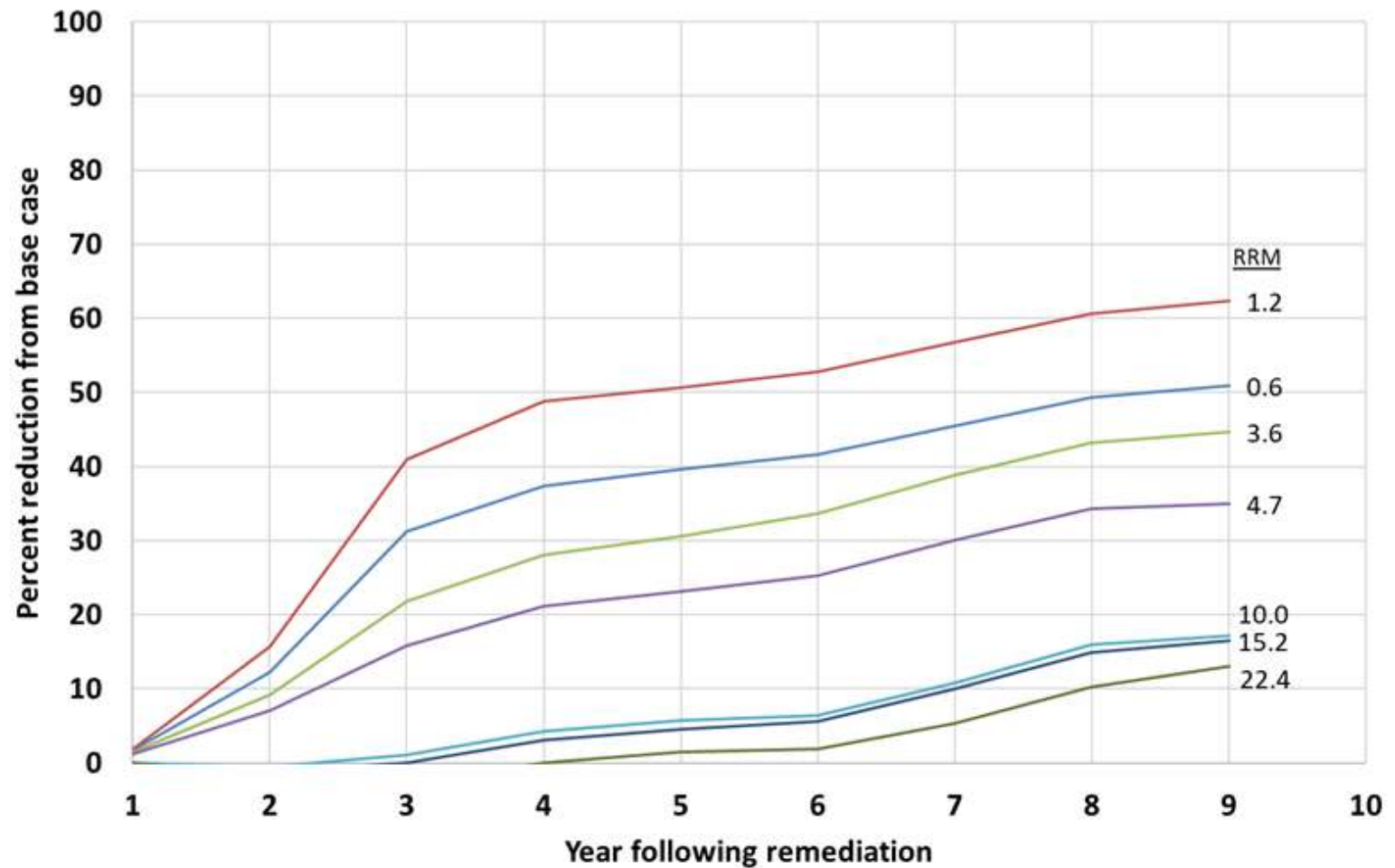


Figure 73. Predicted percent reduction in MeHg concentrations in 250-300 mm smallmouth bass versus time. Values are average declines during year after remediation. Reductions in bank leaching not invoked.

Predicted Effect of Reduced Bank Leaching of Hg

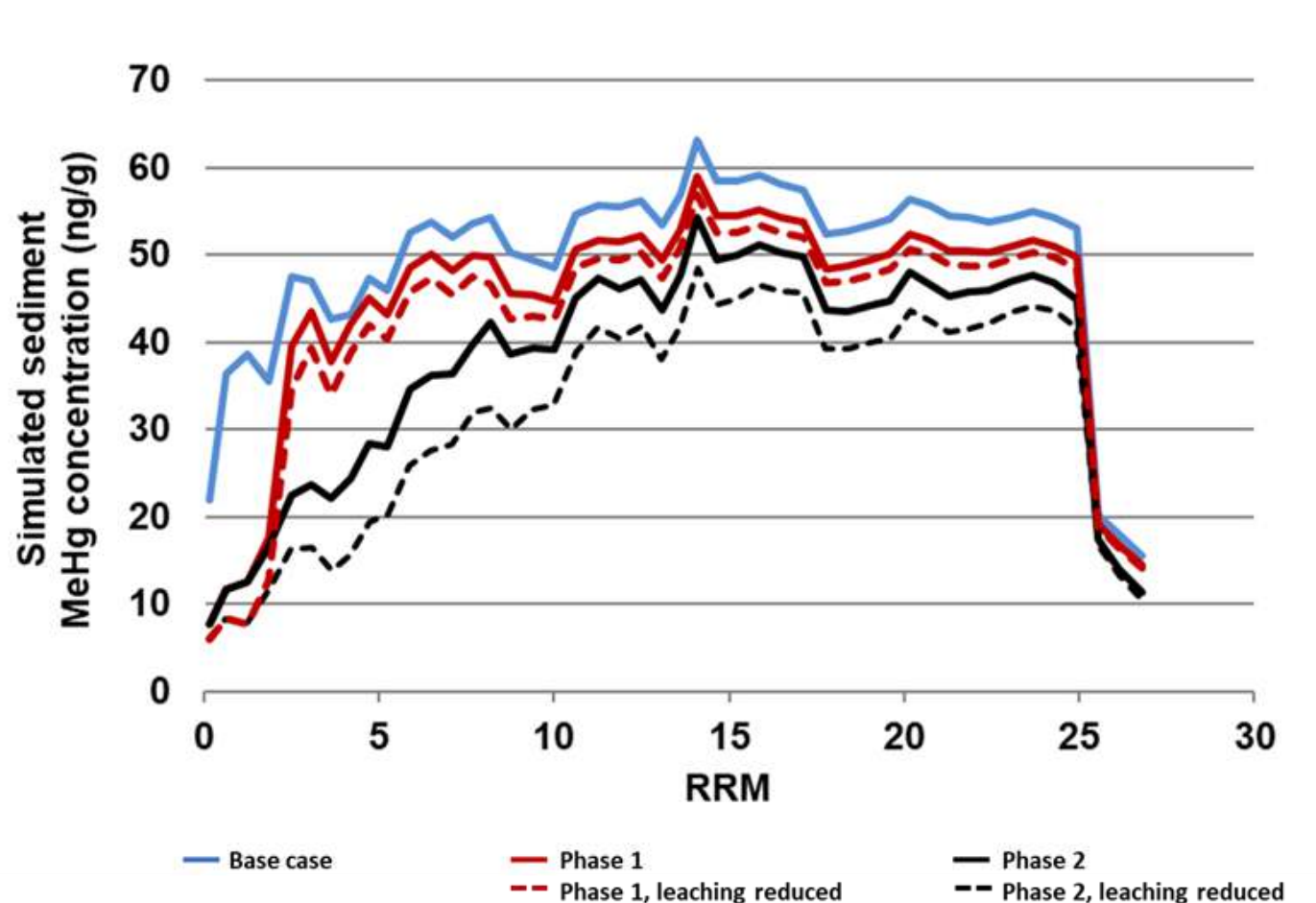


Figure 74. Simulated median MeHg concentrations in surface sediments (0-2 cm) in 2014 for the base case calibration and remediation scenarios. Dashed lines show the predicted incremental effects when bank leaching of inorganic Hg(II) is reduced by the same amounts as inorganic Hg(II) loads for Phase 1 and Phase 2 remediation.

Summary

- **Model captured:**
 - General magnitude and spatial trends of total Hg and MeHg in water, sediments and biota
 - Some of the seasonality observed for total Hg and MeHg in water.
- **River banks are largest source of mercury**
 - Mostly from solids; some leaching
- **Particle dynamics are very important, affecting:**
 - Ongoing supply of mercury from banks
 - Natural rate of recovery
 - Downstream movement of contamination
 - Benefits of bank stabilization.
- **Remediation**
 - Bank stabilization beneficial
 - Benefits emerged over time
 - Benefits greater near remediation locations (RRM 0-5), up to ~60% decline in MeHg in water and fish.
- **Primary uncertainties for modeled remediation:**
 - Particle dynamics and role of high flow events
 - MeHg/Hg(II) relationship (pool of Hg(II) available for methylation)
 - Sensitivity analysis points to importance of quantifying leaching.
 - Are solids erosion rates overestimated for RRM 0-5?

Recommendations

(to improve ability to anticipate effects of remediation)

- Improve understanding of particle budgets (sources, sinks, fate)
- Continue to examine relationship between MeHg and THg in system
- Revisit estimates of solids loads and bank leaching (magnitude and timing)
- Examine whether Phase 1 results consistent with conceptual and numerical models.