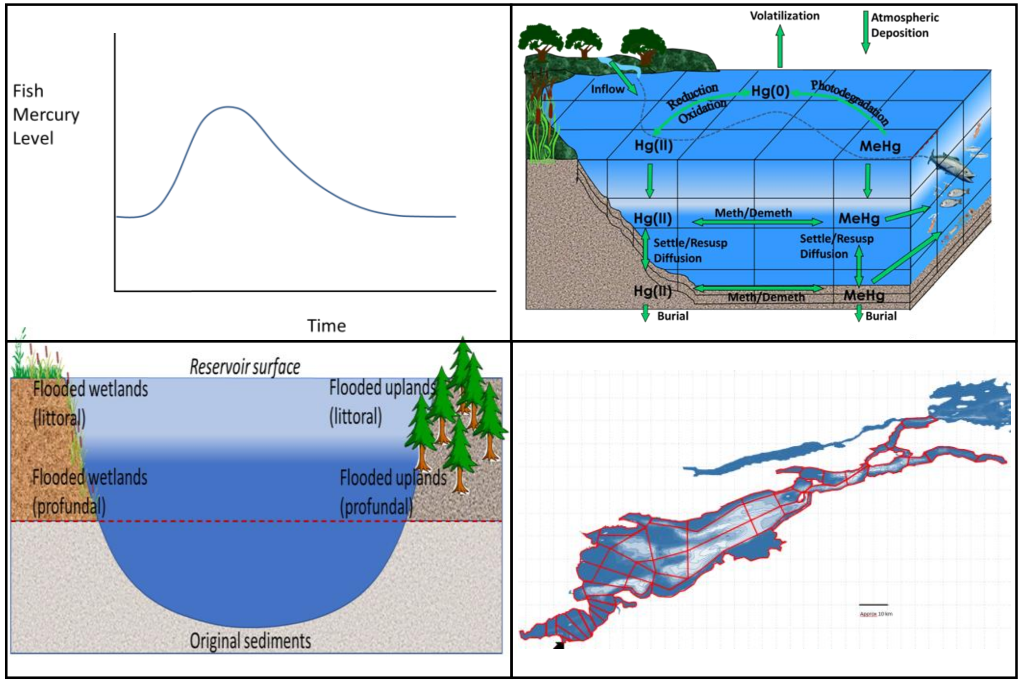
Mercury Modelling Update for Muskrat Falls Project



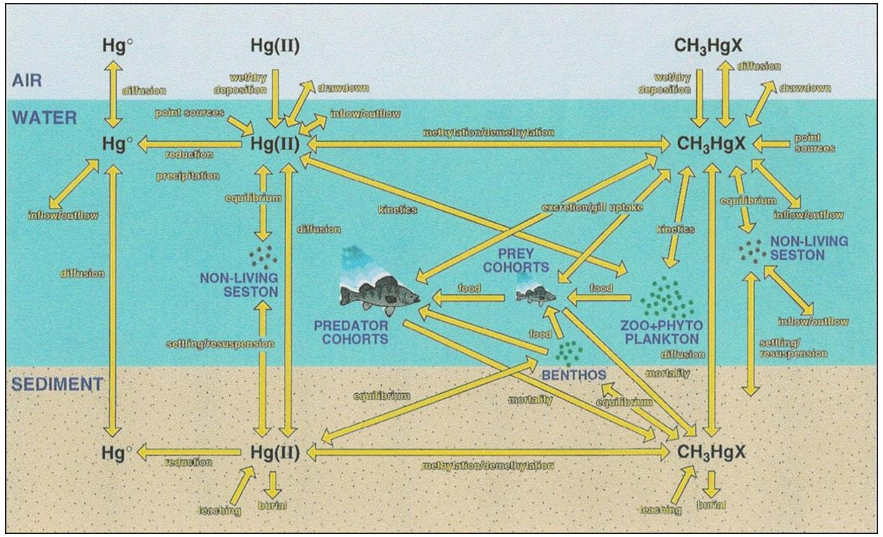
Presented by Reed Harris
February 26, 2018

Outline

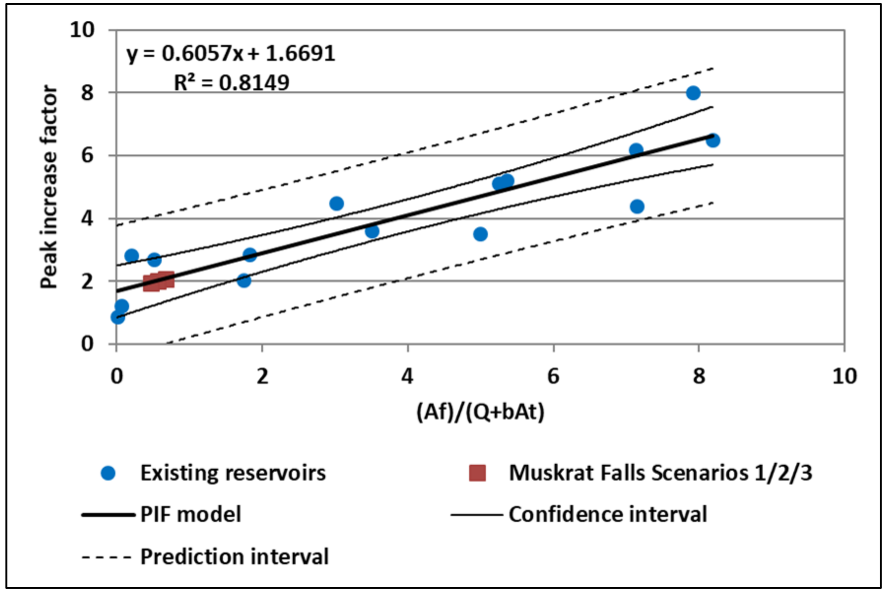
- Predicted increases in methylmercury for Muskrat Falls Reservoir
  - Mechanistic model
  - Regression model
- Effects of carbon removal
- Status of downstream modeling

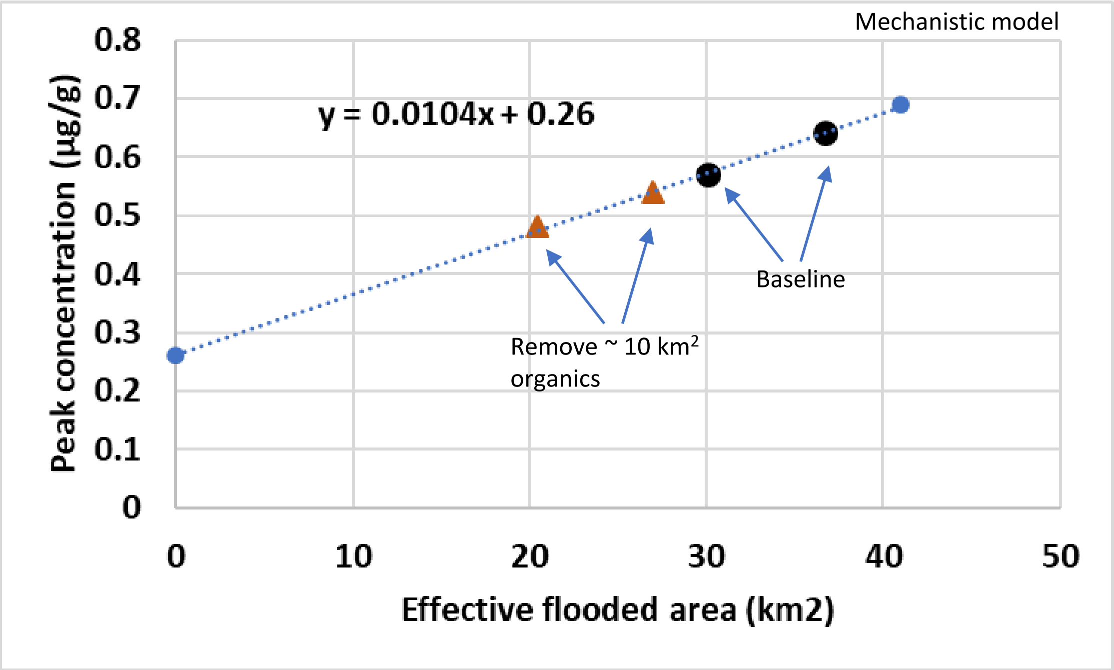
Reservoir modelling: Two approaches

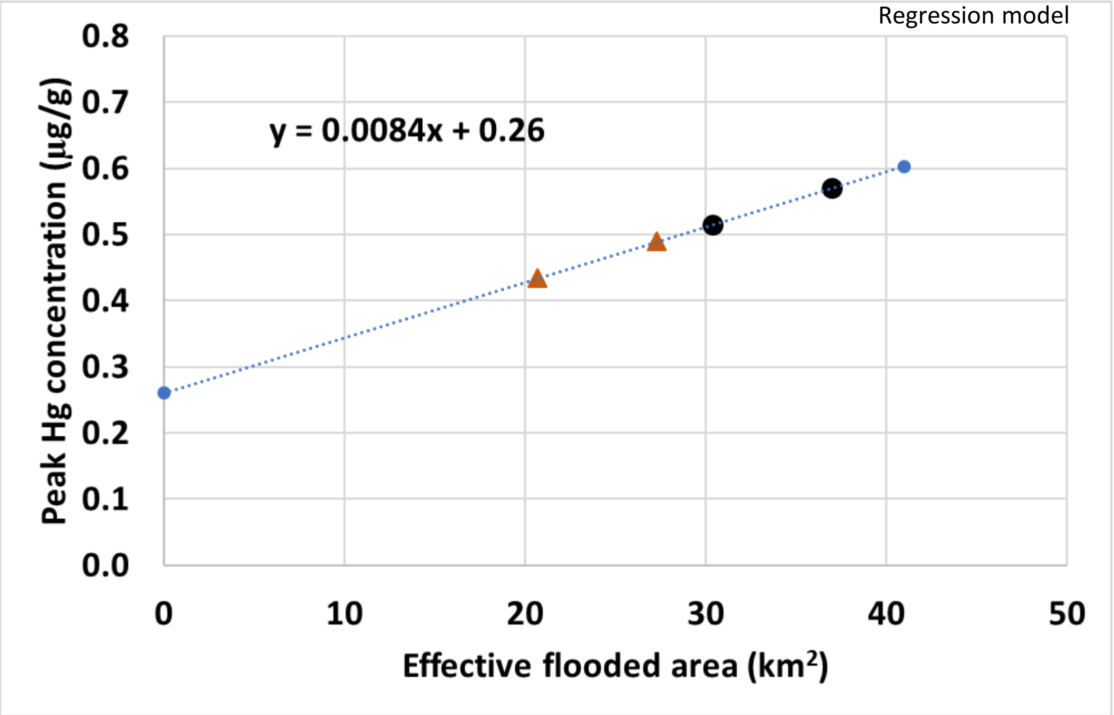
Mechanistic model (RESMERC) predicts THg and MeHg in water, sediments and biota vs time



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





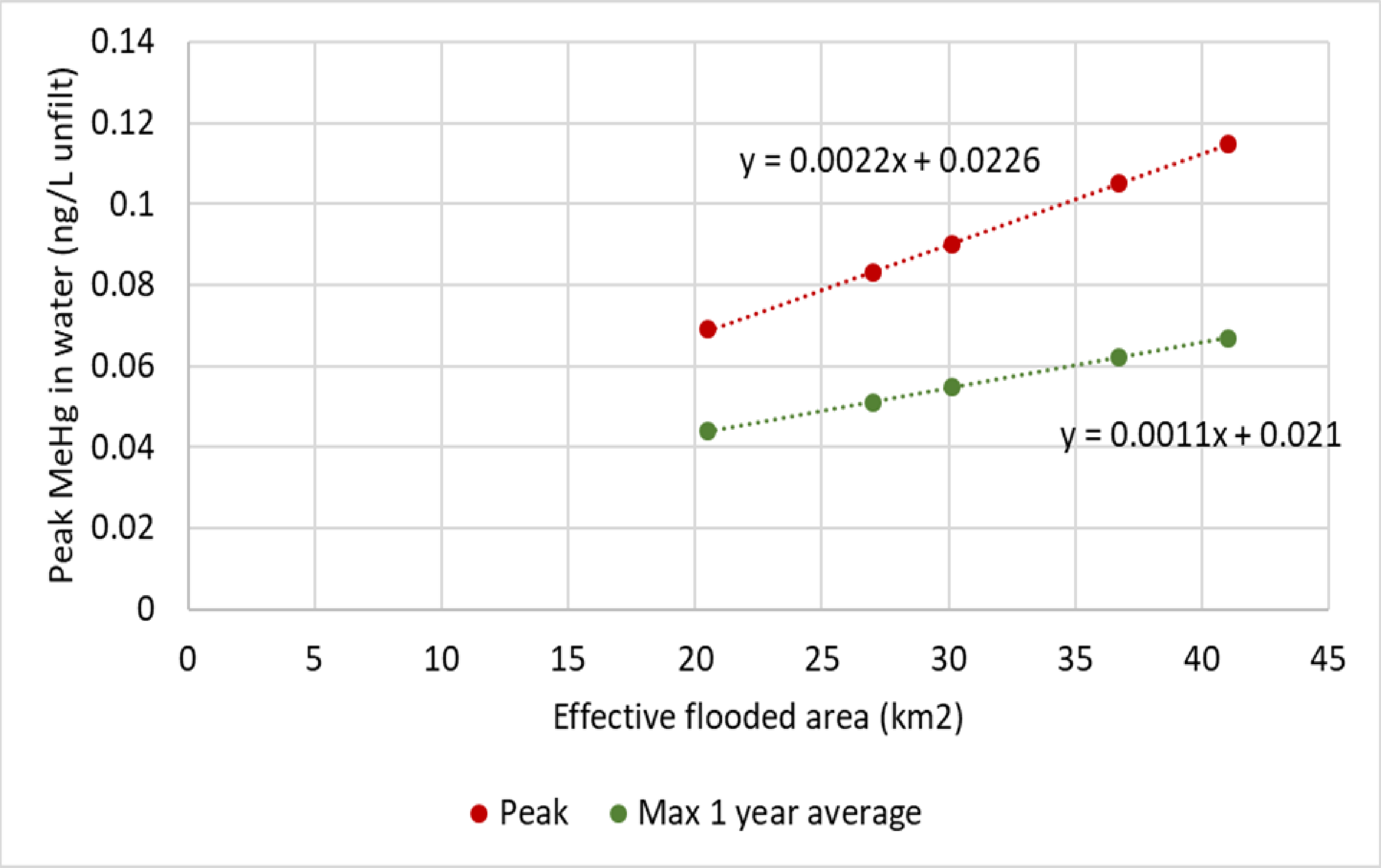


Summary slide for predicted mercury in Northern Pike (700 mm) in Muskrat Falls Reservoir

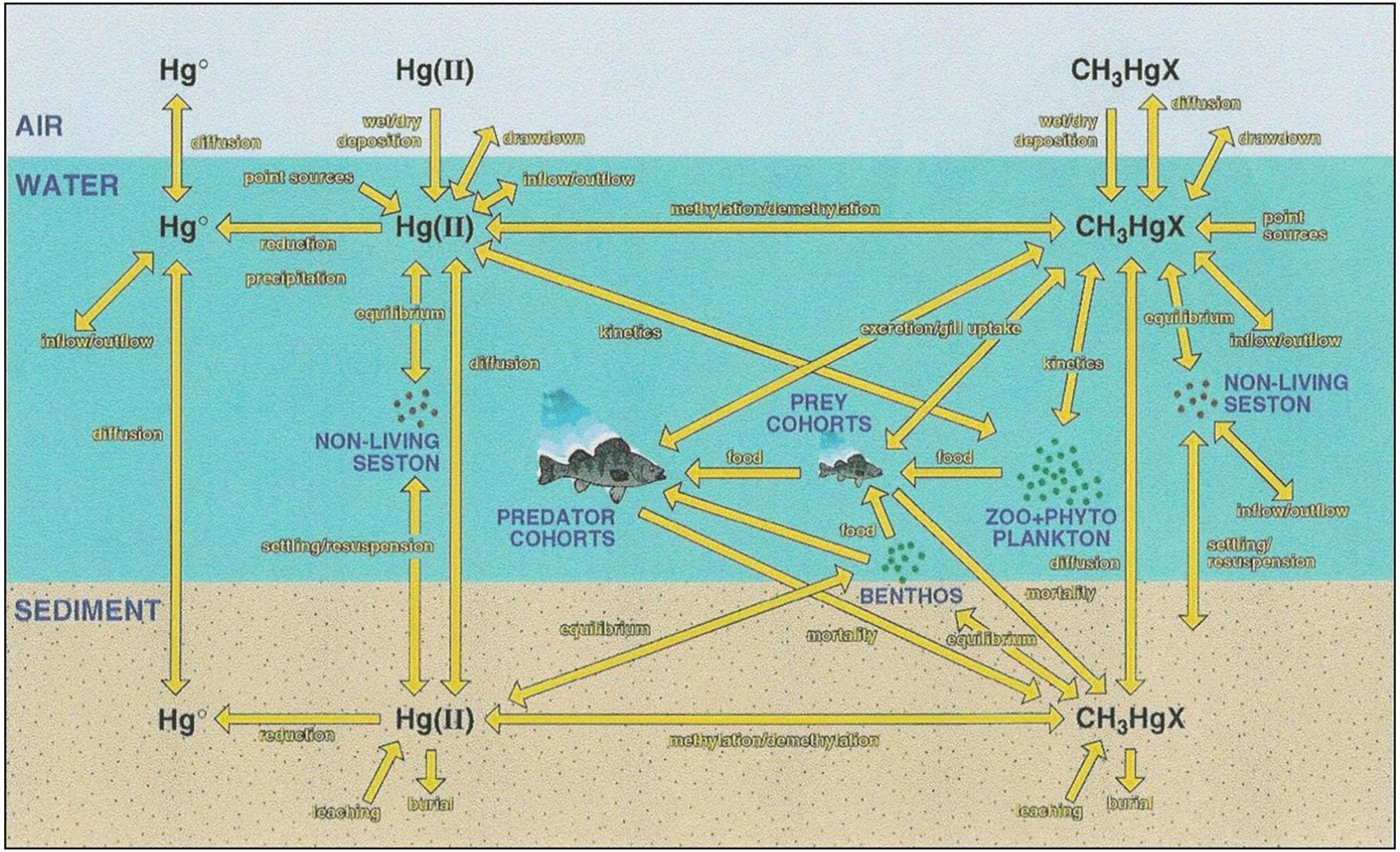
Mechanistic and regression models both add about 0.1 µg/g for every 10 km^2 of flooding (for 700 mm northern pike)

Summary slide for predicted increases in methylmercury in Muskrat Falls surface waters

(only the mechanistic model predicted concentrations in water)

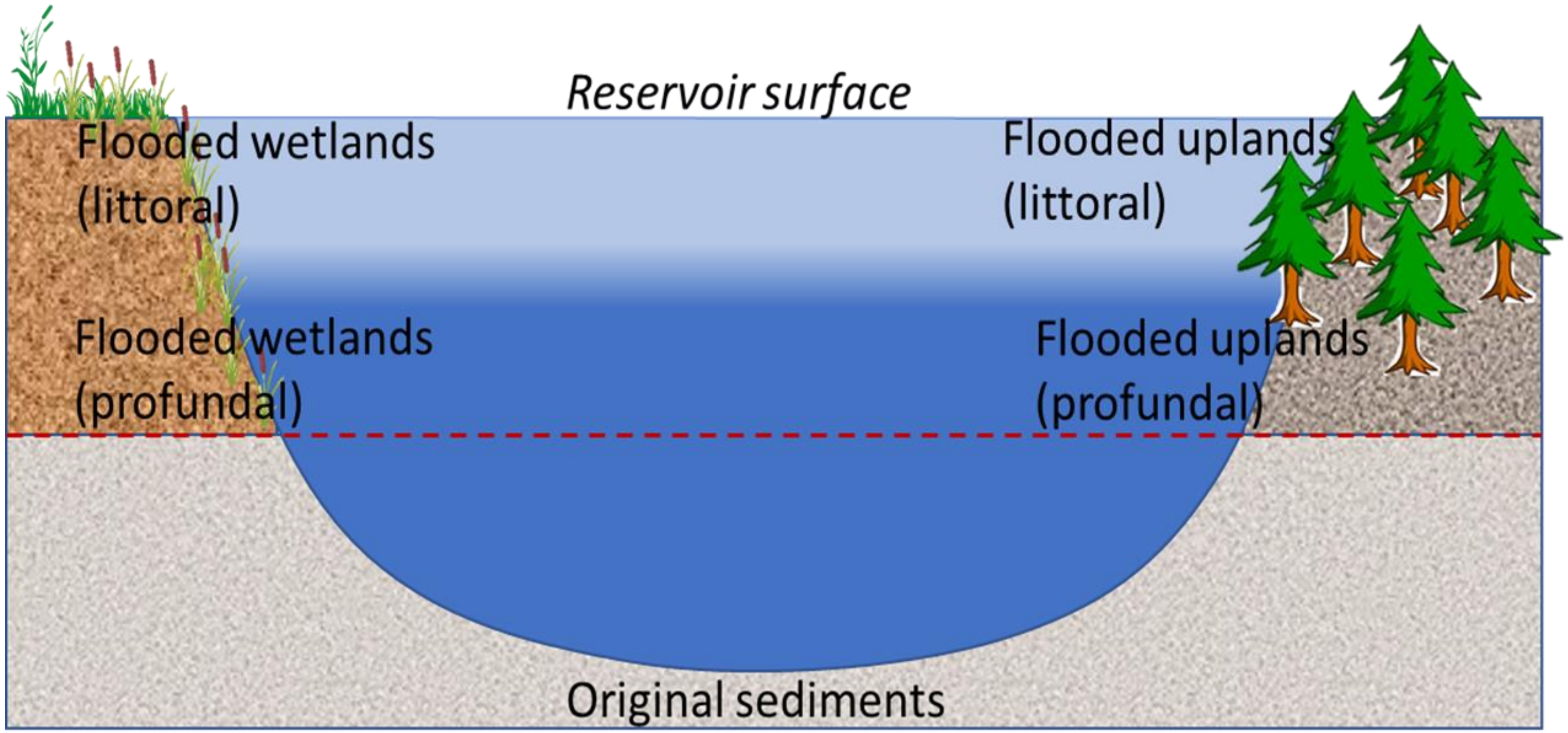


Mechanistic Reservoir Mercury Model (RESMERC)

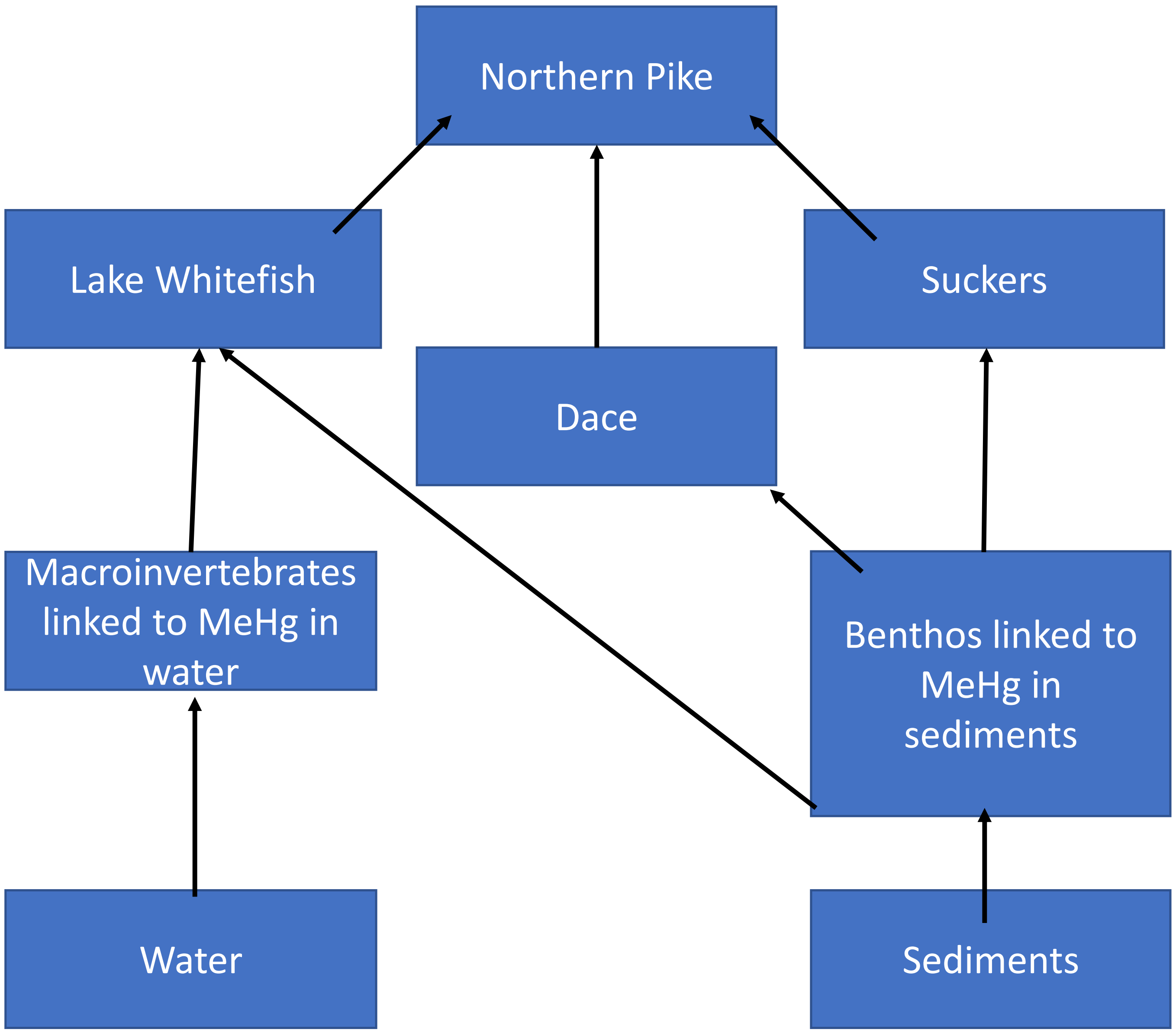


Developed originally at ELA as part of FLUDEX and ELARP studies.
Used for Lower Churchill and Site C.

RESMERC treatment of flood zones

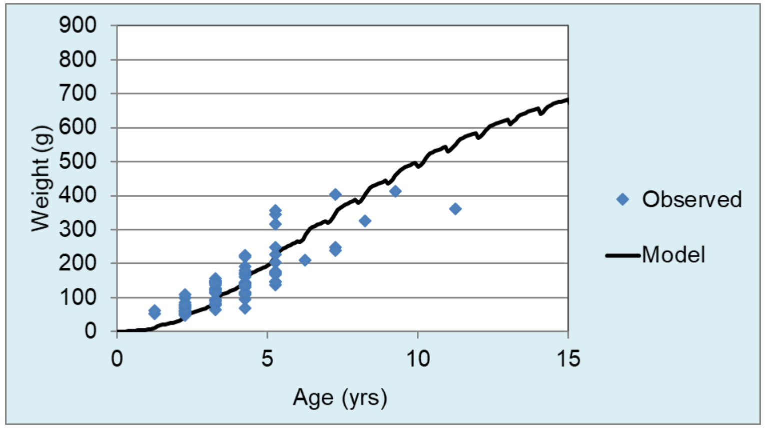


Model Northern Pike Food Web for Muskrat Falls Reservoir

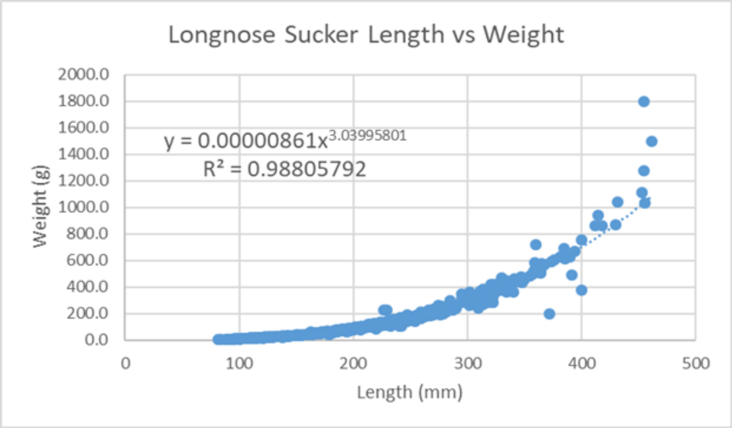


Used site data for fish growth, condition and diets, where available:

Growth (example for Longnose Suckers)



Condition (example for Longnose Suckers)



Diet (example for Northern Pike)

	Cohort				
Prey	1	2	3	4	5
Benthos (epi)	0.01	0.01	0.01	0.01	0.01
Benthos (hypo	0	0	0	0	0
Zooplankton	0.6	0.03	0.03	0.03	0.03
Phytoplankton	0	0	0	0	0
All Fish	0.39	0.96	0.96	0.96	0.96
Fish 1	0	0	0	0	0
Fish 2	0	0	0	0	0
Fish 3	0	0	0	0	0
Fish 4	0	0	0	0	0

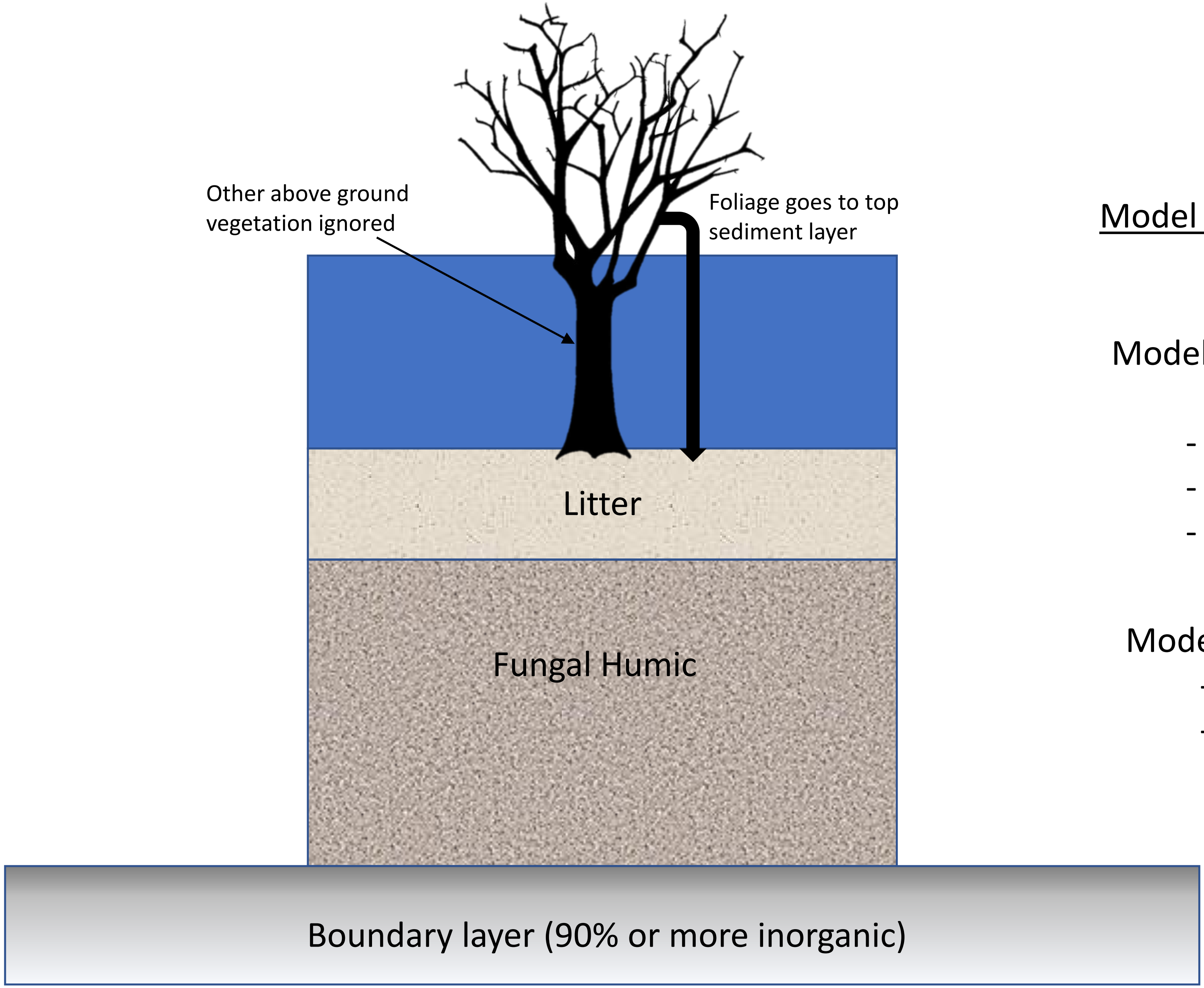
As pike grew, they ate fish from 5-33% of their length…

Inputs for: Muskrat Falls 928 pre-flood Pike

Fish Level 1

Input Name	Units	Input value
LowRat	dimensionless	0.05
HighRat	dimensionless	0.33

RESMERC setup includes water column + 2 sediment layers.



<u>Model setup for Muskrat Falls Reservoir</u>

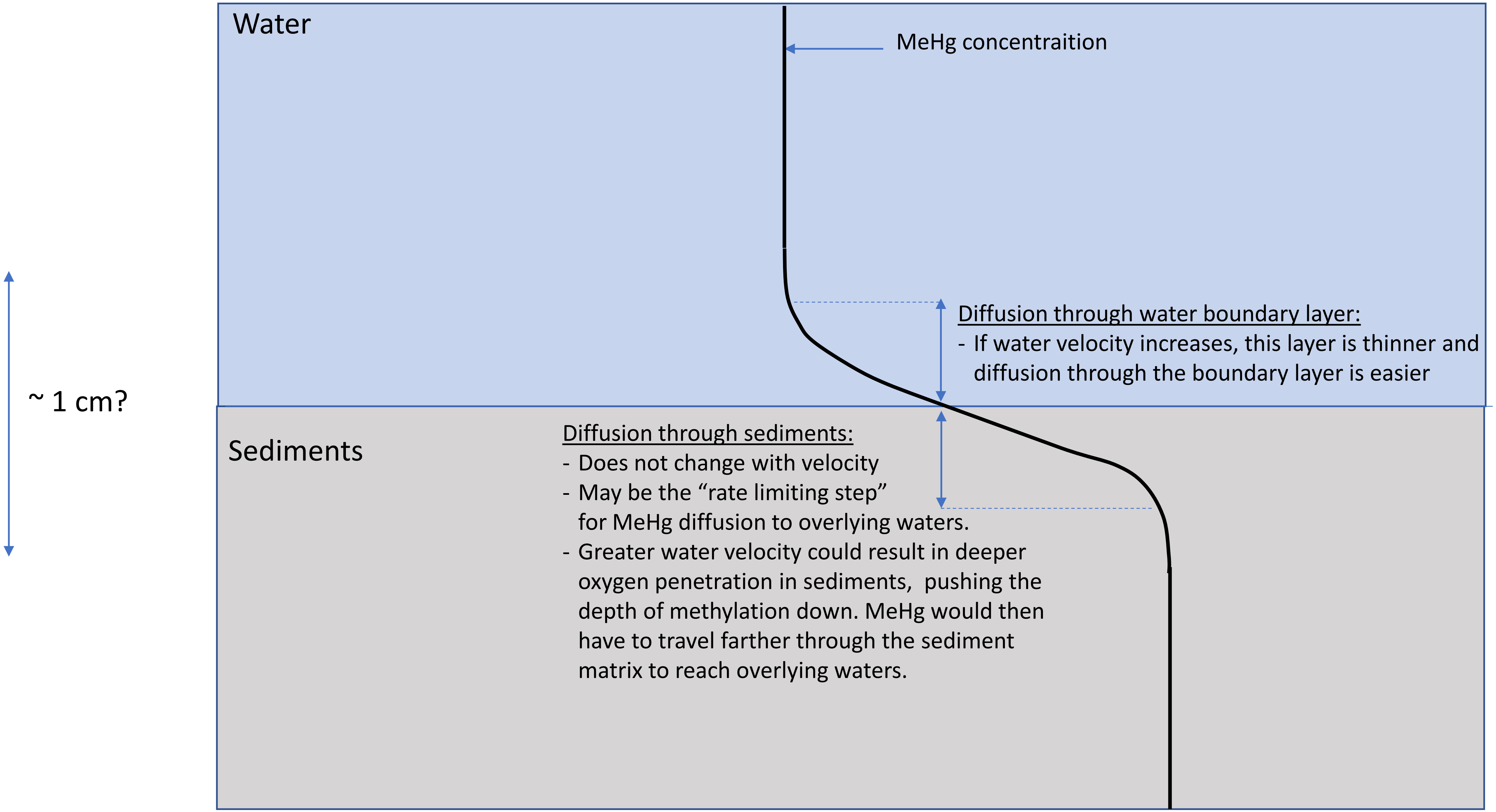
Model layer 1:

- 2 cm, includes foliage and litter
- Foliage =2730 kg/ha
- Litter = 13,300 kg/ha

Model layer 2:

- 9 cm, represents FH layer
- 58,704 kg/ha (Site survey)

MeHg diffusion from sediments to water



MeHg diffusion estimates

- Calder used a diffusion constant about 4X what we used.
- Partly attributed to faster water velocity in reservoir
- In RESMERC, if diffusion constant was increased, the concentration in porewater declined, and the flux was similar in long term.
- Consistent with Hesslein comments that flux can’t exceed supply in the long term.
- Calder seems to calculate a porewater concentration independent of diffusion?

Mechanistic Modeling Approach

Apply model to two full scale reservoirs to estimate the MeHg load required from flood zone to produce observed rise and fall for fish Hg.

Calibrate model to existing conditions in Lower Churchill River at reservoir location

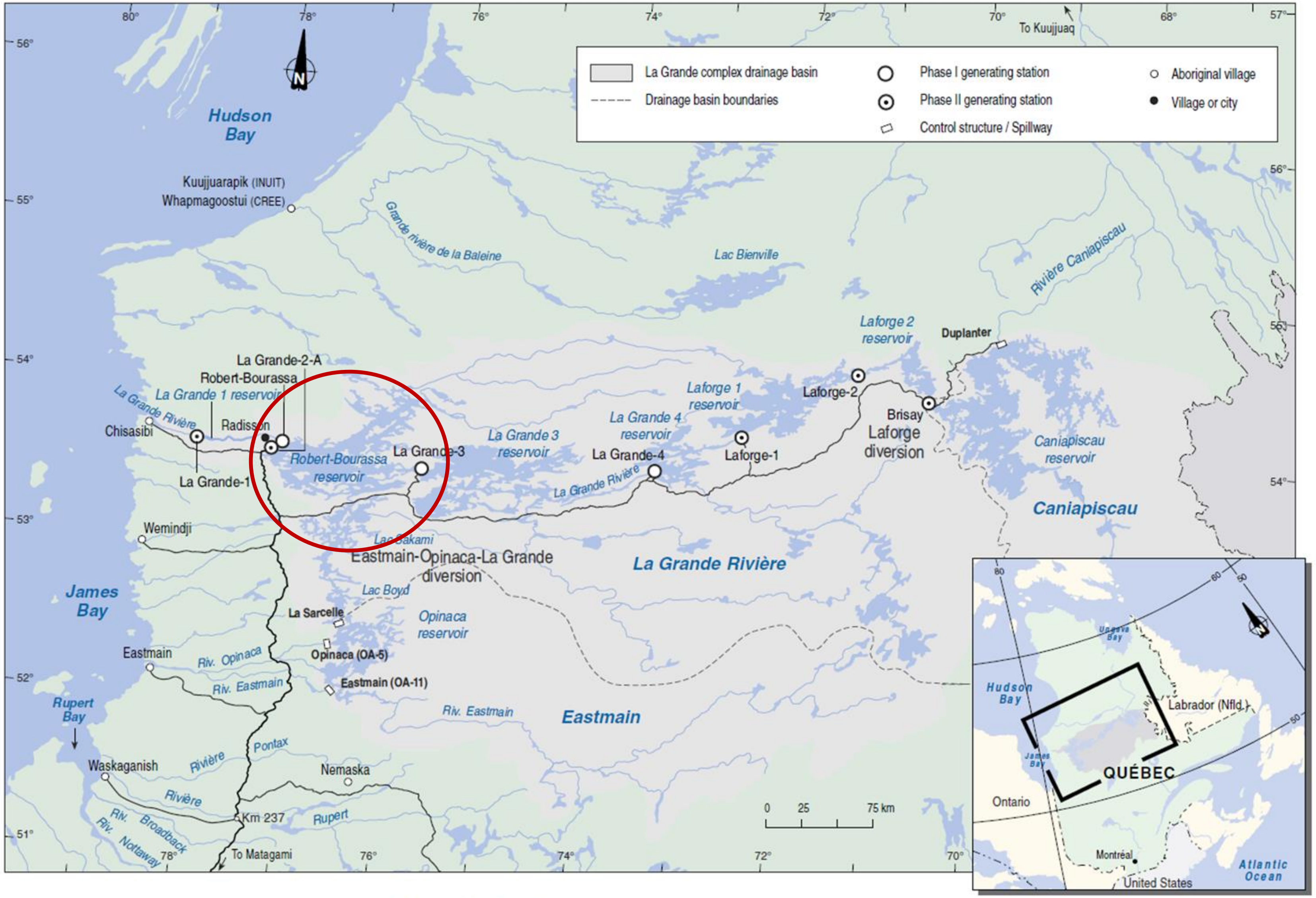
Apply model to Muskrat Falls Reservoir

Mitigation scenarios

Other comments on model application to full scale reservoirs….

1. Sites were Robert Bourassa Reservoir and Notigi Reservoir.
2. R. Bourassa (LG2) was a high C site in Calder et al (2016).
3. We assumed same flood zone carbon pool at R. Bourassa and Notigi as at Muskrat Falls.
4. Divided flood zones into uplands and wetlands.
5. Sought a single model calibration that works for ELA sites and large reservoirs. Not there yet.

Robert Bourassa Reservoir



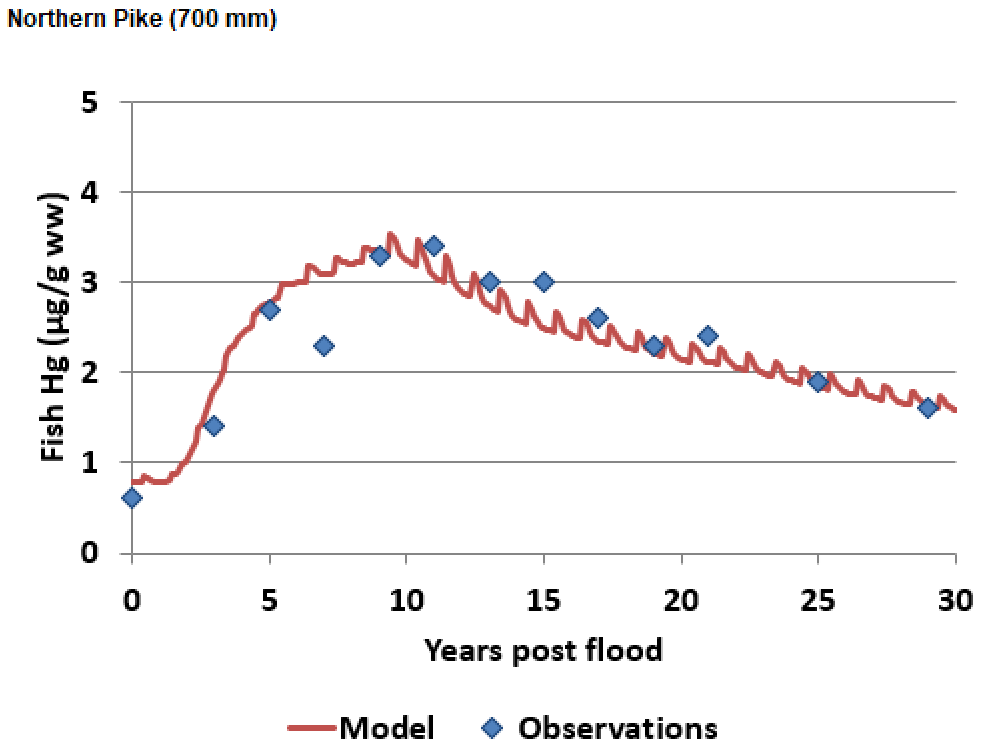
Reservoir area:
2,835 km2

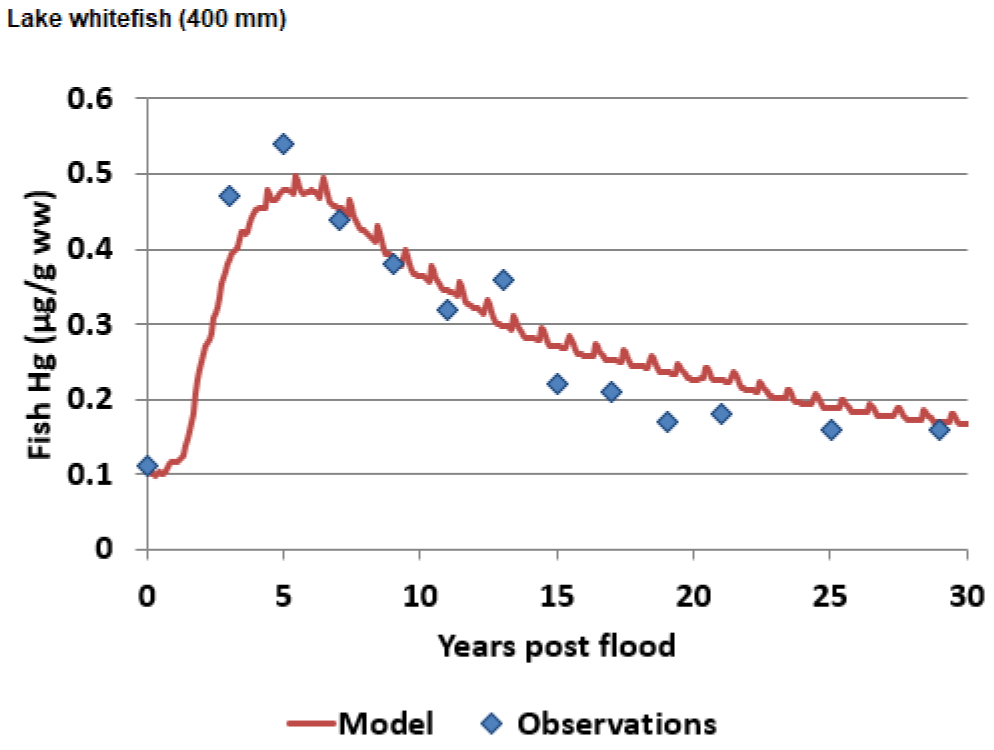
Flooded area:
2,478 km2
(87% of total area)

Water residence time:
7 months

Model calibration to R. Bourassa Reservoir fish Hg

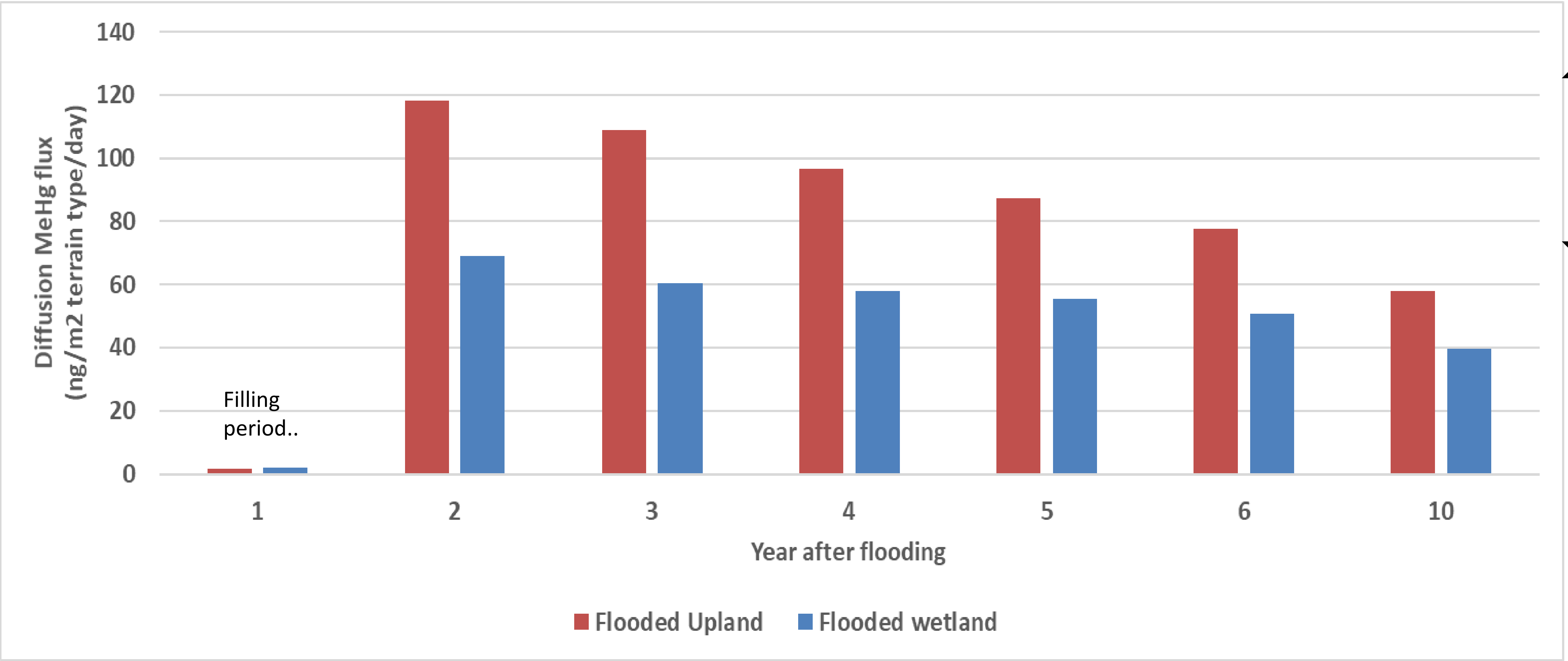
- adjusted carbon turnover rates and methylation constants to improve fit





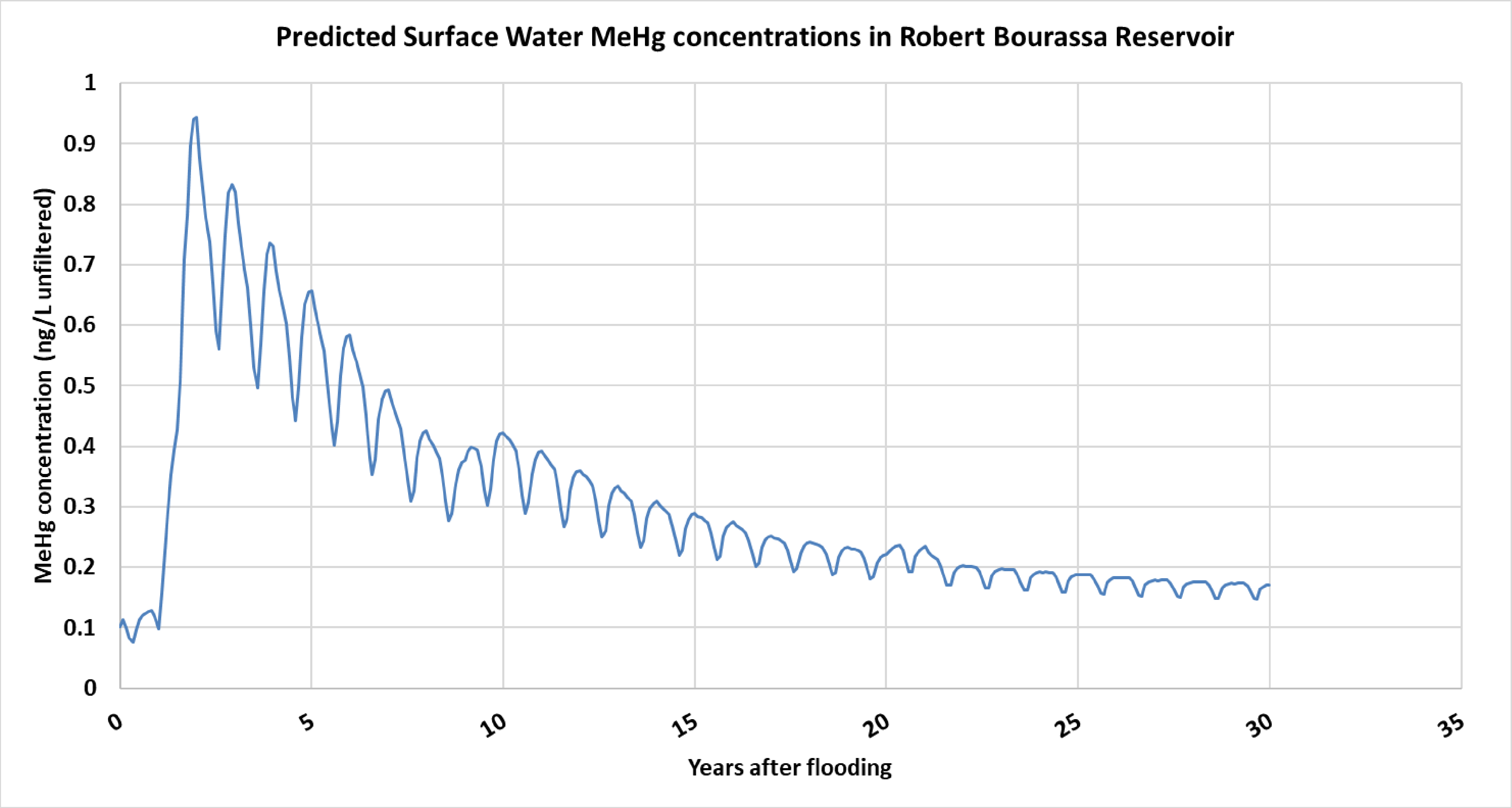
Predicted MeHg diffusion load from R. Bourassa flooded soils…

Calder rate =
664 (constant)

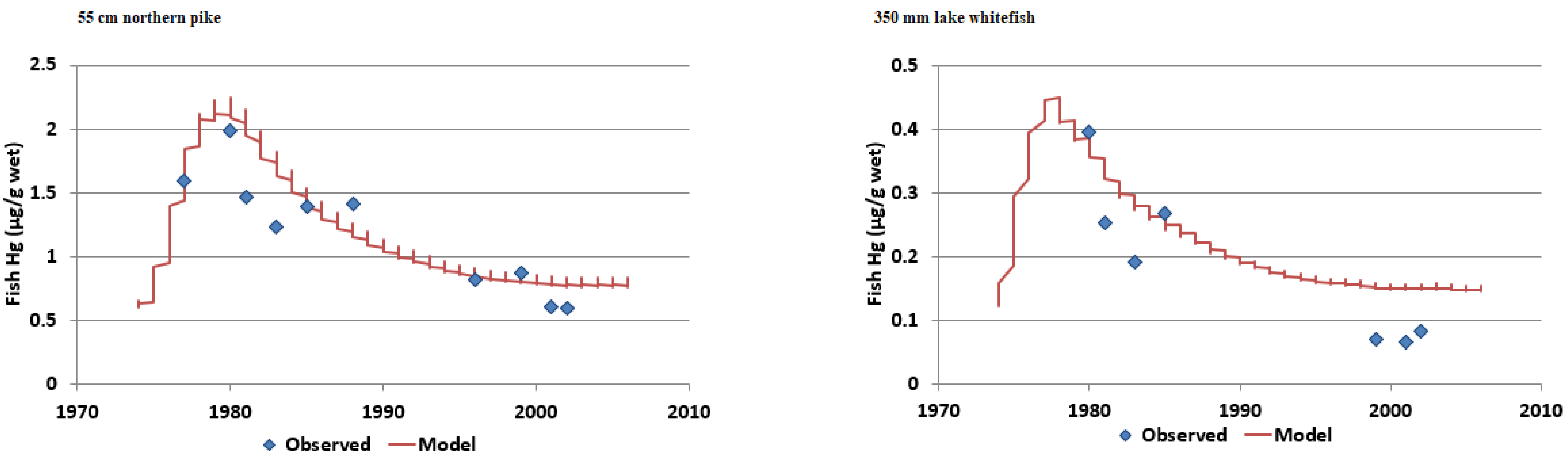


Maximum flood season
fluxes for ELA sites

R. Bourassa calibration required greater MeHg load than at ELA, but less than Calder estimate.


Predicted Surface Water MeHg concentrations in Robert Bourassa Reservoir
MeHg concentration (ng/L unfiltered)
Years after flooding
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35

Application of calibrated model to Notigi Reservoir, MB

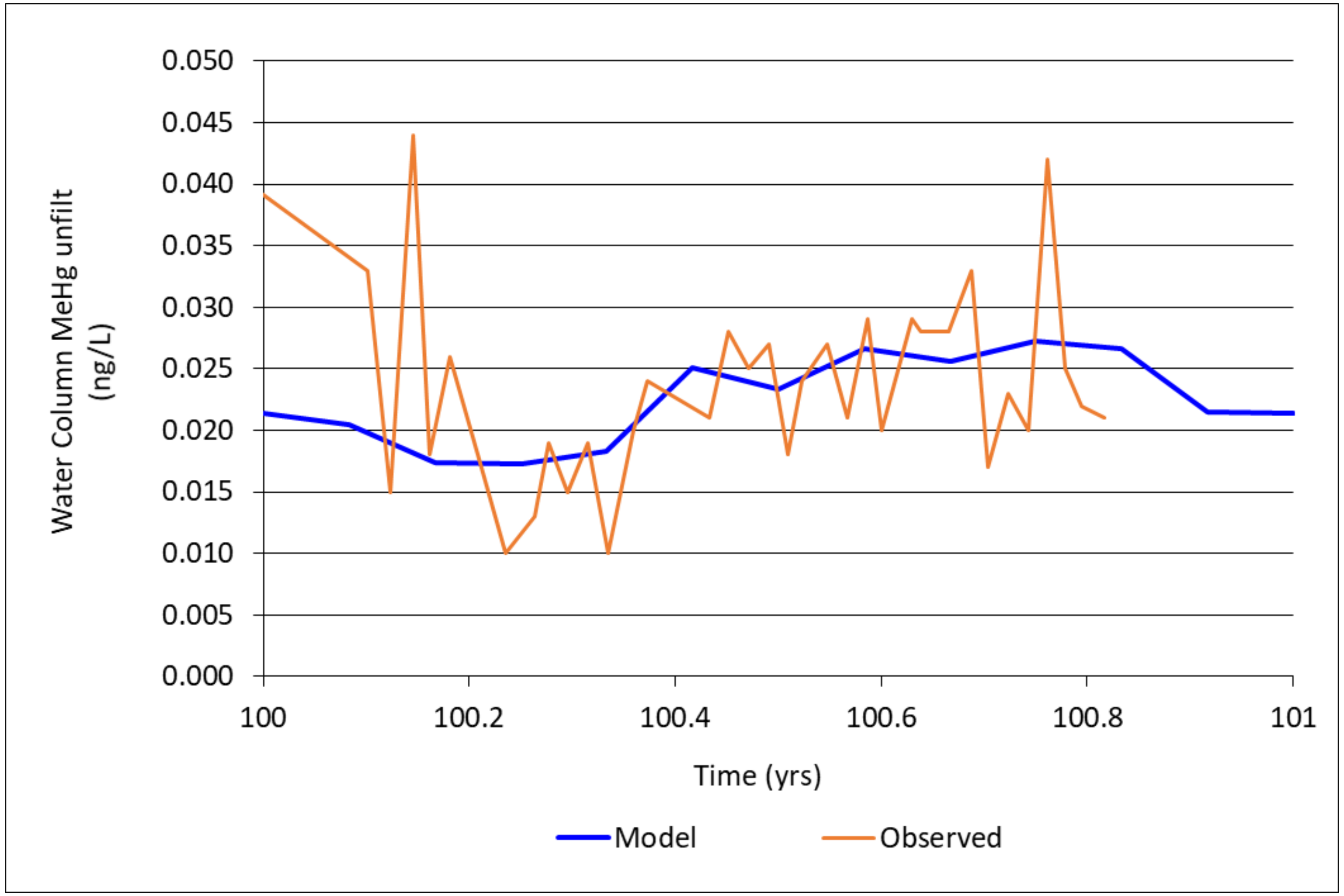


Model application to pre-flood conditions at Muskrat Falls

Repeated annual conditions until concentrations stabilized…

Model results for MeHg in surface at Muskrat Falls site – Existing conditions

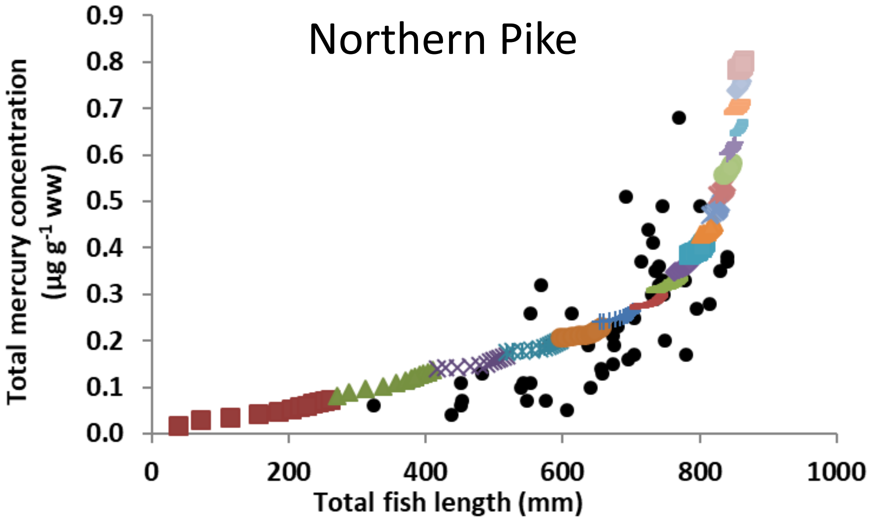
- Concentrations are very similar to inflow values, because of short water residence time.
- Good fit, but not necessarily a strong test of abiotic cycling in model….

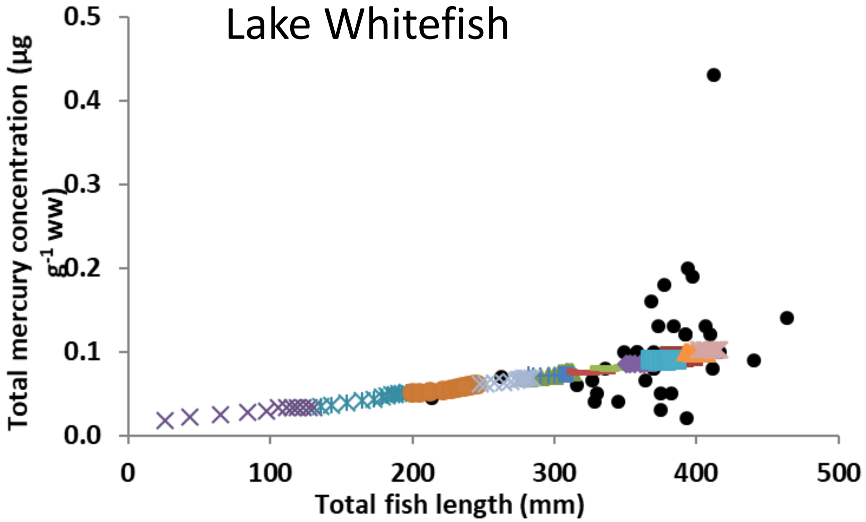


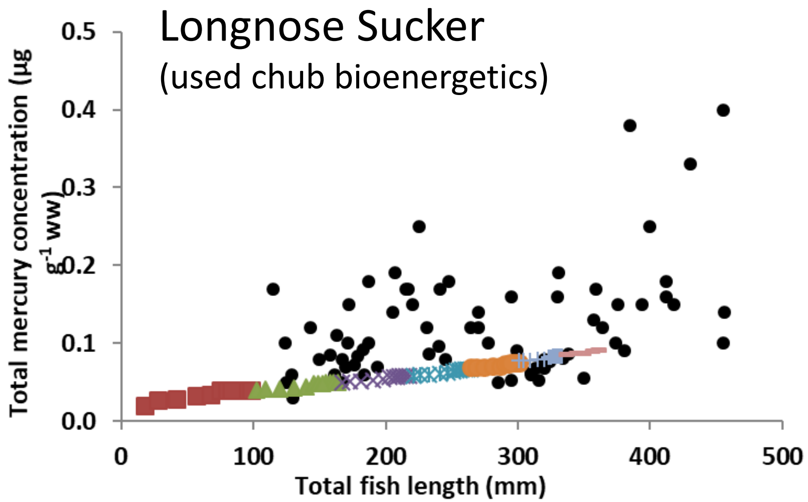
Results for 101st year….

Model results for fish at Muskrat Falls site – Existing conditions

(black dots = observed;   colours = model by age class)







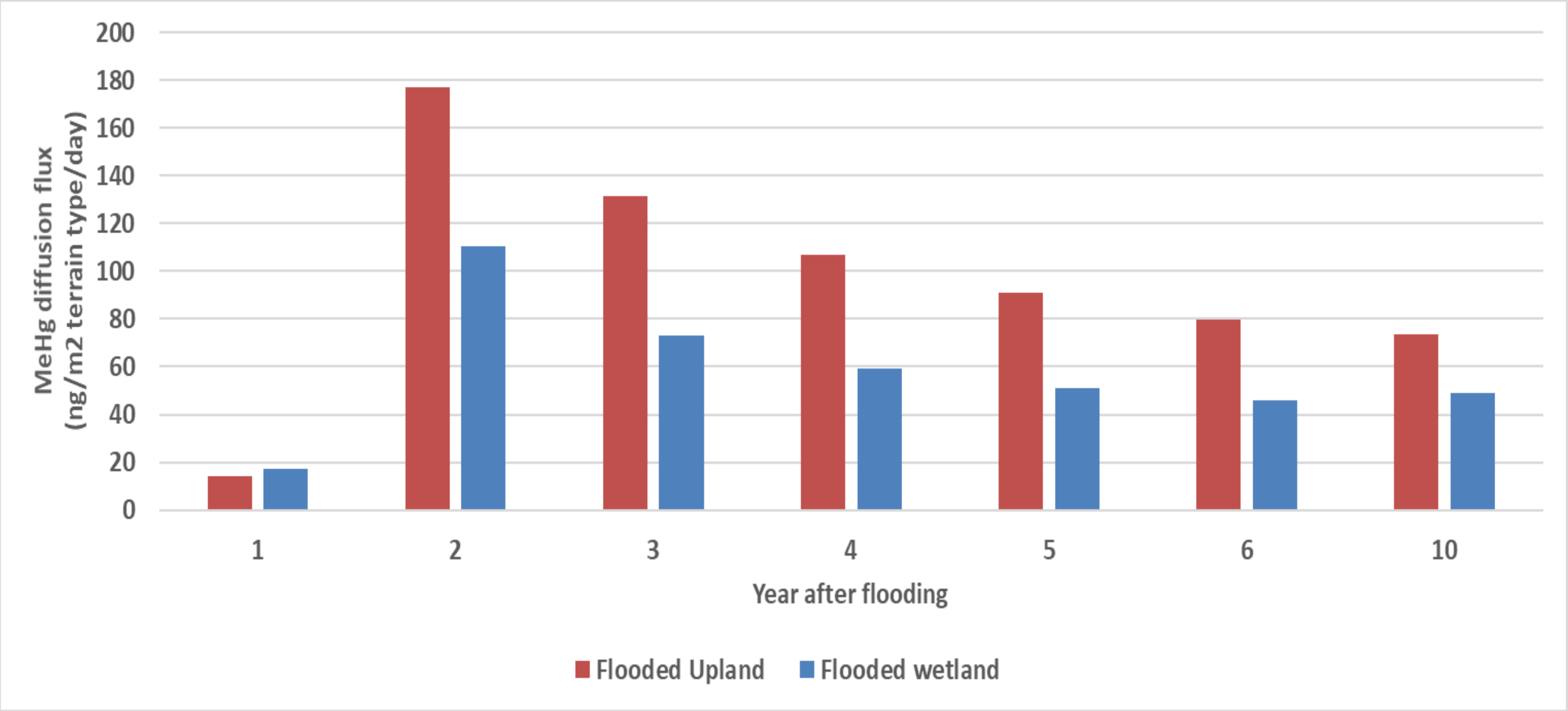
Model application to post-flood conditions at Muskrat Falls

Started with reservoir at full elevation (due to model limitations)

Table 1. Muskrat Falls Reservoir flooded terrain at full elevation (39 m asl).

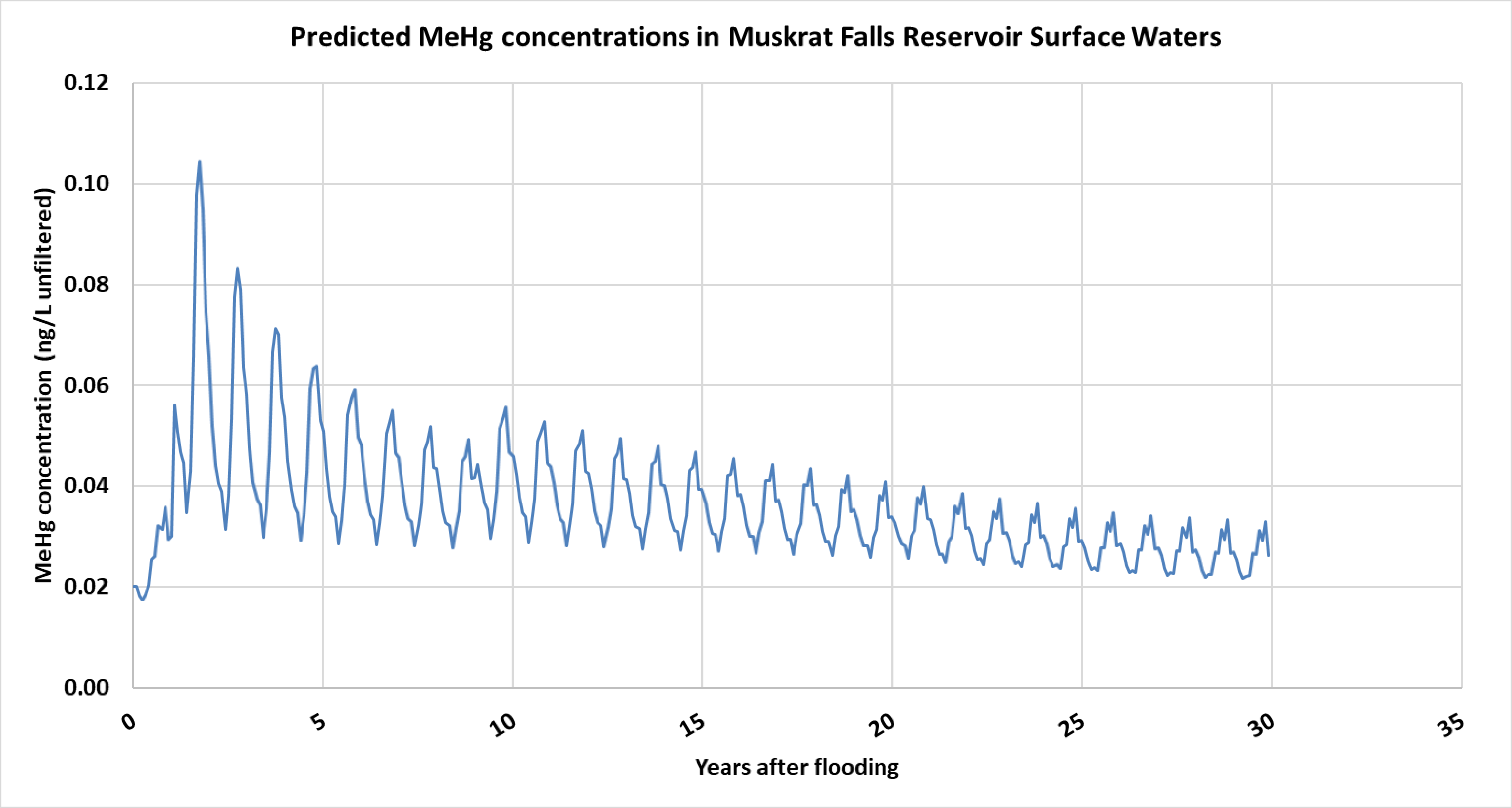
ELC type	Area (km^2)	% of reservoir area	% of flooded area
Black Spruce / Feathermoss Forest	8.59	8.5	19.6
Fir - White Spruce Forest	8.14	8.0	18.6
Black Spruce / Lichen Woodland	0.91	0.9	2.1
Hardwood Forest	2.20	2.2	5.0
Mixedwood Forest	6.96	6.9	15.9
Spruce Fir / Feathermoss Forest	1.16	1.1	2.6
Bl. Spruce/Sphagnum Woodland	0.20	0.2	0.5
Unvegetated	0.04	0.04	0.1
Wetland	2.18	2.2	5.0
Riparian	6.56	6.5	15.0
Gravel Bar	6.92	6.8	15.8
All flooded forest	28.18	27.8	64.2
All flooded forest + wetland	30.38	29.9	69.2
Total flooded area	43.91	43.3	100.0
Total flooded area minus gravel bar	**36.98**	36.4	84.2
Total flooded area minus gravel bar and riparian	**30.42**	30.0	69.3
Water	57.59	56.7	
Total	101.51	100.0	

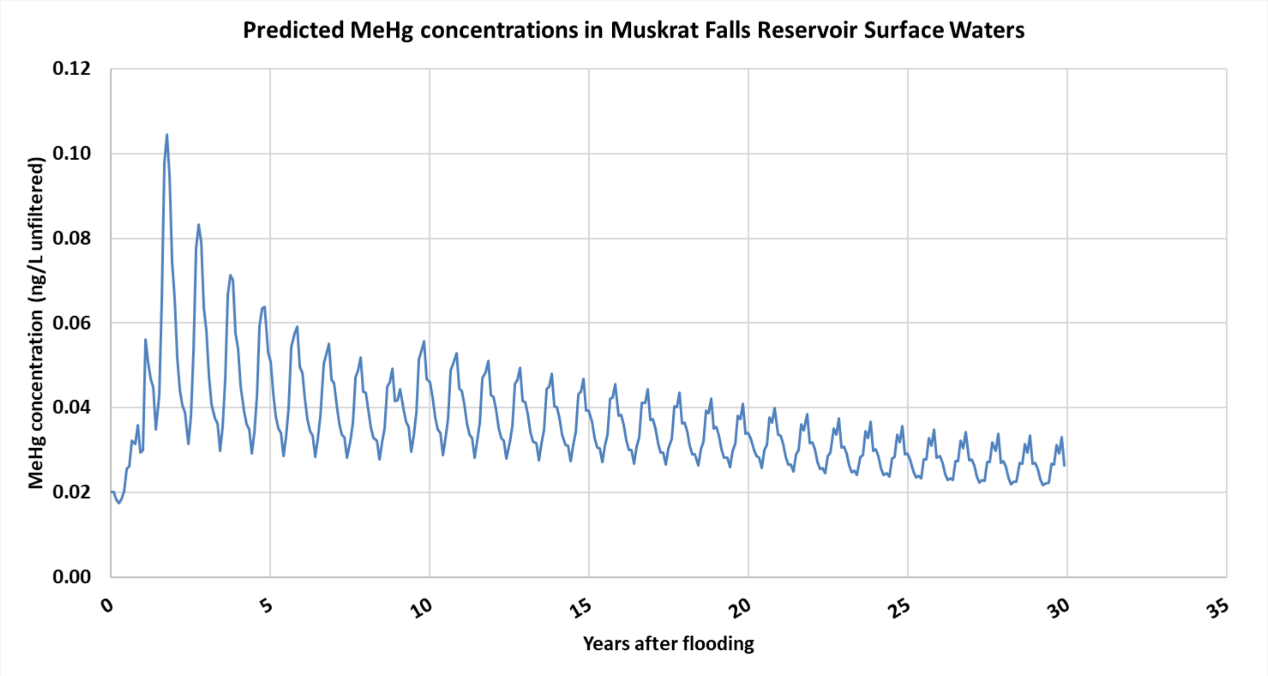
Predicted MeHg diffusion load from Muskrat Falls Reservoir flooded soils…

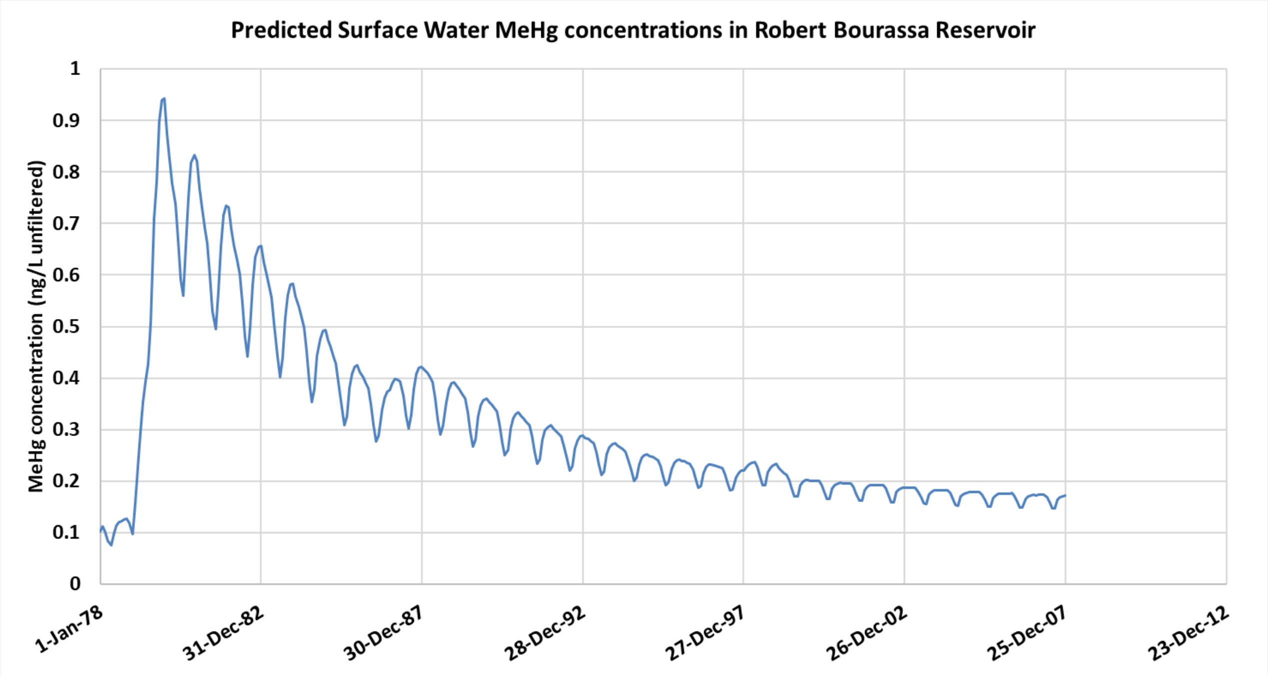


Calder rate = 664
(permanently)

Maximum flood season
fluxes for ELA sites
(net load to water)


Predicted MeHg concentrations in Muskrat Falls Reservoir Surface Waters
MeHg concentration (ng/L unfiltered)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
5
10
15
20
25
30
35
Years after flooding





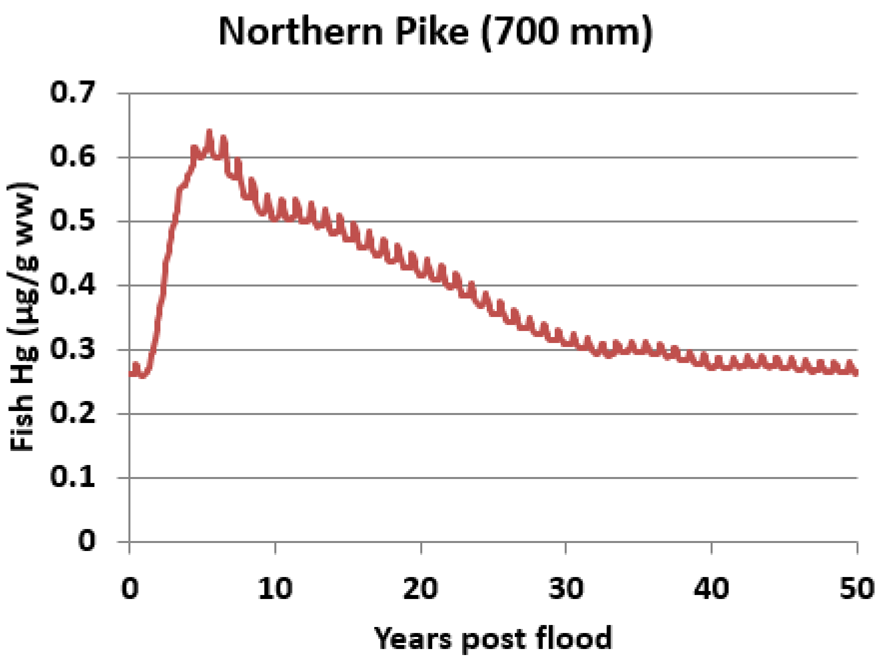
Why does Muskrat Falls simulation have less MeHg increase in water?

- Flow dilution
- Fraction of reservoir that is flooded

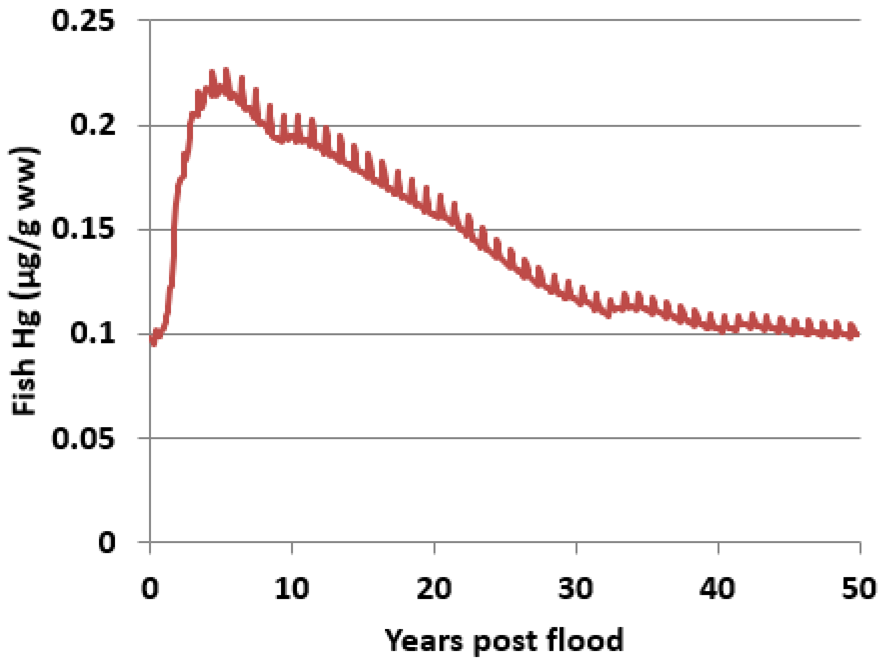
	Muskrat Falls	R. Bourassa
Water residence time	10 days	7 months
Percent of reservoir that is flooded terrain	30-37	87

Predicted MeHg in Muskrat Falls Reservoir Fish

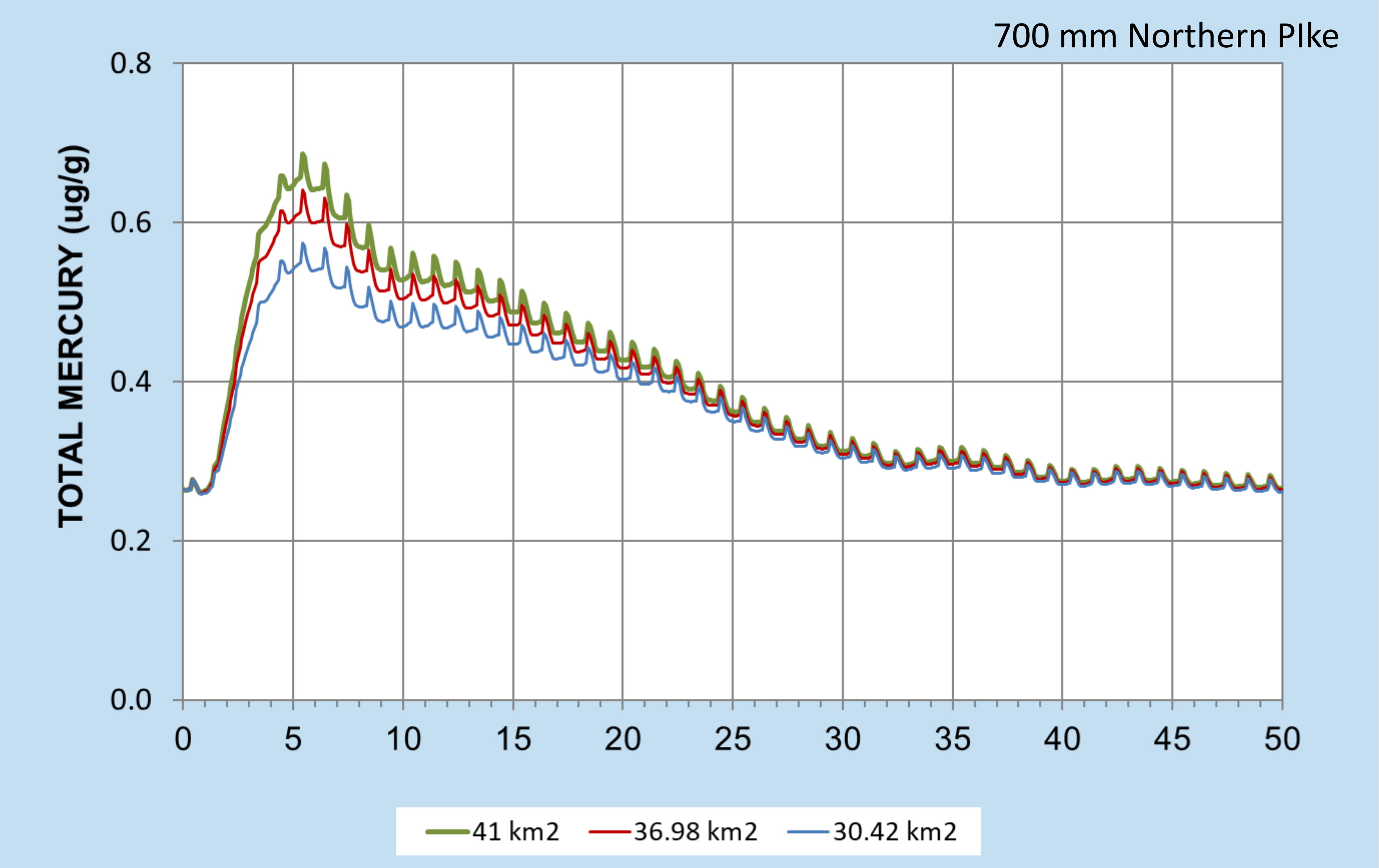
Northern Pike (700 mm)



lake whitefish (400 mm)

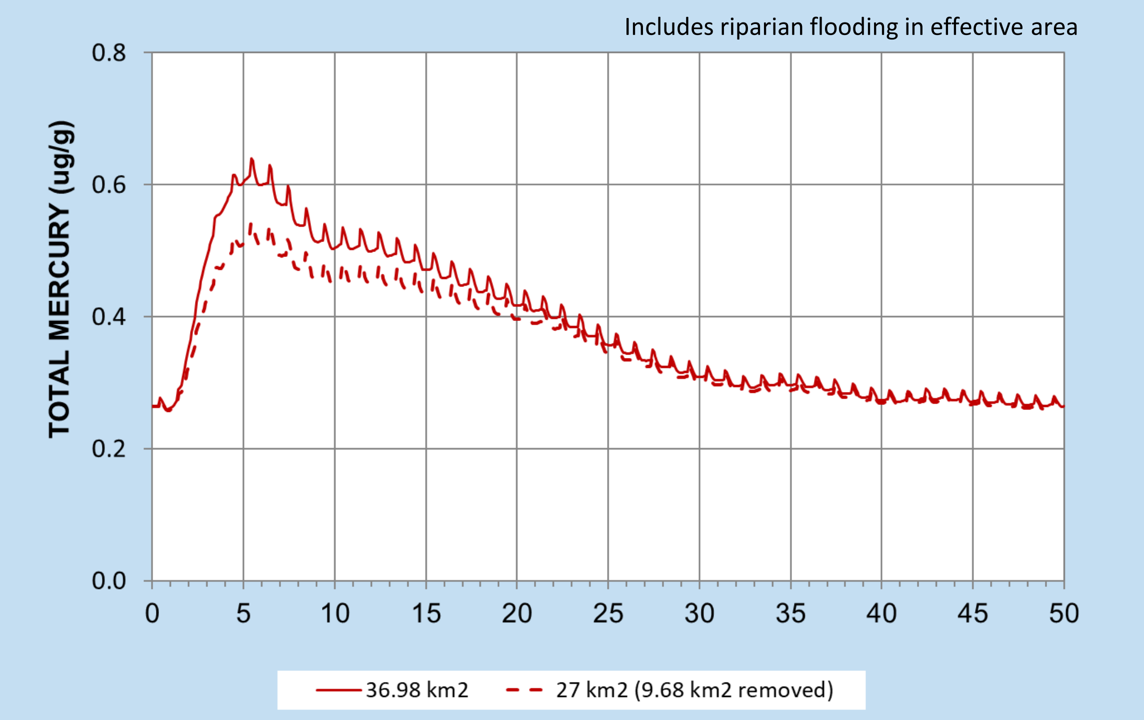


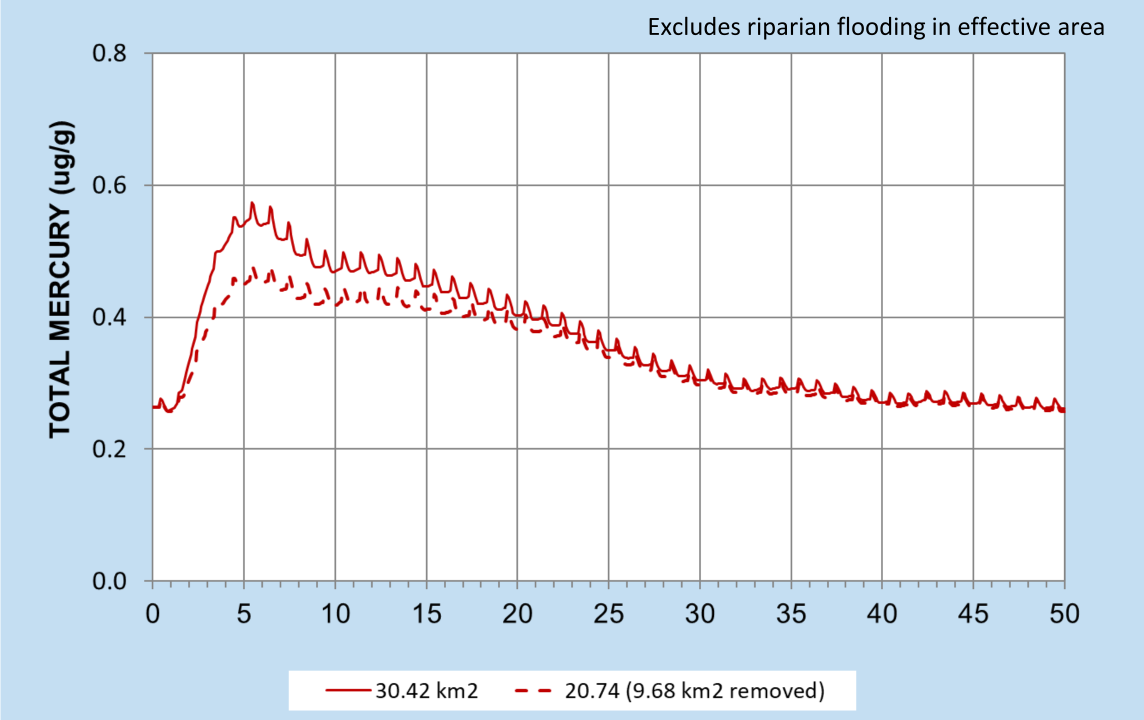
Predicted effect of using different "effective" flooded areas (without mitigation)



Predicted effect of removing organics from 968 ha of flood zone

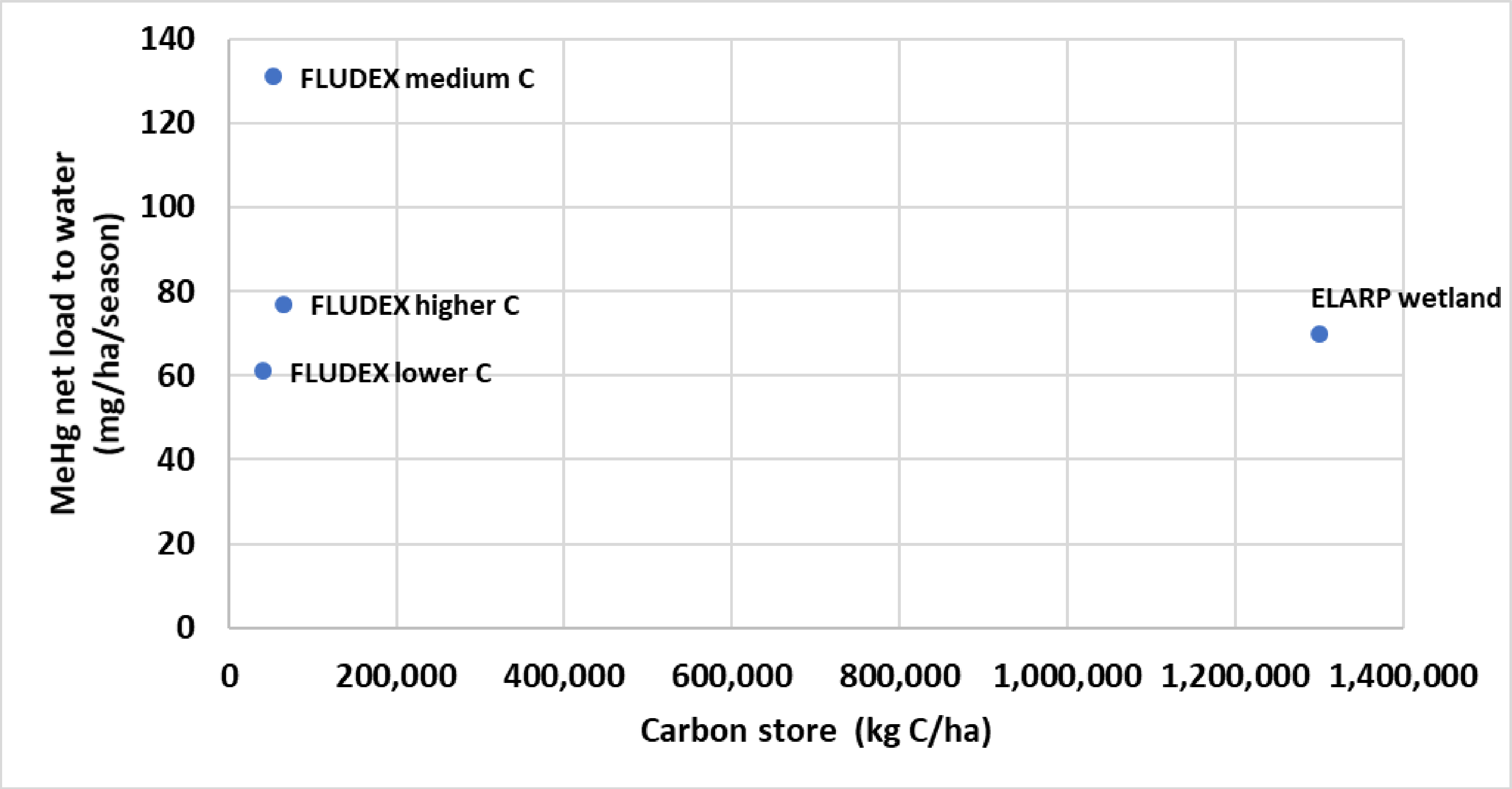
700 mm Northern Pike





Flooded wetlands and uplands at ELA had similar loads to water.. but wetland loads persisted longer.

Removing or covering 60 ha of wetland is predicted to reduce Hg increase in adult Northern Pike by ~0.01 µg/g



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

Regression Modelling

Regression model has "mechanistic roots…"

Assume…

MeHg mass rate of change In water ***= Inflow + Load from flood zone + Atm. Dep. – Outflow – Photodegradation – Settling***

= (Qin*Cin) + (Af*k1) + (Qprec* Cprec) - (Qout*C) - (At*k1*C) - (At* k2*C)

Where:

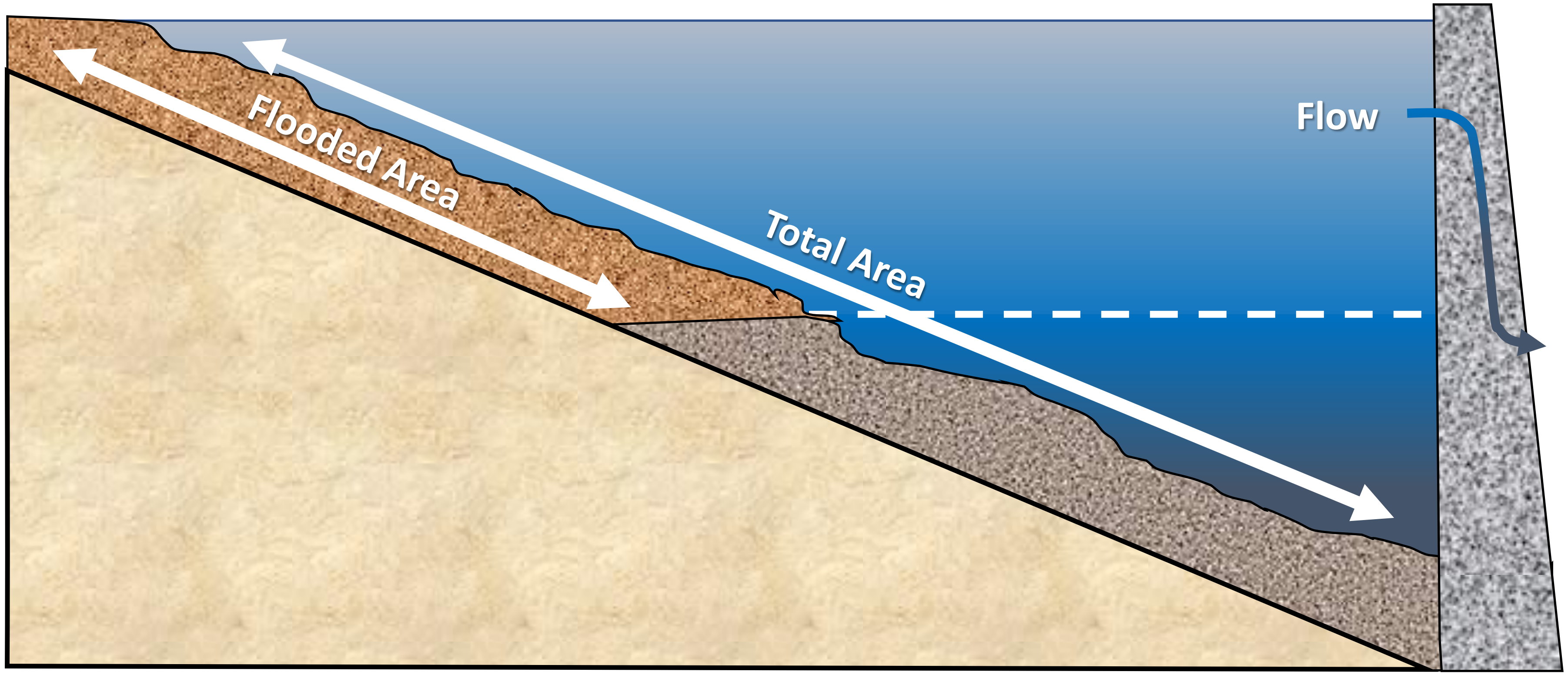
Rate of change for MeHg mass = µg MeHg/day
Af = flooded area (m^2)
At = total area (m^2)
Qin = flow (m^3/day)
Qout = flow (m^3/day)
Qprec = flow (m^3/day)
k1 = loading rate (µg/m^2/day)
k2 = removal rate constant for MeHg photodegradation (m/day)
k3 = removal rate constant for MeHg by settling (m/day)
C = concentration (µg/m^3)

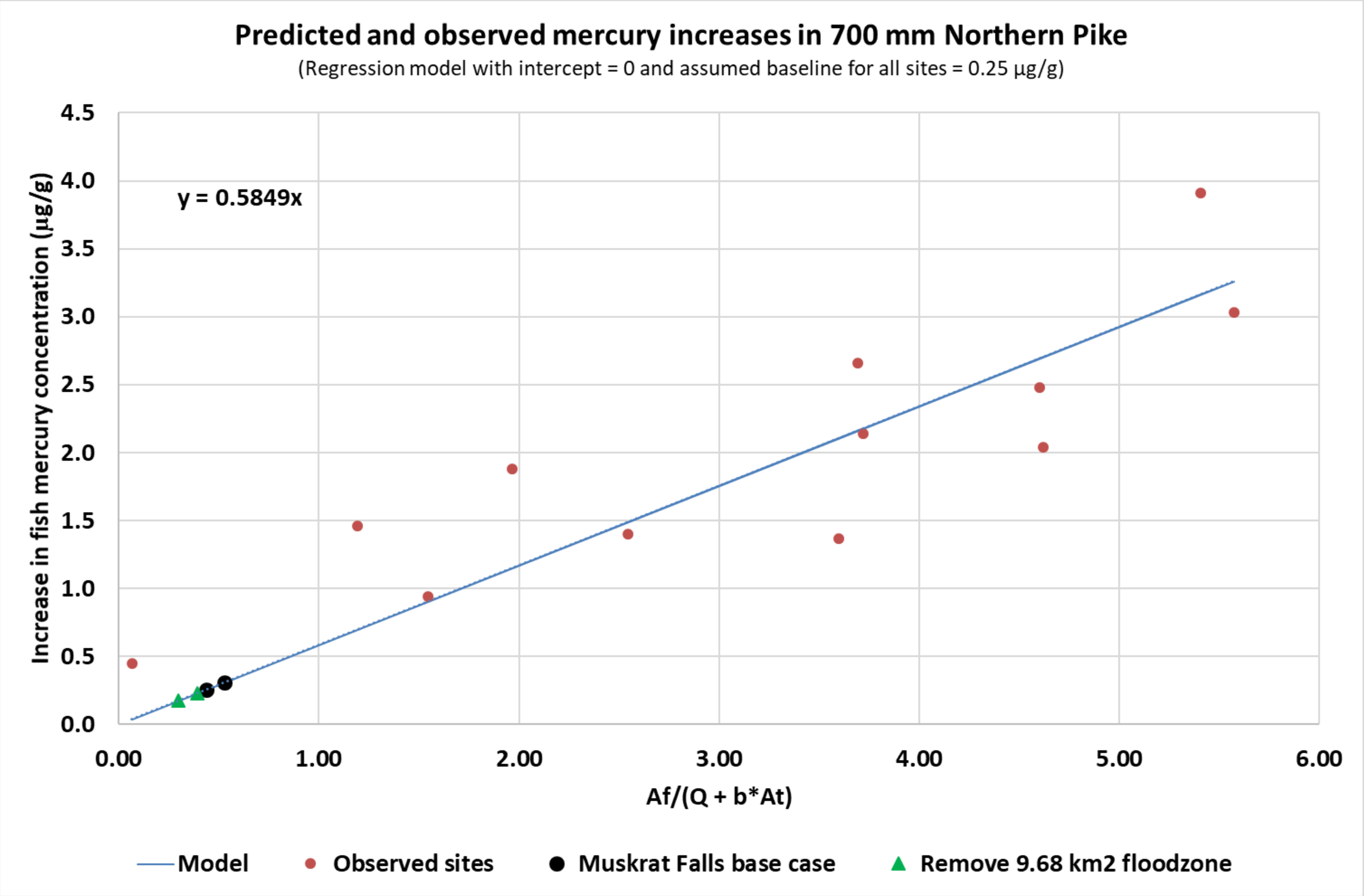
We ended up with…

Peak increase in concentration related to: $k_1 \left(\frac{A_{flooded}}{(Q + k_2 A_{total})} \right) + k_3$

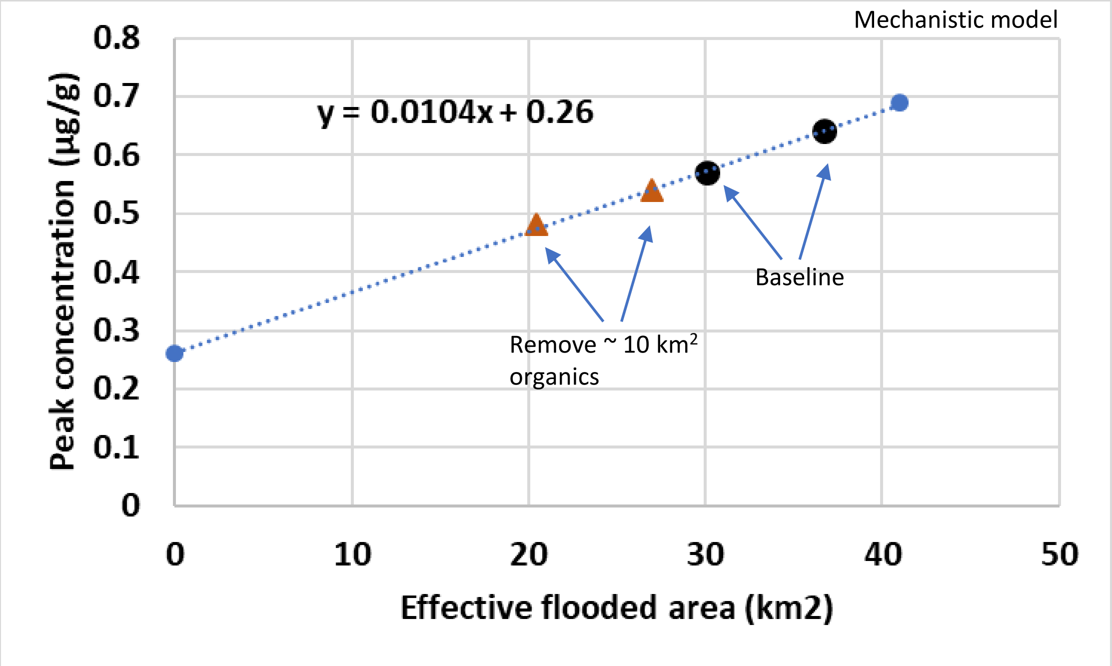
Where:

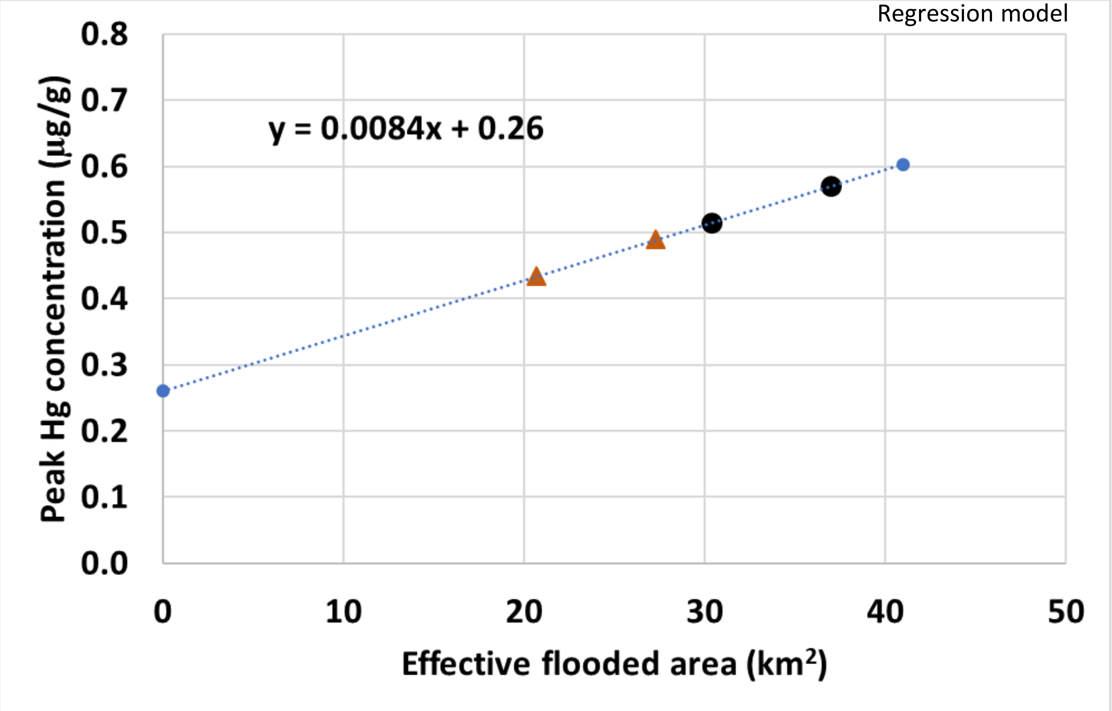
$A_{flooded}$	= flooded area (km^2)
Q	= mean annual flow (km^3/yr)
k_1	= regression coefficients (km/yr)
k_2	= regression coefficients (km/yr)
A_{total}	= Total reservoir area (km^2)





Predicted and observed mercury increases in 700 mm Northern Pike
(Regression model with intercept = 0 and assumed baseline for all sites = 0.25 µg/g)
y = 0.5849x
Increase in fish mercury concentration (µg/g)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Af/(Q + b*At)
Model
Observed sites
Muskrat Falls base case
Remove 9.68 km2 floodzone



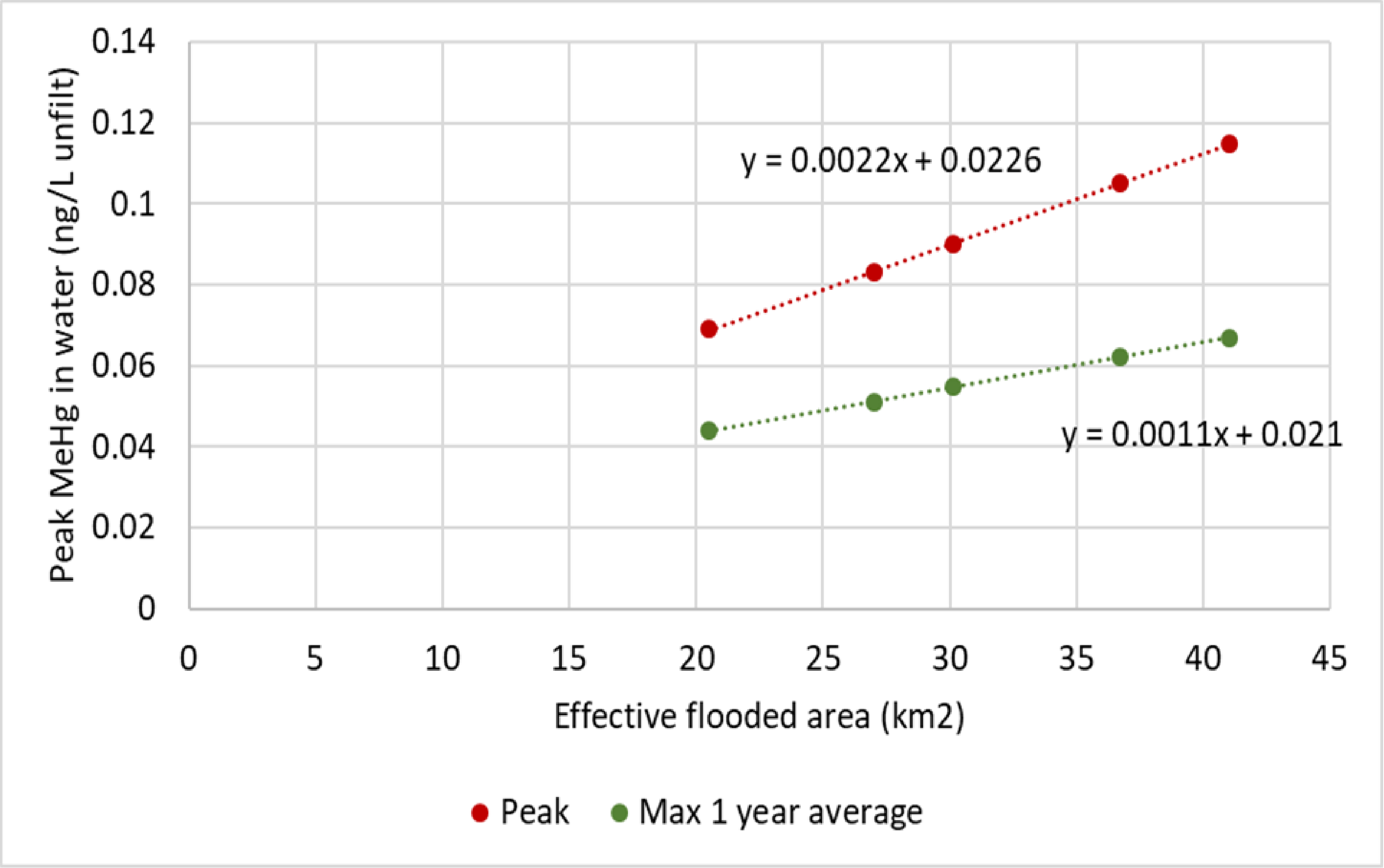


Summary slide for predicted mercury in Northern Pike (700 mm) in Muskrat Falls Reservoir

Mechanistic and regression models both add about 0.1 µg/g for every 10 km^2 of flooding (for 700 mm northern pike)

Summary slide for predicted increases in methylmercury in Muskrat Falls surface waters

(only the mechanistic model predicted concentrations in water)



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 for peak fish Hg:

- Based on field data from ~12 sites, but we often don't know the site baselines.
- Muskrat Falls is outside conditions used to calibrate model.

Mechanistic model (RESMERC):

- Better in principle
- Limited testing against real world reservoirs (no data for MeHg in water for example)

Calder model:

- No site-by-site testing yet against field data for MeHg in water or fish?

Summary

- Model was first applied to two full scale reservoir to examine MeHg loads from flood zone required to produce observed fish mercury levels.
- Model then applied to existing conditions at Muskrat Falls site.
- Applied model to Muskrat Falls Reservoir:
  - Water peak ~0.1 ng/L; less when averaged over a year or more. These values are lower than Calder prediction of about ~0.2 ng/L.
  - Adult pike in reservoir not predicted to increase as much as water (~2.5X vs ~4-5X)
  - Removing organics from 968 ha of upland predicted to reduce peak Hg in adult pike by about 0.1 ug/g (~0.64 to 0.54 ug/g, about 15% reduction in concentration)
  - Covering 60 ha of wetland predicted to have little effect because of small area (about 2% of flood zone).

Next steps

- Examining effect of fish being linked to MeHg in sediments vs water
- Sensitivity analysis ongoing
- Write up results for reservoir modeling
- Downstream modeling ongoing.