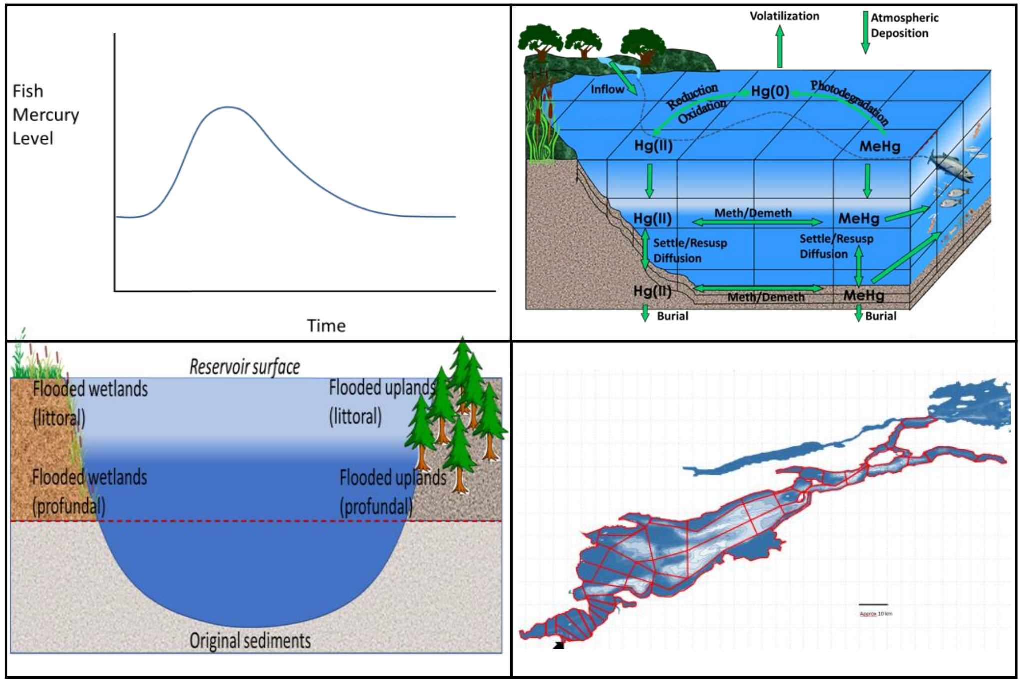
Mercury Modelling Update for Muskrat Falls Reservoir and Downstream



Presented by Reed Harris
December 18, 2017

Outline

- Brief comments on observed MeHg in reservoir to-date.

- Reservoir Modelling
  - Regression modelling
  - Mechanistic modelling
  - Calder et al. Model

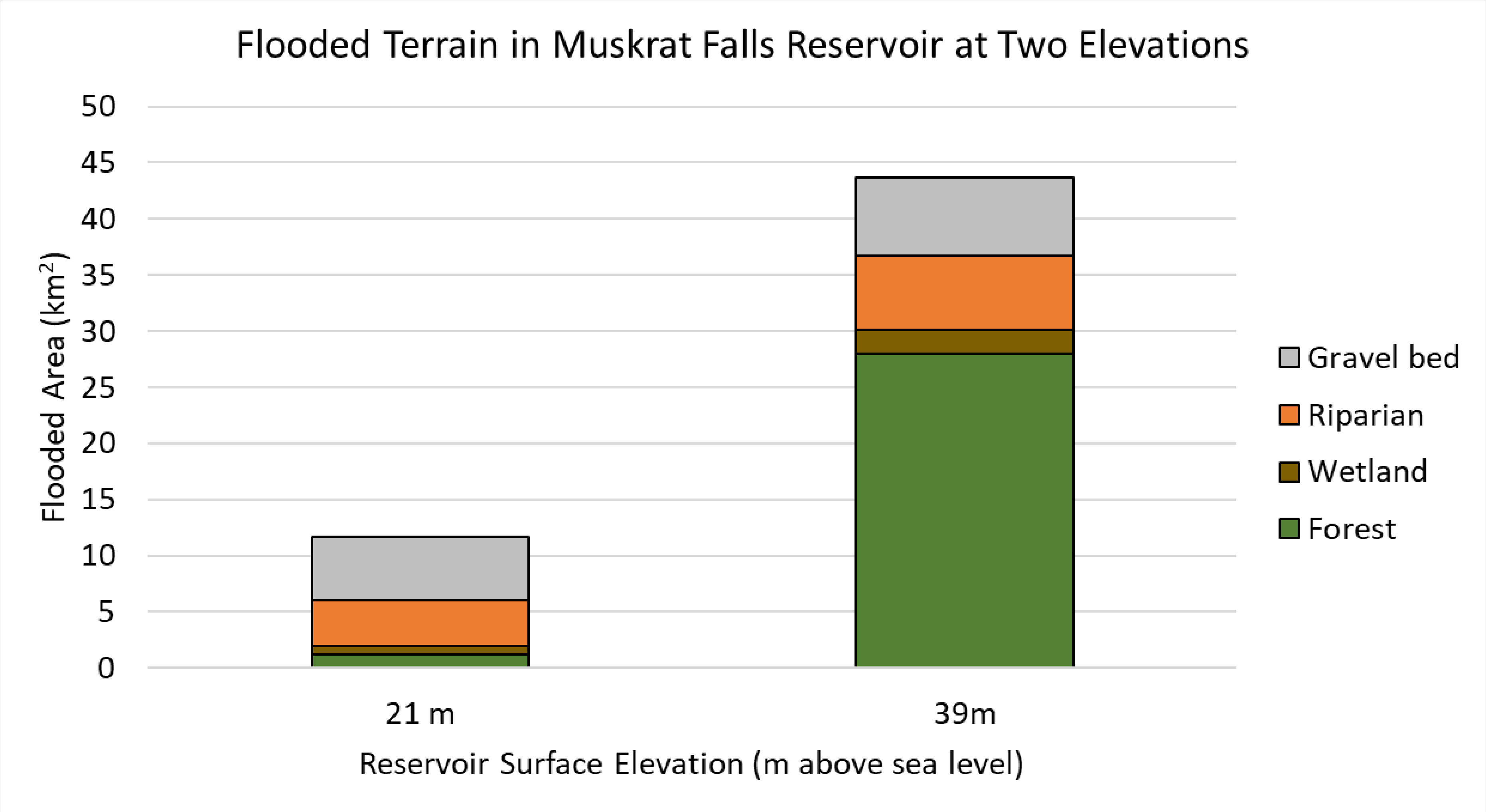
- Modelling downstream of Muskrat Falls

- Next Steps

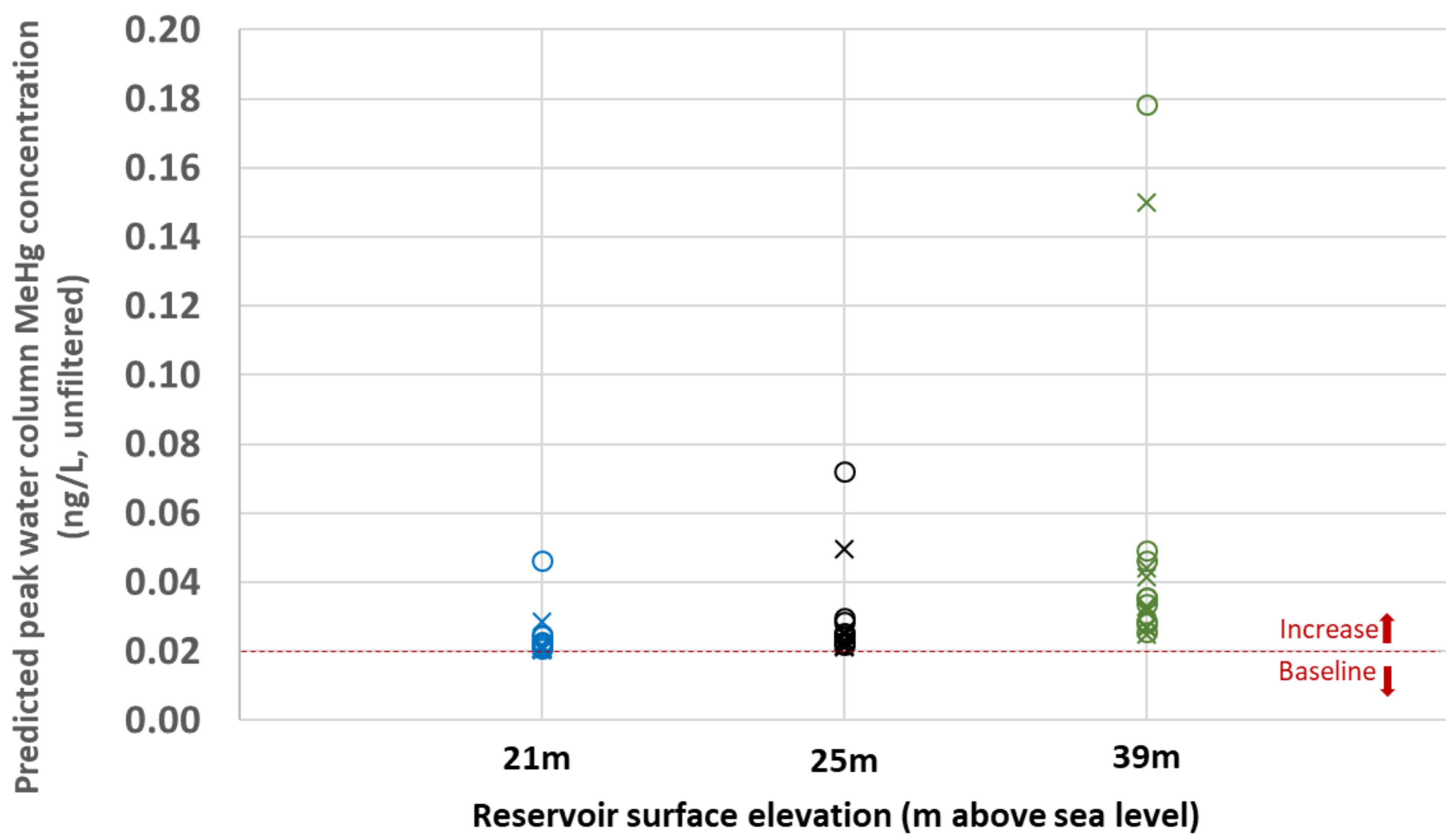
- Schedule

Existing and Future Flooded Areas

- Much of the flooding at 21 m is riparian and gravel bed.



Predicted peak methylmercury concentrations in Muskrat Falls Reservoir using a range of areal loading rates from the flood zone.



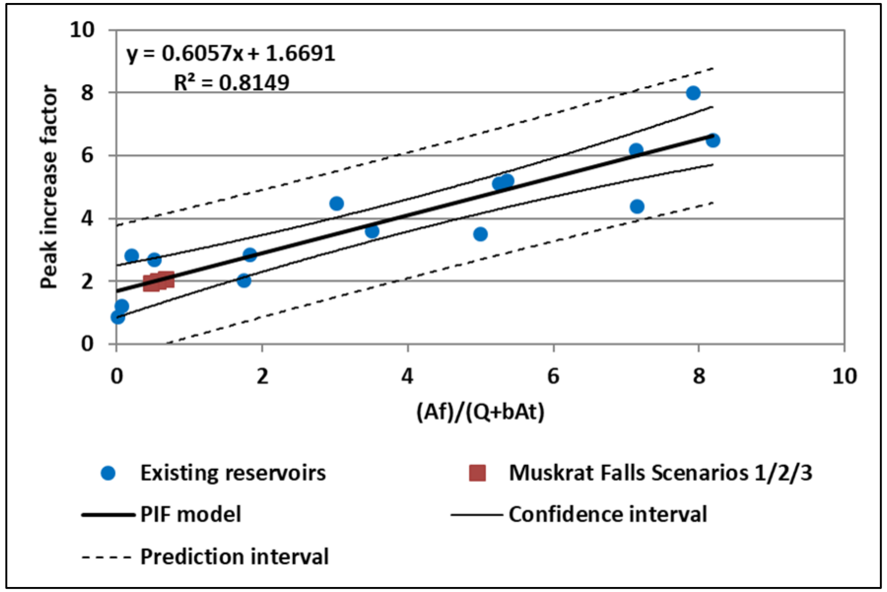
Circles include riparian and gravel bed flooding. X's excludes riparian and gravel bed flooding
Increase = Estimated MeHg load from flood zone m ixed into mean annual flow

Values are based on a simple calculation:

- Start with a range of MeHg loading rates (per m^2) from flooded soils from different studies:
    - ELA flooded upland experiments (FLUDEX)
    - Schartup *et al* (2015) soil core incubations
    - Harris *et al* previous RESMERC model applications to ELA and 2 full scale reservoirs
    - Calder *et al* (2016)
- Multiply these rates by the flooded areas at each elevation (21, 25, 39 m)
- In each case, divide the load by the mean annual flow at Muskrat Falls.
- The result is a range of predicted increases in water column MeHg concentration.
- Add the predicted increase to a baseline concentration (0.02 ng/L) to estimate the overall concentration (y axis in figure).

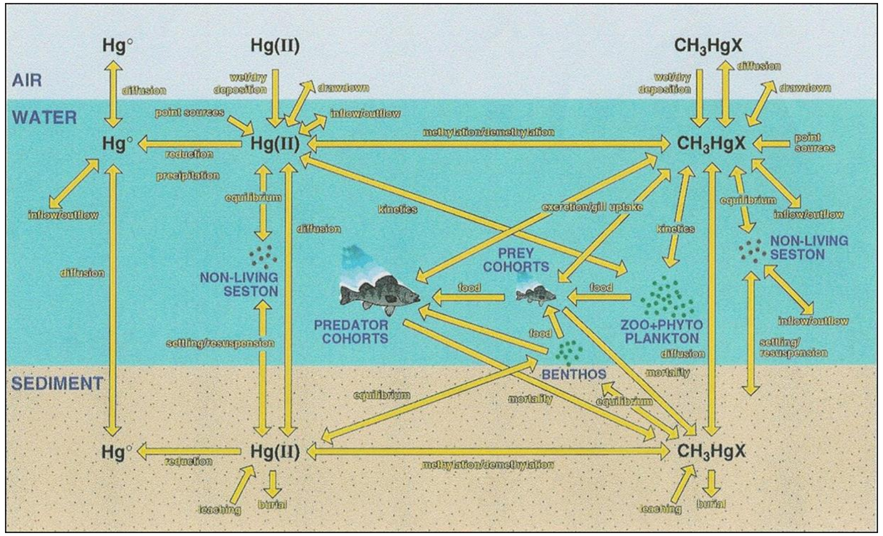
Reservoir modelling: Two approaches

Simple regression model based on extent of flooding and flow.
(only predicts peak fish Hg)



Mechanistic model (RESMERC) predicts THg and MeHg in water, sediments and biota vs time

- Allows scenario testing.



Regression Modelling

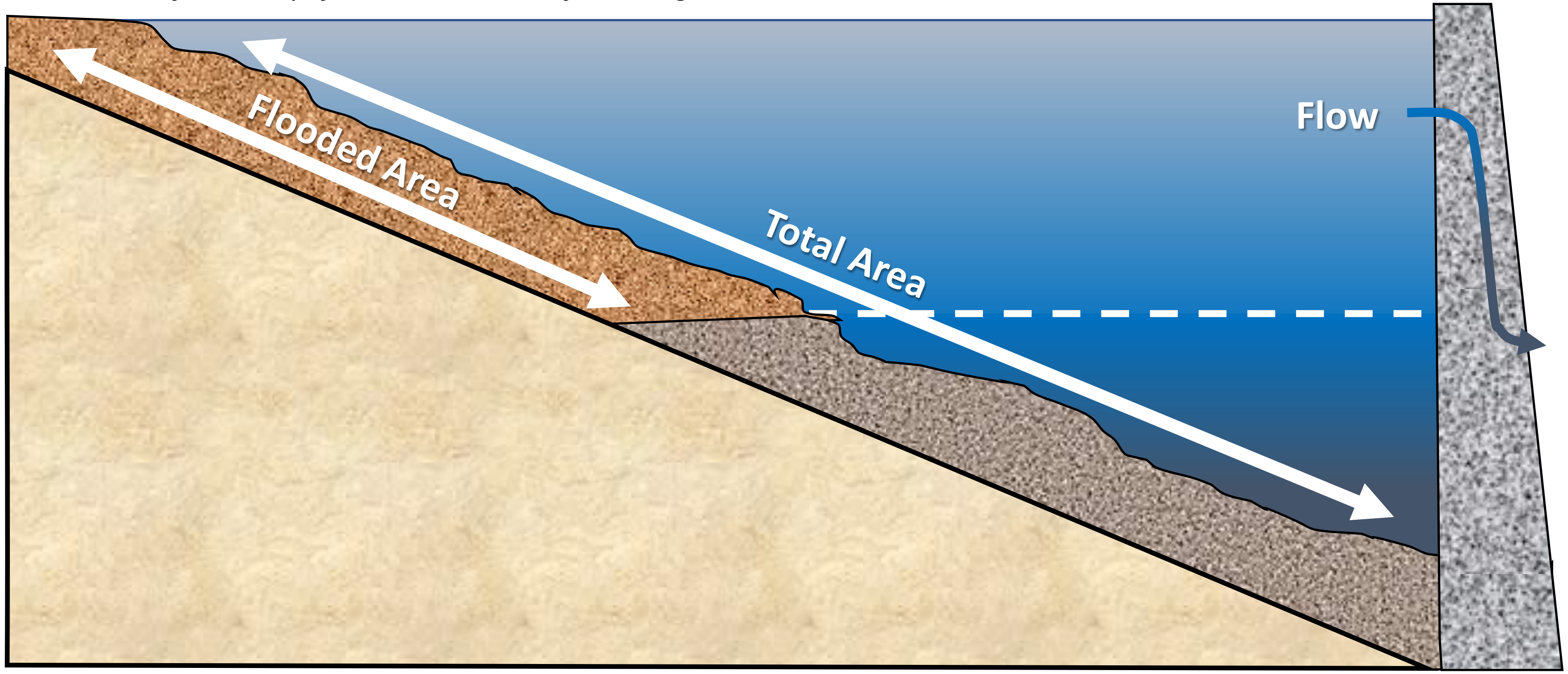
Form of regression model…

Peak Concentration or Relative Increase $= 1 + k_1 \left(\frac{A_{flooded}}{(Q + k_2 A_{total})} \right)$

Where:

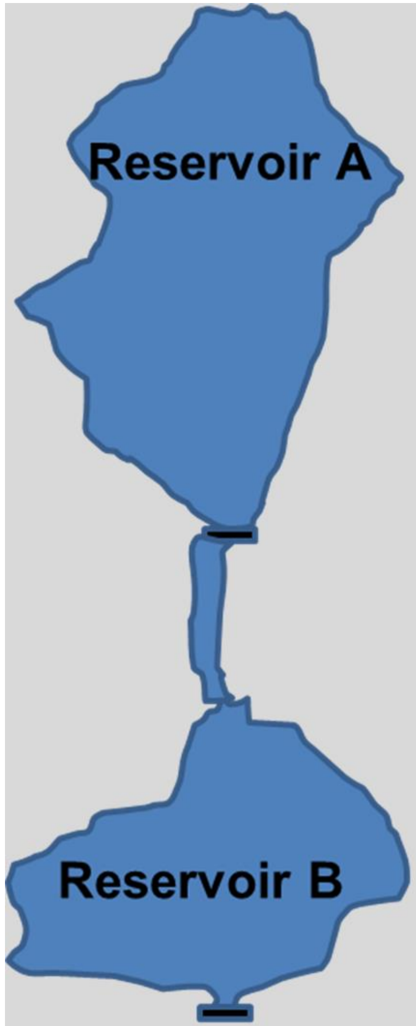
$A_{flooded}$	= flooded area (km^2)
Q	= mean annual flow (km^3/yr)
k_1	= regression coefficients (km/yr)
k_2	= regression coefficients (km/yr)
A_{total}	= Total reservoir area (km^2)

Derived from simplified mass balance for MeHg sources and sinks in reservoirs



Reservoirs in Series

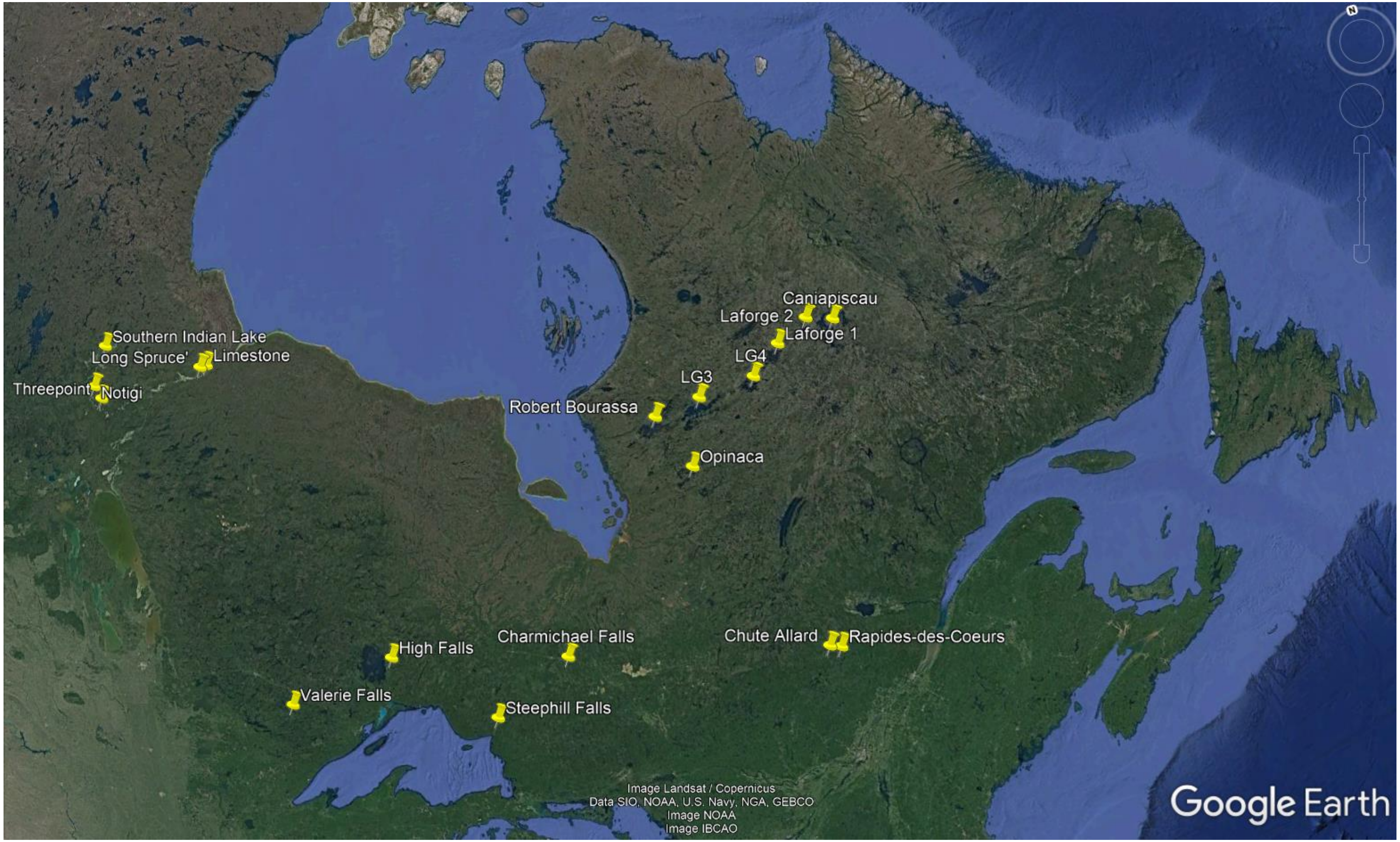
Treated as one reservoir that gets bigger traveling downstream



For example at left, predictions for Reservoir B would be estimated using combined areas of Reservoirs A and B if:

- ✓ **Reservoirs flooded <10 yrs apart**
- ✓ **Travel time between reservoirs less than a threshold (optimized to 1 week with model)**
- ✓ **No large new flow introduced between reservoirs**

Reservoirs used in development of regression models



Sites with northern pike data used in model analysis

(n= 12 large, 7 small)

Site	Year flooded	Site specific baseline data	Northern pike sampling, years post flood																																	
			0	1	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Large sites (>20 km^2)																																				
Caniapiscau, QC	1982							■		■		■		■		■		■		■				■				■					■			
Opinica, QC	1980						■		■		■		■		■		■		■				■				■			■		■		■		
Laforge 2, QC	1983								■		■		■		■		■		■				■				■					■				
Laforge 1, QC	1984					■		■		■		■		■		■		■				■				■					■					
La Grande 4, QC	1983						■		■		■		■		■		■		■				■				■			■		■				
La Grande 3, QC	1981							■		■		■		■		■		■		■		■				■				■				■		
R. Bourassa, QC	1979					■		■		■		■		■		■		■		■		■		■				■				■				■
Southern Indian Lake, MB	1976				■	■	■	■	■	■	■	■	■	■	■				■		■															
Notigi, MB	1975						■					■	■	■	■	■	■	■			■		■													
Threepoint, MB	1977						■		■	■	■	■	■	■	■		■	■		■																
Limestone, MB	1990	1989	■	■	■	■	■																													
Long Spruce, MB	1977										■	■			■			■	■																	
Small sites (<20 km^2)*																																				
High Falls, ON[1]	1992	1989																		■																
Carmichael Falls, ON	1991	1989				■																														
Steephill Falls, ON	1990	1990							■																											
Umbata Falls, ON	2008	2004		■		■		■																												
Shekak[1]	1995	1993			■			■													■															
Quebec 1	2008	1990						■																												
Quebec 2	2008	1990						■																												

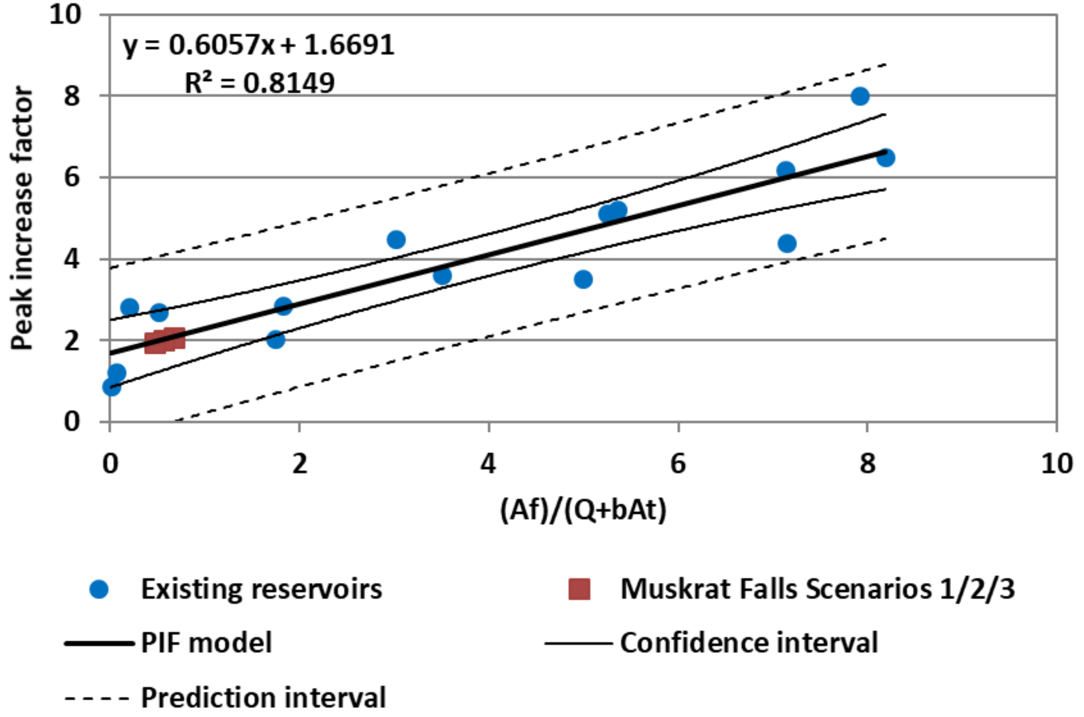
[1] – Not used in model calibrations

* All small sites < 10 km^2 except Steephill Falls (17.7 km^2)

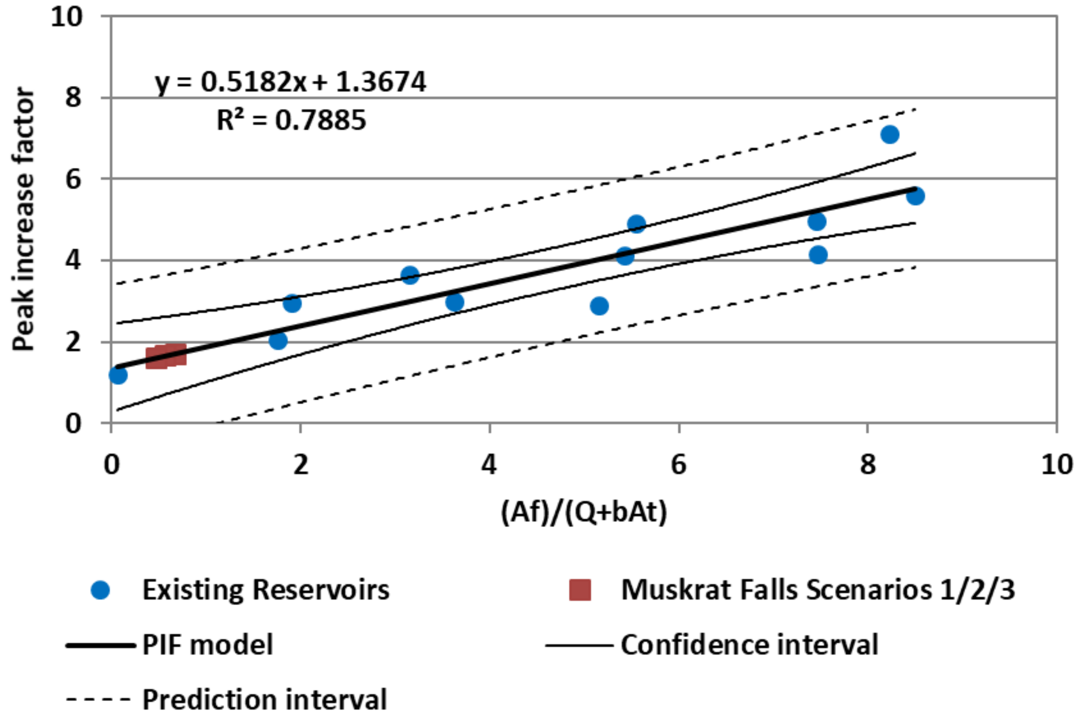
Relative Increase Model Applied to Muskrat Falls Reservoir

Peak concentration = PIF x Baseline concentration

55 cm Northern Pike



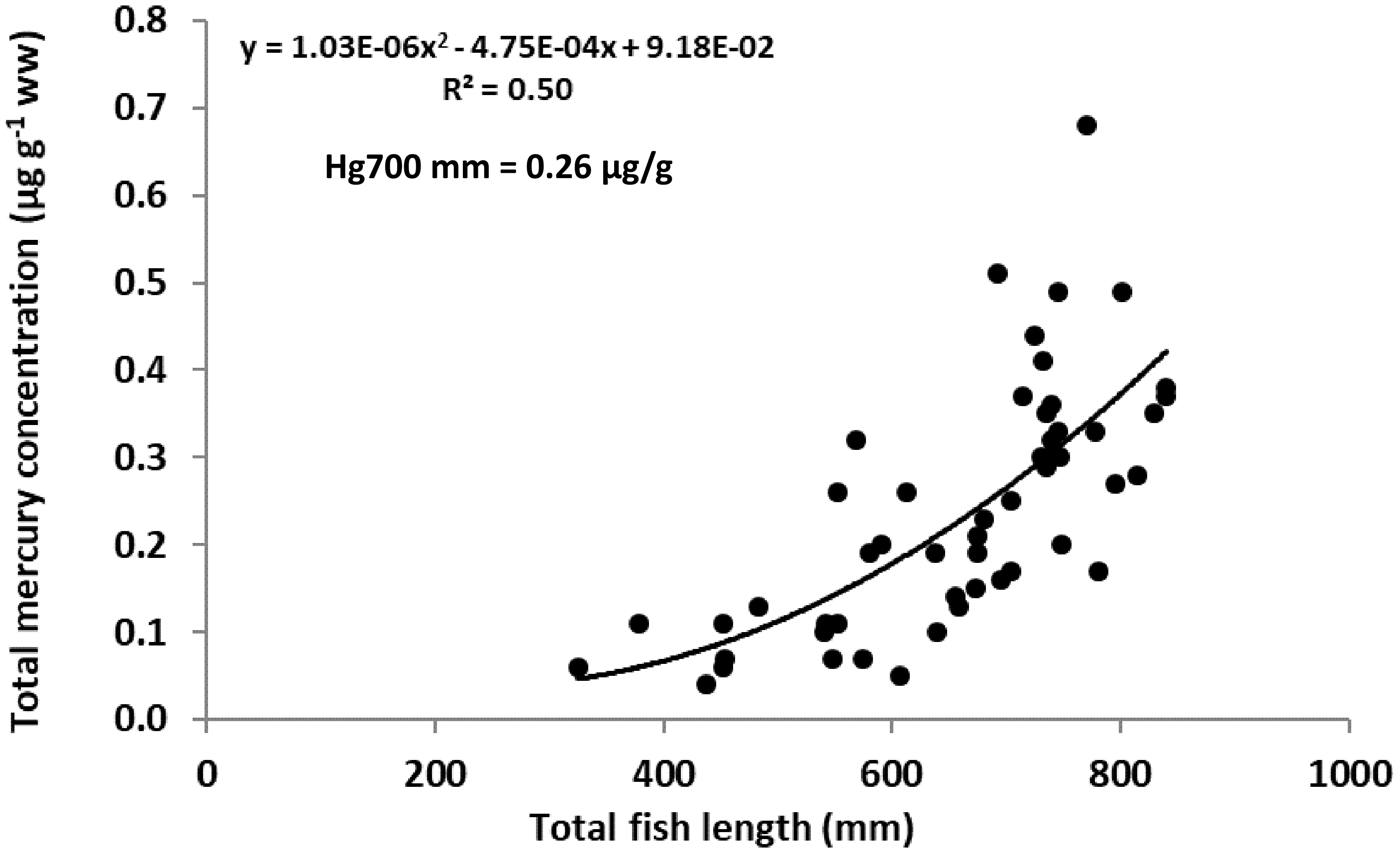
70 cm Northern PIke

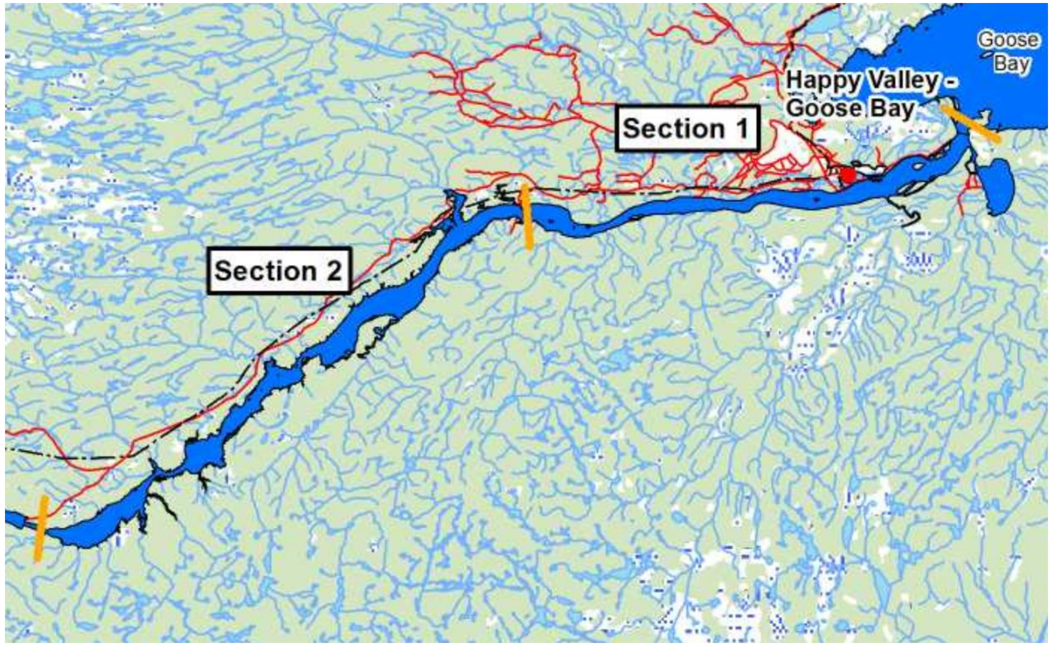


These models predict roughly a doubling of Hg in adult pike
-but baseline fish Hg was higher in the regions where these data came from.

Scenarios represent different assumptions about effect of flooded gravel beds and riparian zones.

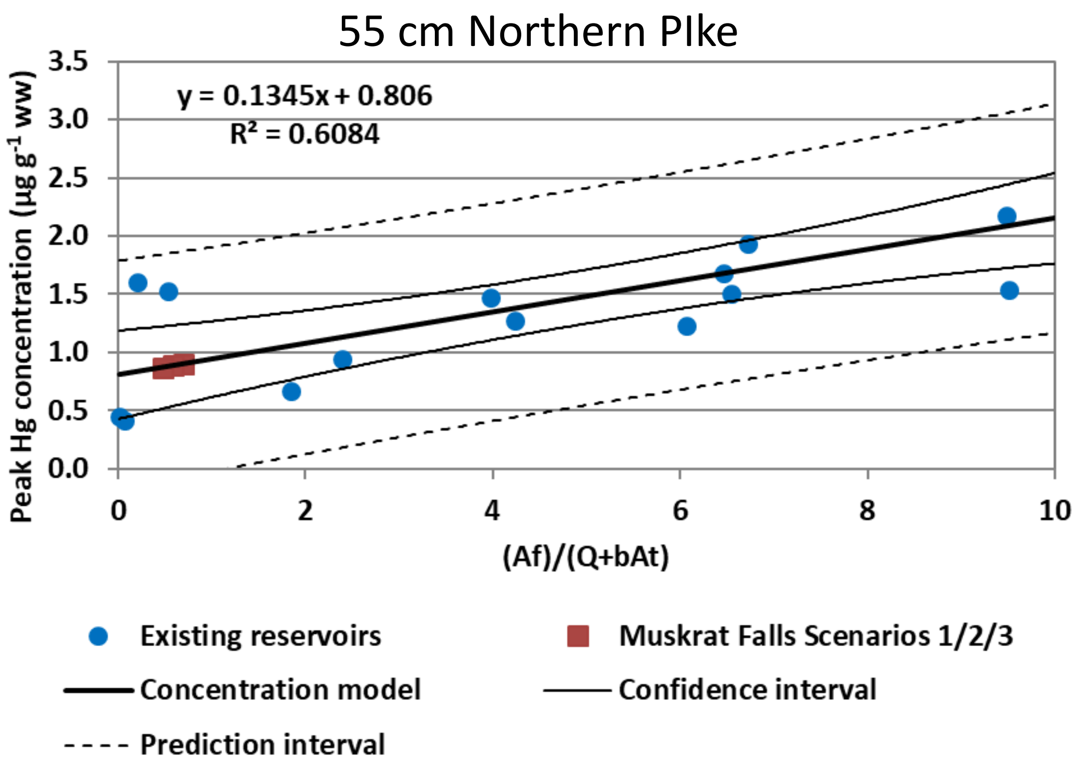
Northern pike mercury concentrations vs length for reservoir area (River Section 2)

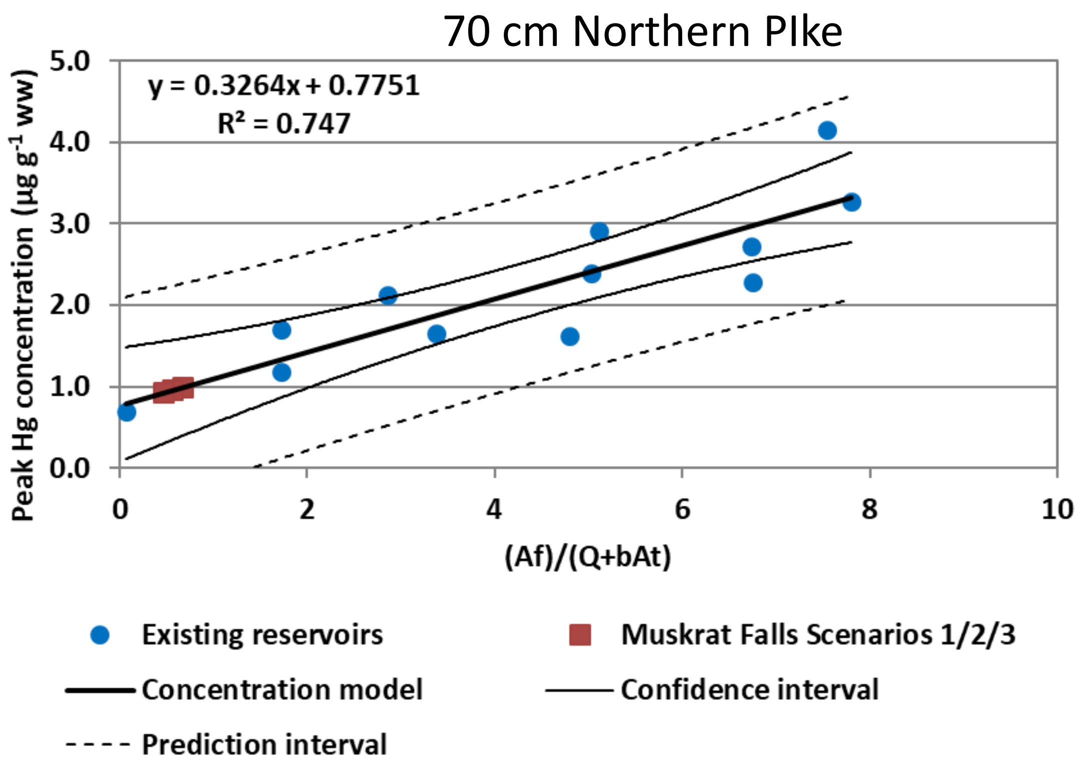




Peak Concentration Model

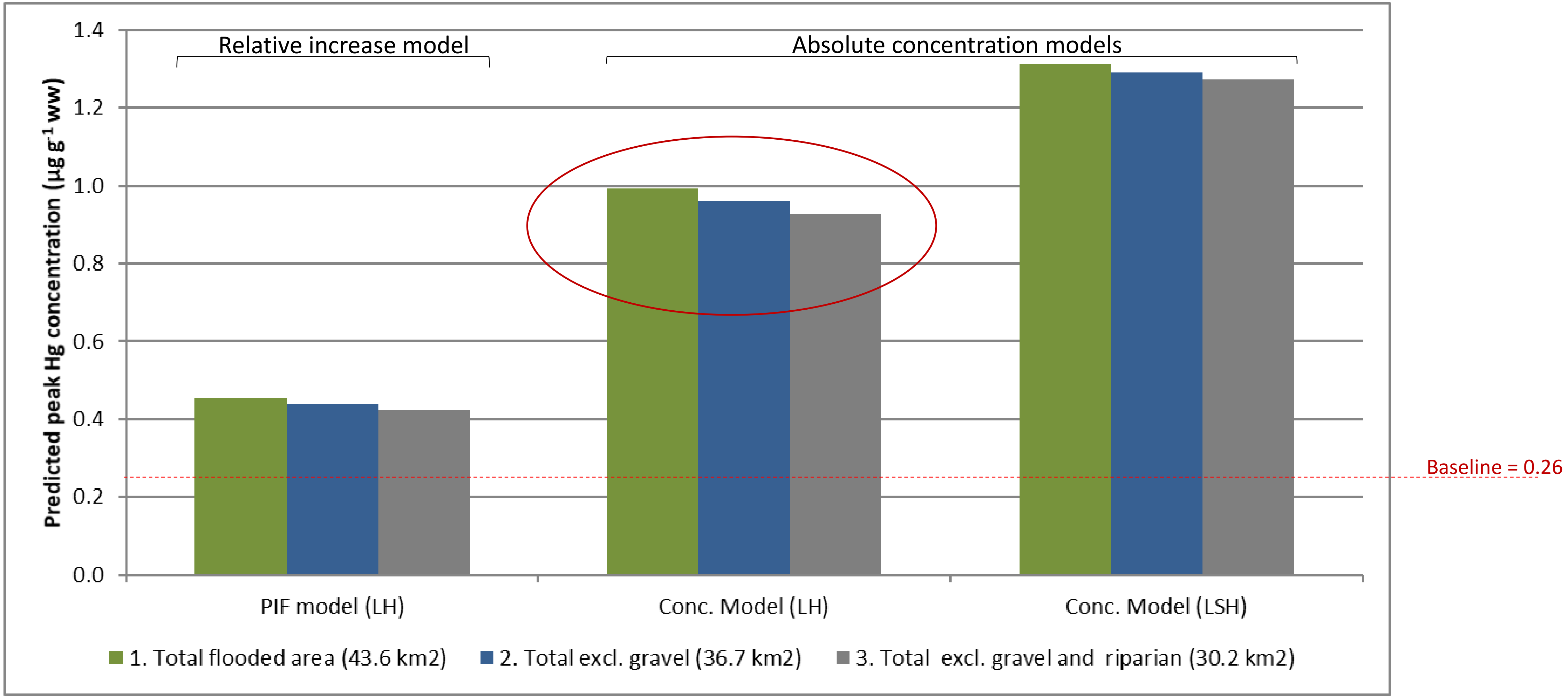
Does not consider baseline. Only flooding and flow matter.





These models predict peak Hg ~ 0.9 µg/g in adult Northern Pike
- But the starting point is about 0.8 µg/g with no flooding..

Regression model predictions for 700 mm northern pike



PIF = Peak Increase Factor; LH = Large Hydro sites only (> 20 km^2); LSH = Large and Small Hydro sites

In 2009 we used a relative increase model, but baselines were often higher..

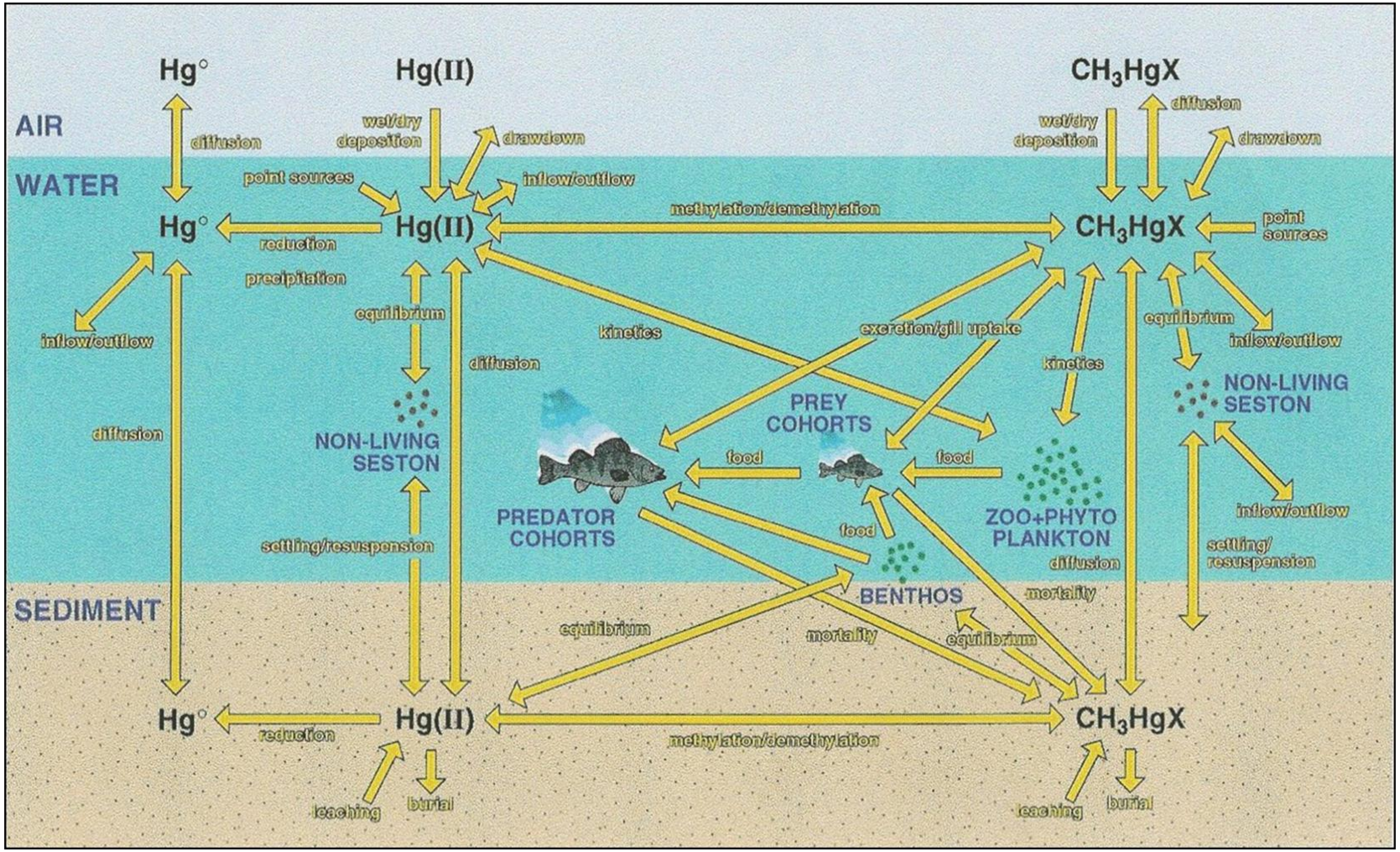
Table 1 Updated Peak Fish Hg Concentrations (Standard Lengths Related to Sample Means) Associated with the Project

Site	Species and Standard Length	Estimated Baseline Concentration	Peak Increase Factor Used	Predicted Peak Concentration		Maximum Concentration Observed from Smallwood Reservoir (Sandgirt or Lobstick)	Notes
Gull Island Reservoir		ug/g wet muscle		ug/g wet muscle	ug/g whole body	ug/g wet muscle	
	Lake Trout (600mm)	0.95	2.27	2.16	1.66	1.40	4
	Northern Pike (700 mm)	0.81	2.27	1.83	1.41	1.16	1
	White Sucker (400 mm)	0.26	2.27	0.60	0.46	0.32	6
	Longnose Sucker (400 mm)	0.25	2.27	0.57	0.44	0.44	3
	Lake Whitefish (400 mm)	0.19	2.27	0.42	0.32	0.34	2
	Brook Trout (300 mm)	0.08	6.00	0.49	0.38	No data	5
	Ouananiche (300 mm)	0.08	6.00	0.48	0.37	No data	7
Muskrat Falls Reservoir and Downstream	**Species and Standard Length**	**Estimated Baseline Concentration**	**Peak Increase Factor Used**	**Predicted Peak Concentration**		**Maximum Concentration Observed for Winokapau Lake or Gull Lake**	
(if different to above)							
	Lake Whitefish (400mm)	0.19	4.94	0.91	0.70	0.75	8
	Longnose Sucker (400 mm)	0.25	3.24	0.81	0.63	0.80	9
	White Sucker (400mm)	0.26	2.27	0.60	0.46	0.34	10

From response to IR 156

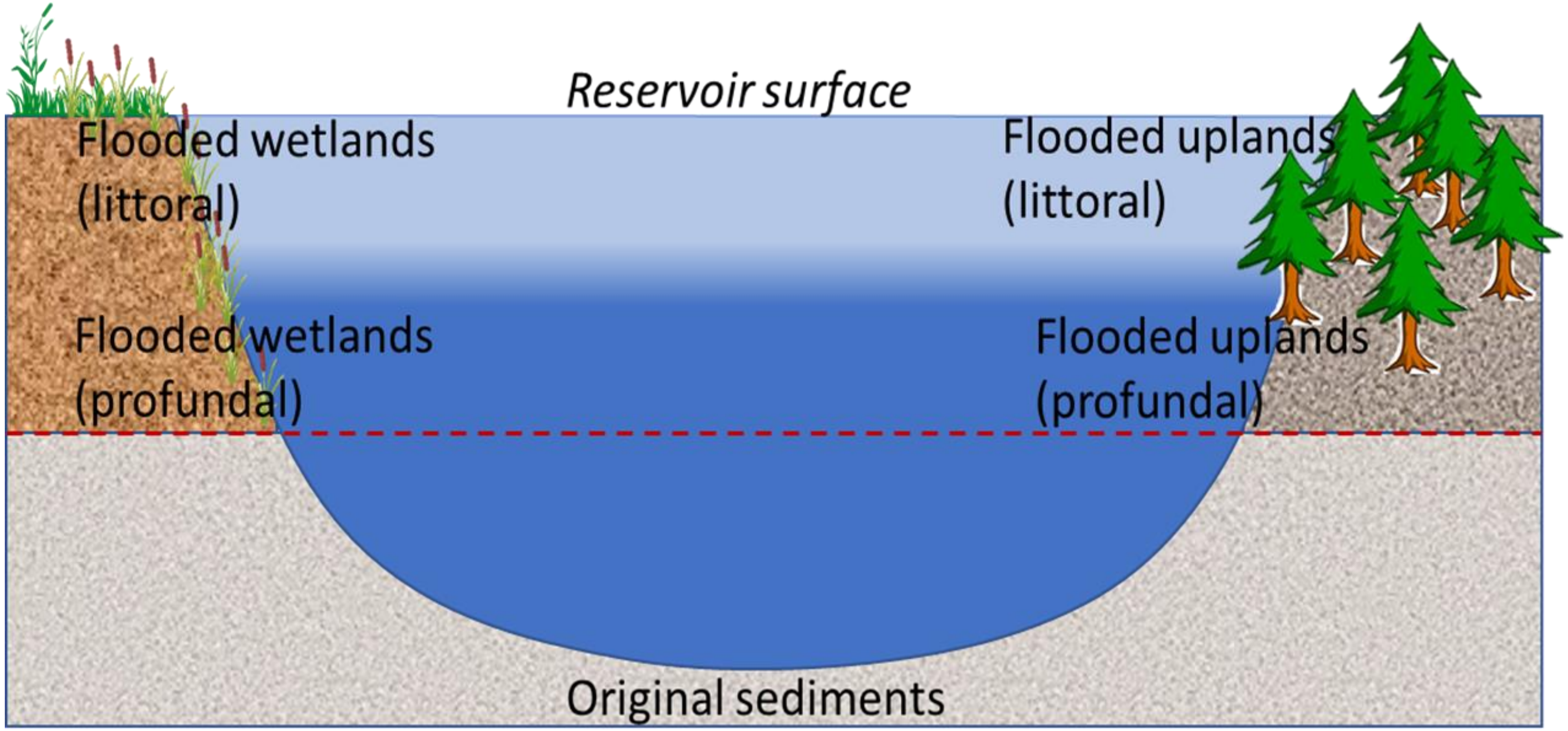
Mechanistic Modelling

Mechanistic Reservoir Mercury Model (RESMERC)

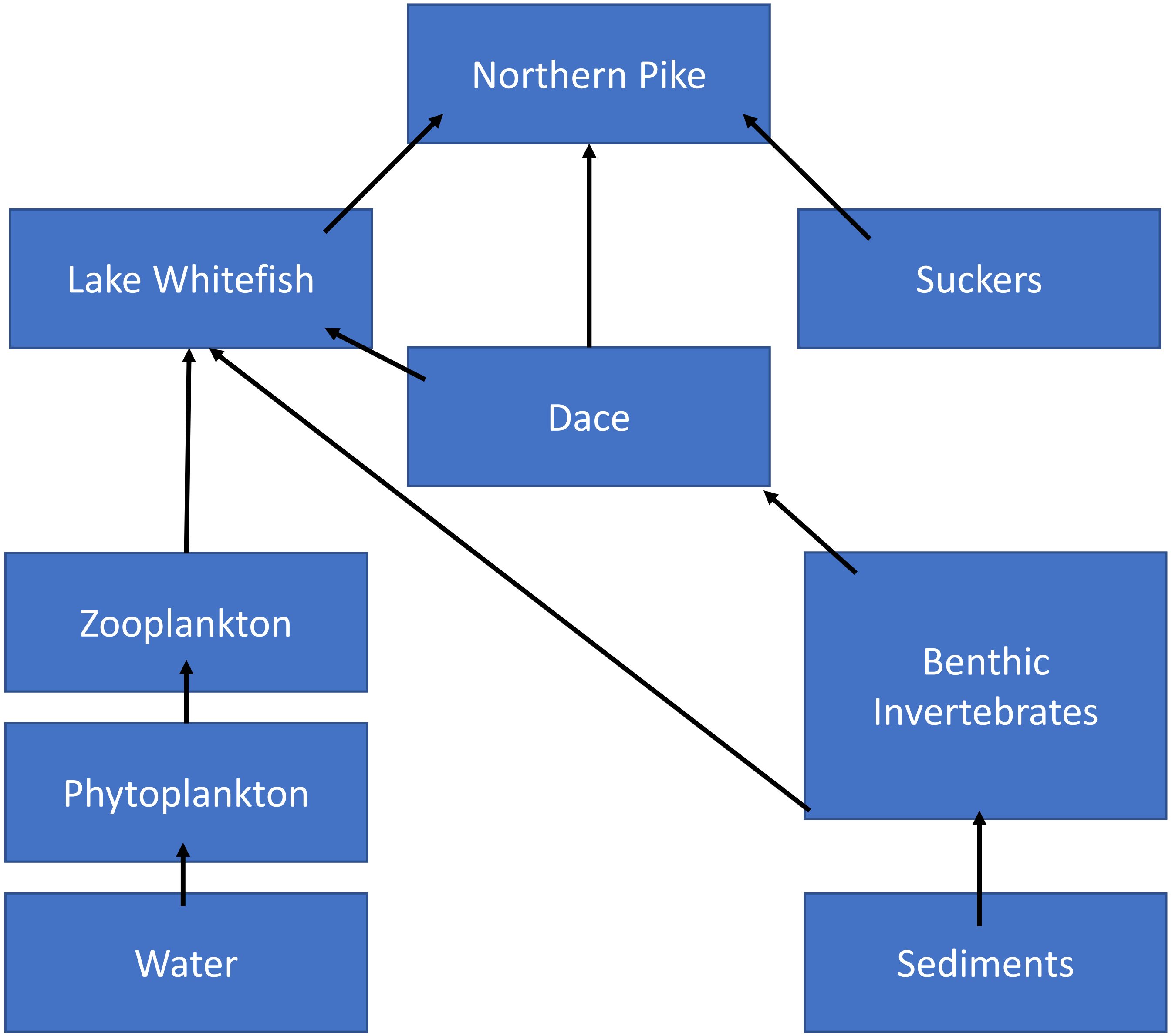


Developed originally at ELA as part of FLUDEX and ELARP studies.
Used for Lower Churchill and Site C.

RESMERC treatment of flood zones



Possible food web for Muskrat Falls Reservoir



Mechanistic model predicts bigger relative increases in water than in fish,

This is because the increase in MeHg in water doesn't last long enough for fish to "catch up".

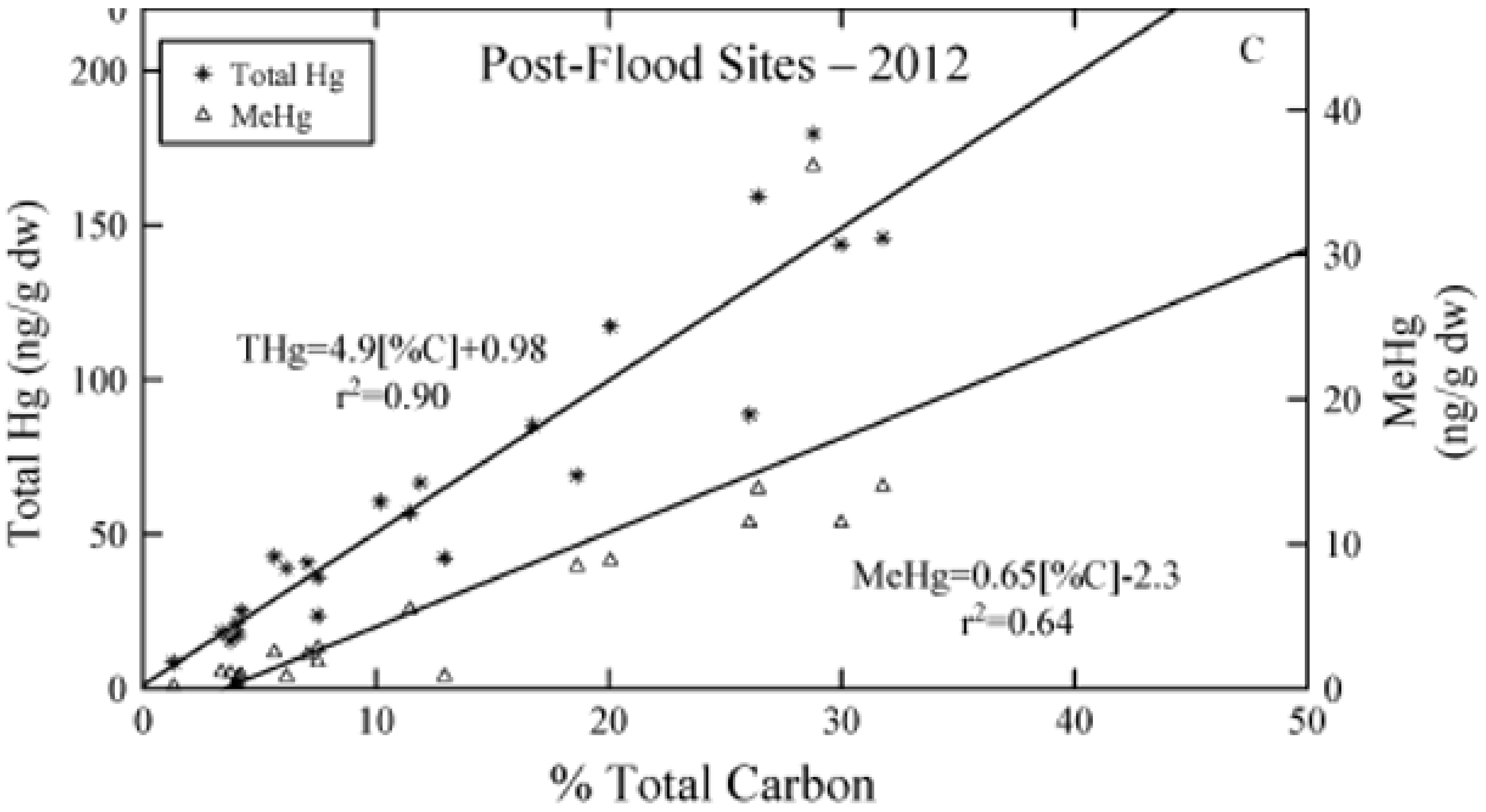
Draft..May change..

The effect of carbon pool size in the flood zone

Some topics covered in the next slides:

- Everyone agrees more flooded carbon leads to more decomposition and more MeHg production.
- More production in soils does not necessarily lead to more flux to overlying water.
- The experimental upland sites at ELA likely have less carbon than at Muskrat Falls, But how much less?
- What soil depth is appropriate to consider when comparing carbon pools at different sites?

Field data show there is more MeHg in flooded soils where there is more carbon



FLUDEX data from Rolfhus et al (2015)

Mechanistic models by Harris and Calder both include carbon in the flood zone as an important factor

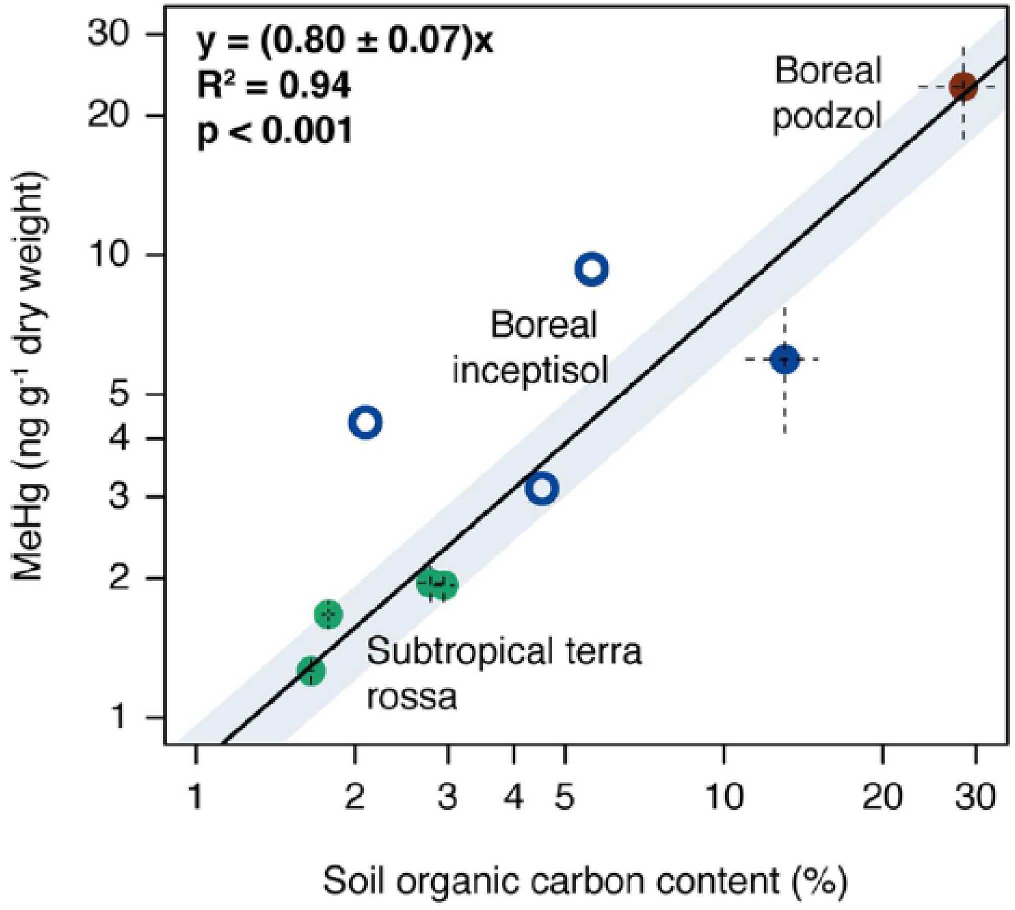
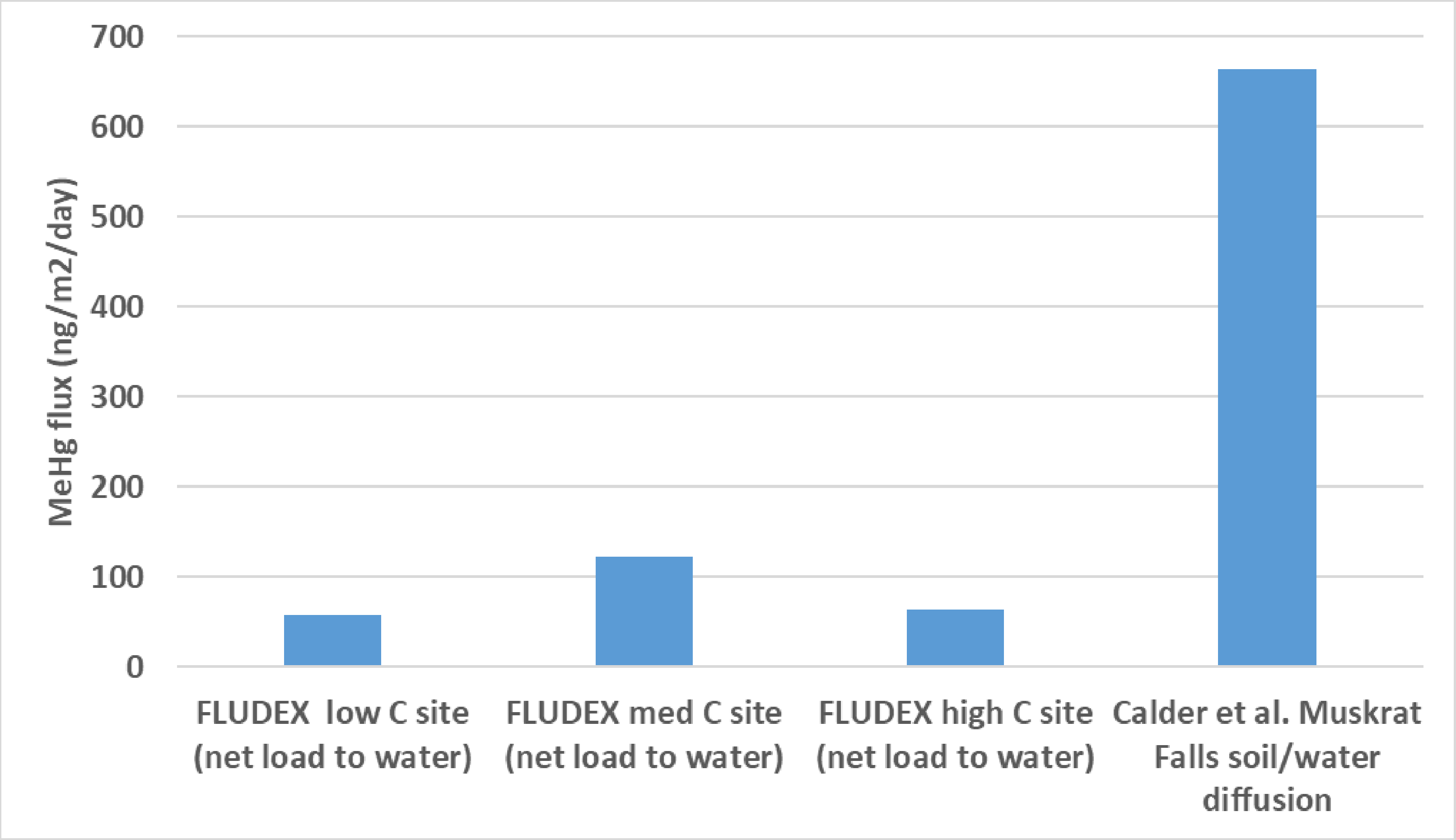


Figure 1. Relationship between soil organic carbon content and MeHg concentrations (ng g^{-1} dry weight) of flooded soils. Each data point represents an individual sampling location. Hatched lines indicate standard errors around the mean. Soil cores are from the Wujiangu reservoir, China (subtropical terra rossa),[28] the Experimental Lakes Area (ELA, boreal inceptisol) in Northern Ontario, Canada,[7,26] and La Grande-2 (Robert Bourassa) Reservoir in Quebec, Canada.[27] ELA data indicate the site-wide peak in MeHg (1–2 years postflood) except for the filled circle, which represents 9-years post flooding.

The carbon content of flooded soils is also a key component of the Calder model.

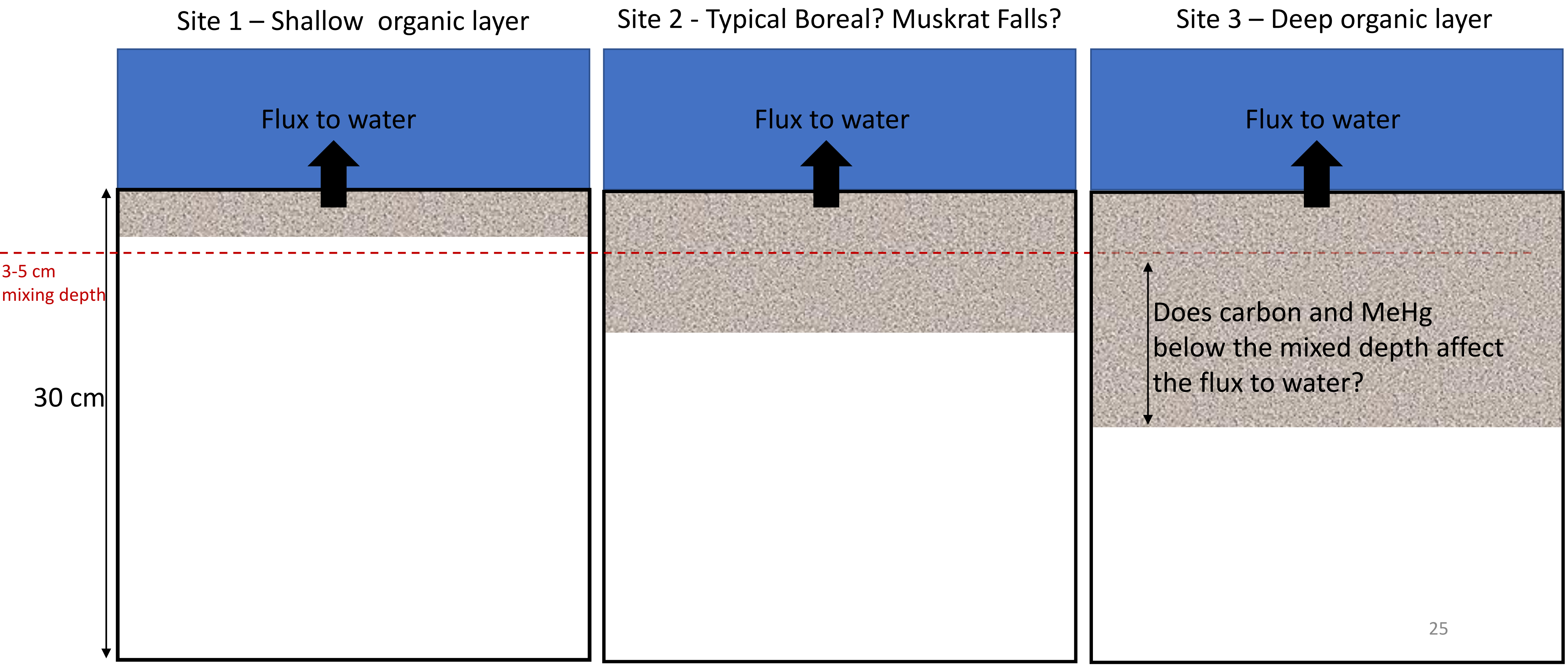
Carbon pool differences were a key reason Calder et al predicted much higher MeHg loads to water at Muskrat Falls vs ELA…



Should we consider the carbon content in the full organic horizon, or just the top layer (~5 cm)?

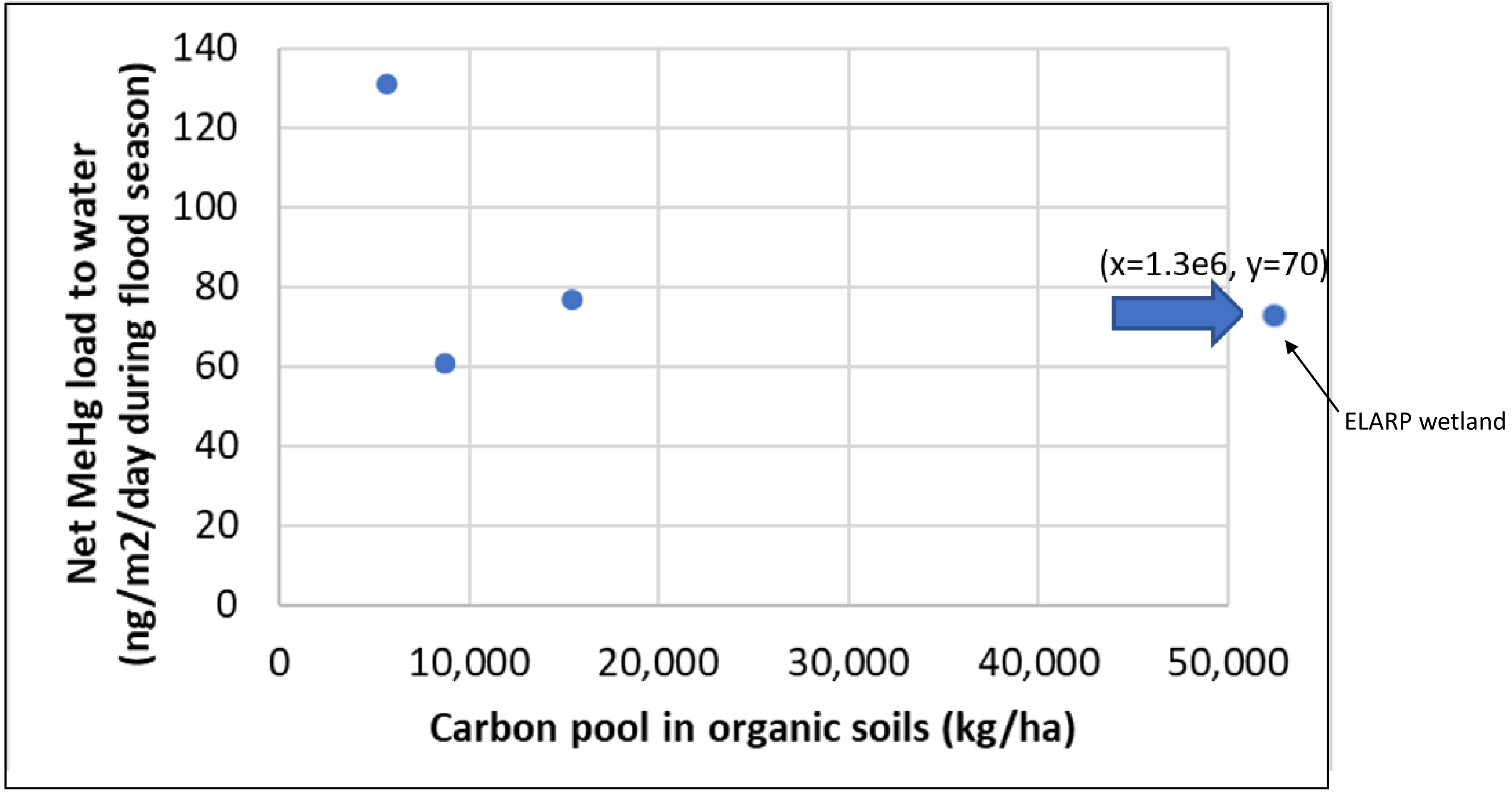
Assume these three sites have the same carbon concentrations in the top 3 cm but different averages over 30 cm.

Would we see the same or different MeHg load to overlying water?



If it is only the top several cm that matter, that could help explain why the MeHg load to water does not increase in proportion to overall carbon pool (per m^2)….

Net MeHg loads to water from ELA experiments in flooded uplands and wetland



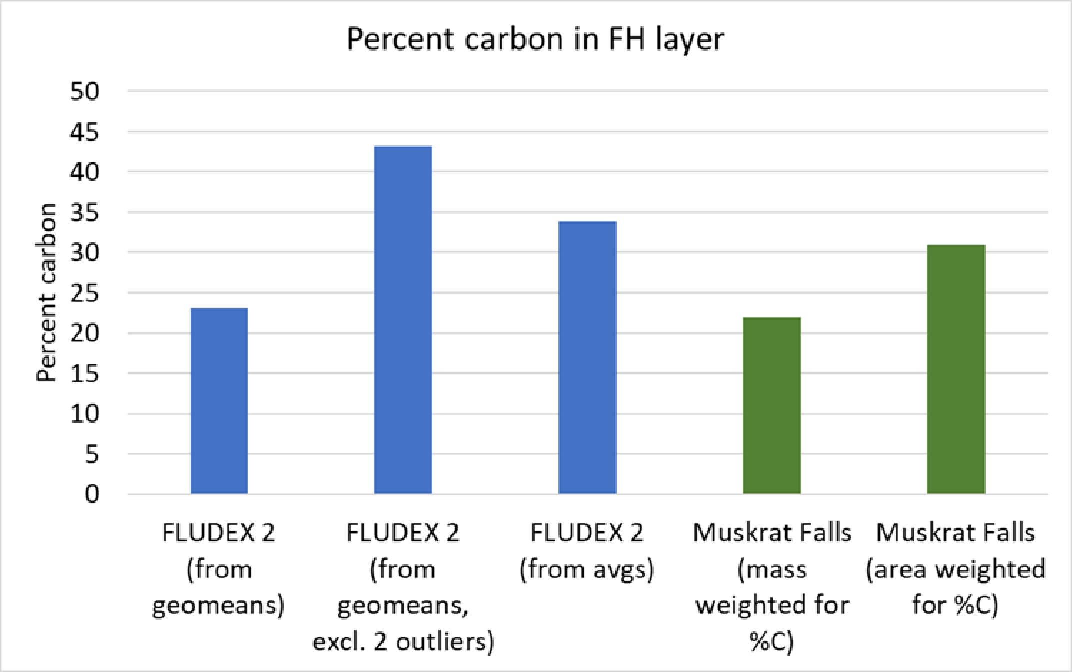
Data from Hall et al. (2005) and St. Louis et al (2004)

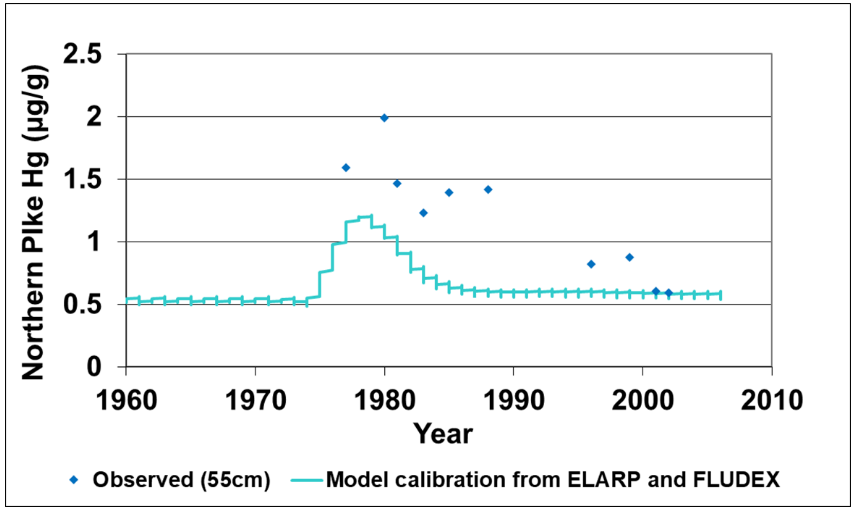
Organic content of soils at ELA vs Muskrat Falls

Overall there is less C in flooded ELA upland soils than at Muskrat Falls, but how much less?
(Still working on those numbers with ELA researchers)

% carbon in ELA organic horizon seems similar to Muskrat Falls based on analysis of data from both sites.
(Need to discuss methods and results with Ryan Calder)

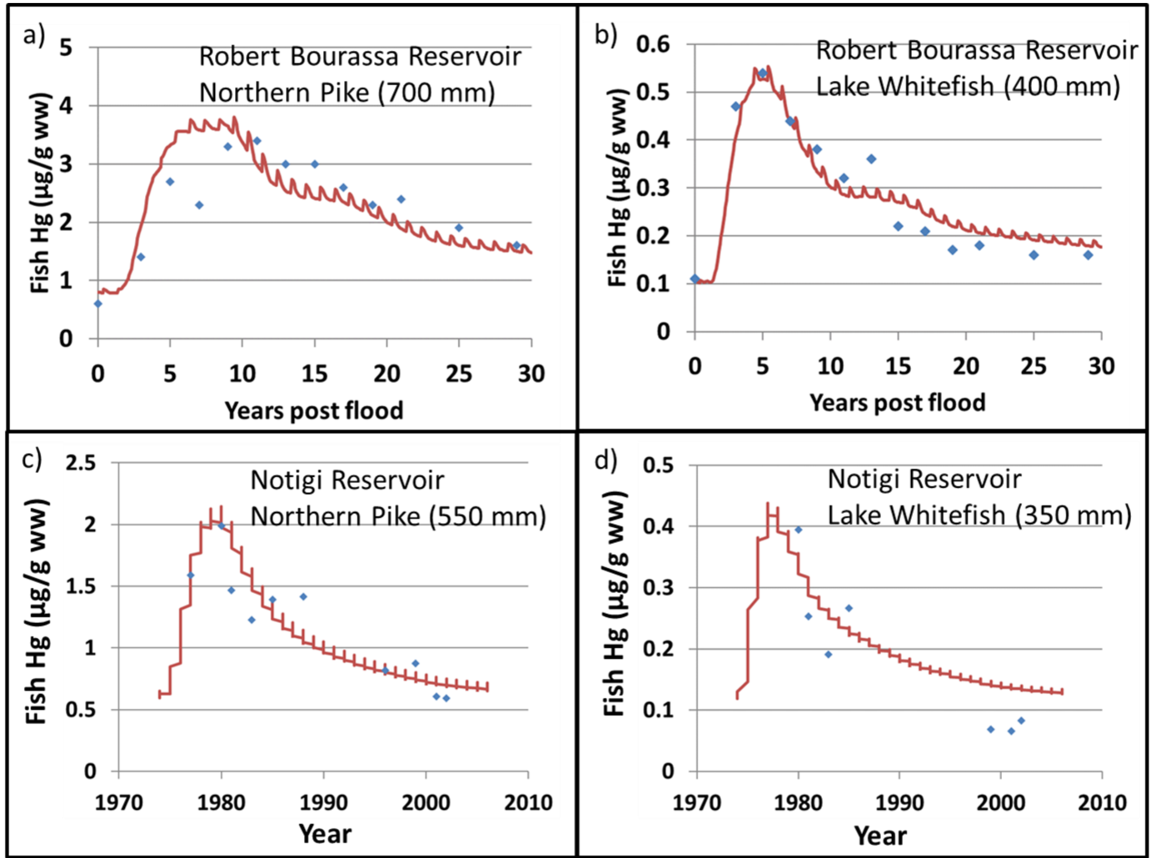
However, ELA soils are thinner and less dense, possibly due to a fire in 1980.
(Still working on those numbers with ELA researchers)





Initial application of ELA model calibration to a full scale reservoir (Notigi) was low…

May be due to lower carbon pool at ELA?



…. Model was recalibrated to better fit full scale reservoirs

We will start with this calibration for Muskrat Falls.

Goal is to "peg" models to real world data as best we can

.. *We don't have data from a group of reservoirs similar to Muskrat Falls (low baseline)*

Reservoir Modelling:

All approaches:

- Data-limited for sites comparable to Muskrat Falls

Regression model:

- Based on field data from ~12 sites
- Muskrat Falls is outside conditions used to calibrate model.

RESMERC:

- Won't be easy to scale carbon effect from ELA to Muskrat Falls.
- Tuning model to ELA, scaling to 2 full scale reservoirs and applying to Muskrat Falls.

Calder model:

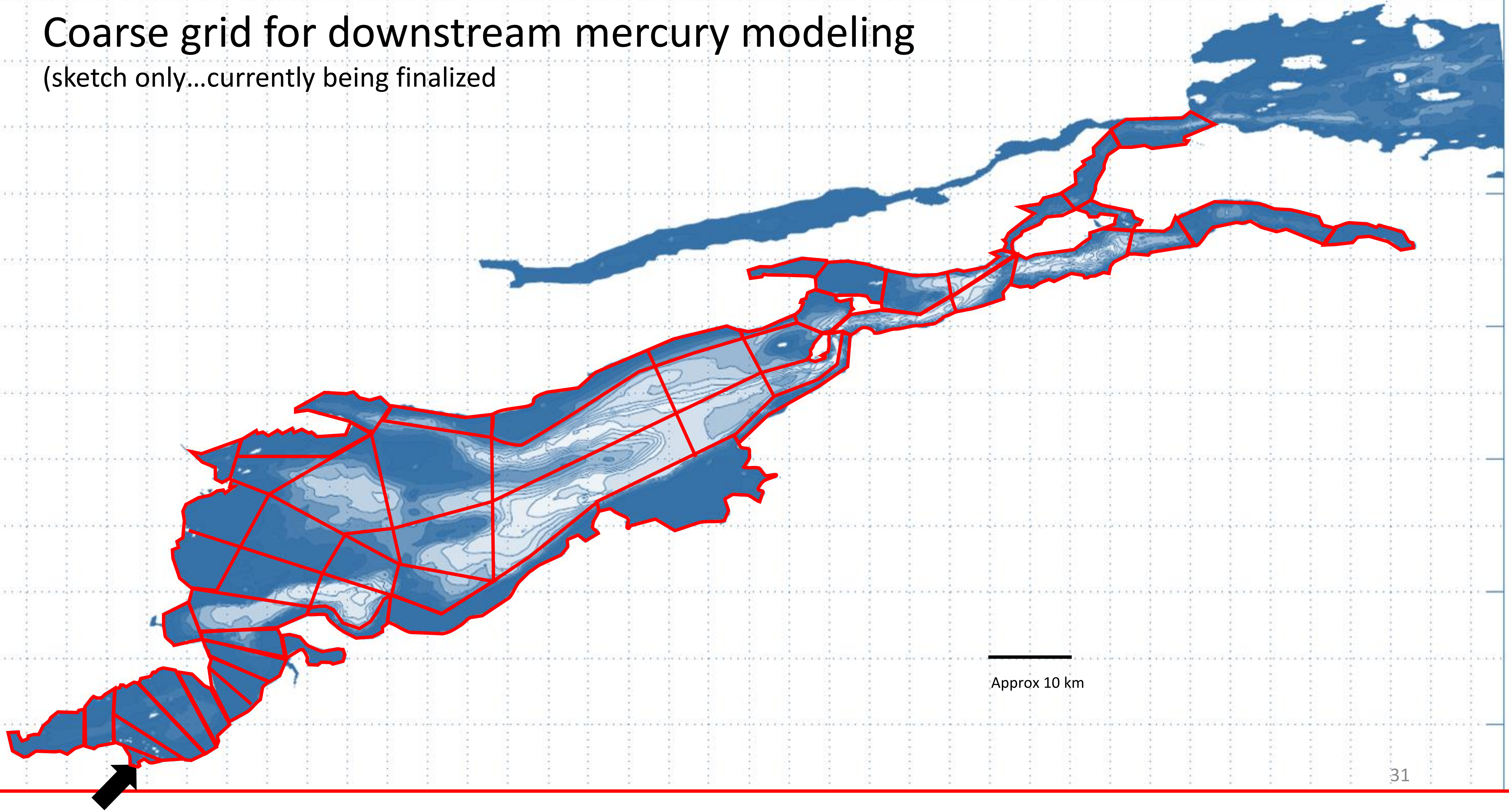
- Uses observations to estimate soil MeHg as function of soil carbon.
- No site-by-site testing yet against field data for MeHg in water or fish?

Hydro Quebec model?

Downstream Mercury Modeling

Coarse grid for downstream mercury modeling

(sketch only…currently being finalized



Summary

- Range of regression and mechanistic models being applied.
- Regression models for relative vs absolute increases produce different results. Currently leaning towards “absolute concentration” approach.
- Effects of flood zone carbon are different for MeHg production and loads to overlying water.
- Importance of soil depth used in carbon pools needs discussion.
- Reservoir modelling likely to predict peak MeHg in water higher than in 2010, but lower than Calder et al (2015).
- Peak predictions for northern pike likely to be lower than in 2010; not sure yet if this will be the case for other fish species.

Next Steps for Modelling

- Reservoir modelling will be completed in December
- Continue discussions with R. Calder. Hope to work towards common interpretation.
- Examining effects of increased water velocity on MeHg diffusion.
- Contacted Hydro Québec about applying their mechanistic model. Waiting for reply.
- Set up and apply downstream model in January.
- Scenario testing