Geomorphology Update Fall 2011 Expert Panel Meeting

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Outline

- Predictions of
  - mercury concentration on banks
  - mercury loading from eroding banks
- Estimating residence time of hyporheic zone particles
  - Radiometric dating
  - Scour chains
- Overview of geomorphic processes along the South River

Quantify Hg Accumulation on Streambanks, 1930-2007, RRM 0-10

- Represent mercury accumulation as a sedimentation process
    - Mercury attached to suspended particles accumulates when areas are inundated by floodwaters

The Most Important Variables

- Frequency of inundation by floodwaters at a location
    - Elevation of a site relative to the river channel
        - Quantify inundation frequency with a detailed inundation frequency model
            - A independent computation using detailed stage-Q model
- Riparian vegetation (forest vs non-forest)
    - Vegetation traps sediment and mercury
        - Quantify with a simple model of vegetation-induced sediment trapping
- Sediment accumulation…can influence…subsequent sediment accumulation
    - Rates are mostly too low to worry about
        - But important at some sites where thick deposits have accumulated since 1930 (HRADS, or Hg release age deposits)
        - Quantify with a simple model of net sedimentation at HRAD sites only

Variables Neglected

- Distance downstream
- Post depositional physical erosion/remobilization
- Other sources of Hg (e.g. atmospheric deposition, etc)
  - We know it's negligible
- Geochemical transformations
  - Volatilitization
  - Leaching
  - Methylation
  - Etc.
- Local processes that cause unusually fine or organic-rich sediments (with abundant Hg) to accumulate

The Mathematical Model

- A simple closed form analytical equation that predicts Hg inventory at any South River near-bank location
  - RRM 0-10
- Hg inventory:
  - The total mass of mercury per unit floodplain surface area
    - Units: kg Hg/m^2

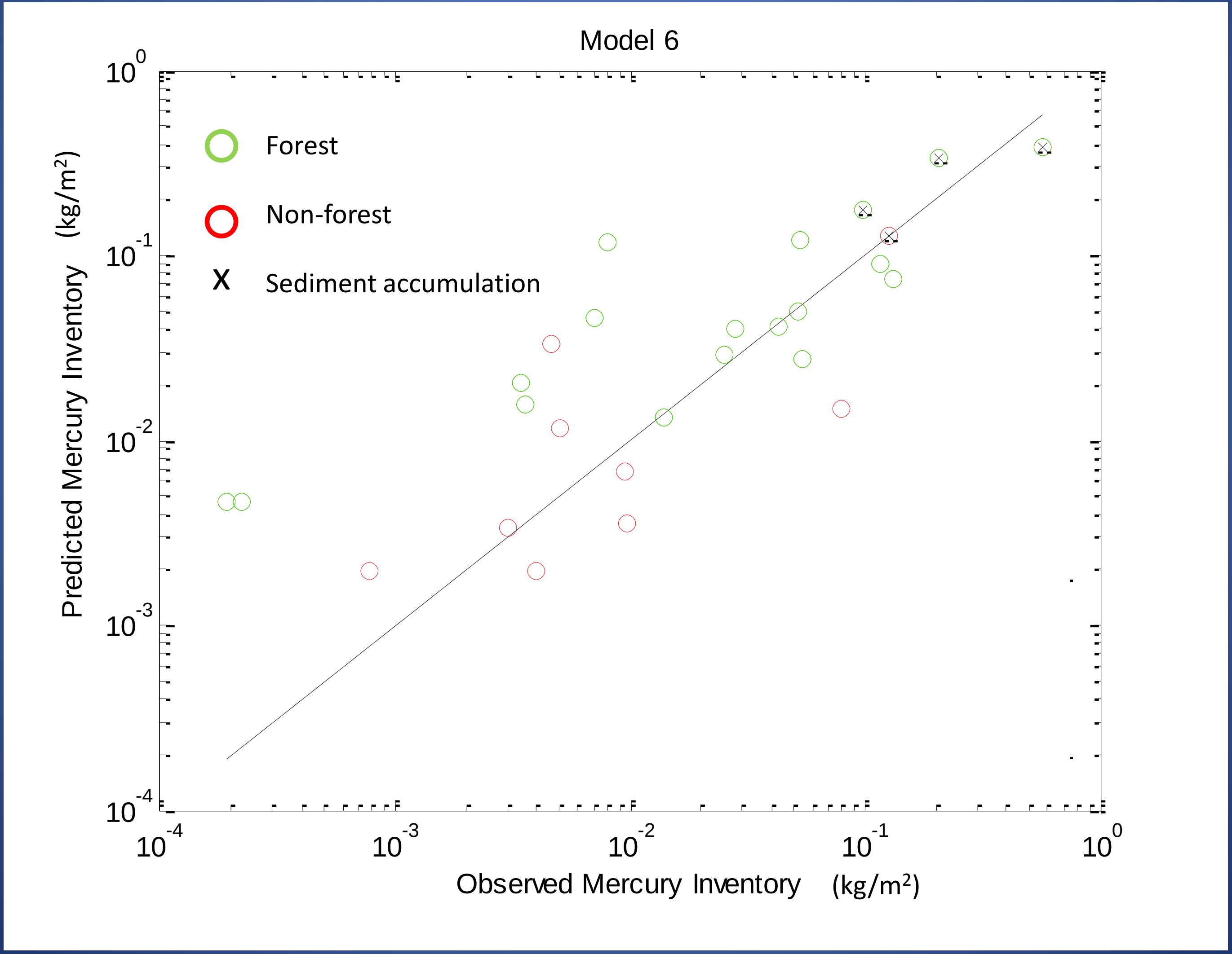
Model Calibration

- Use 27 sites where detailed data are available.
- Calibration determines 4 parameters that represent:
  - Hg accumulation rate during flooding
  - Increased accumulation caused by “forest” relative to “non-forest”
  - Maximum inundation depth for mercury accumulation
    - Floods deeper than a threshold value do not accumulate sediment or mercury
  - # of years required to accumulate HRAD deposits
- Approach:
  - Minimize rms error between observed and computed Hg inventories

Calibrated Model Results

2/3 of variance "explained" by calibrated model

rms error = 0.0573 kg/m^2



Parameter Values and 95% Confidence Intervals

Parameter	Value	95% Confidence Interval
Hg deposition rate ($kg/m^2/yr$)	0.0055	0.0044-0.0066
Forest/non-forest Hg deposition ratio	3.05	2.43-4.72
Maximum inundation depth for Hg accumulation (m)	0.98	0.45-1.53
Time for HRAD deposition (years)	39	22-56

Predictions of Hg Loading From Bank Erosion (RRM 0-10)

- Combine Hg inventory predictions with bank erosion rate estimates

Approach

- Divide banks into segments
  - Each segment has characteristic geomorphic features and processes
- Computations not made for:
  - Banks modified by engineering structures
  - Banks with exposed bedrock
  - Banks dominated by sand deposition or erosion
    - No point bars, for example

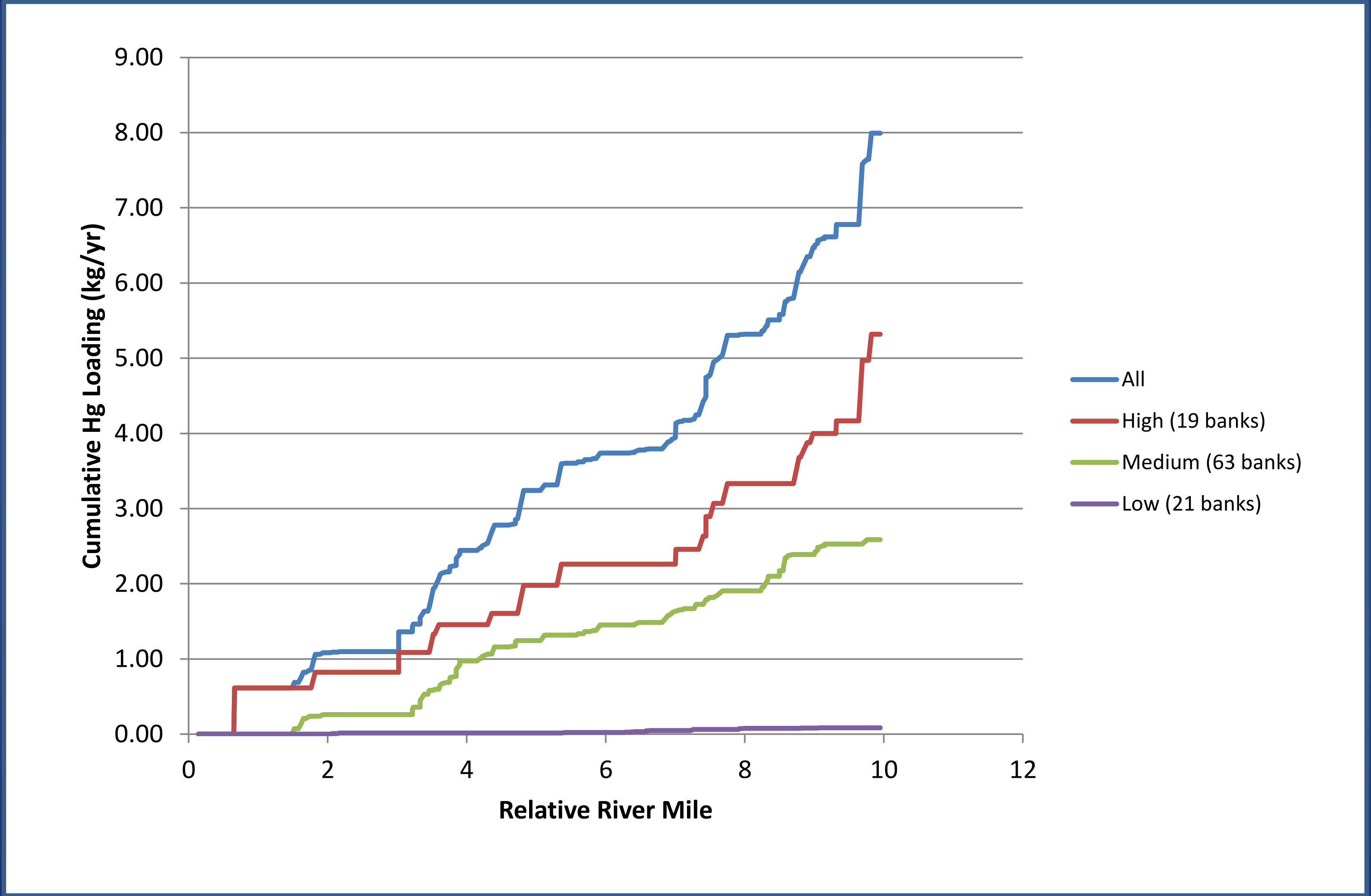
Data Required To Estimate Loading

- Detailed cross-section and local river slope
  - Field surveys
  - 2010 USGS LiDAR
  - Contours from 2005 LiDAR data
- Riparian vegetation 1937-2005
  - From historical aerial photos
- JEP hydraulic/hydologic model of flooding frequency
- Mercury concentration in banks
  - Field measurements on or NEAR banks
    - Data available for 60% of bank segments
  - No field data, use calibrated model
    - Model used for 40% of bank segments
- Bank erosion rate from (in order of preference)
  - Tripod lidar measurements
  - Historical aerial photographs
  - Channel curvature-based hydrodynamic erosion modeling
  - Visual mapping (with assumed 1 m retreat over 1937-2005)

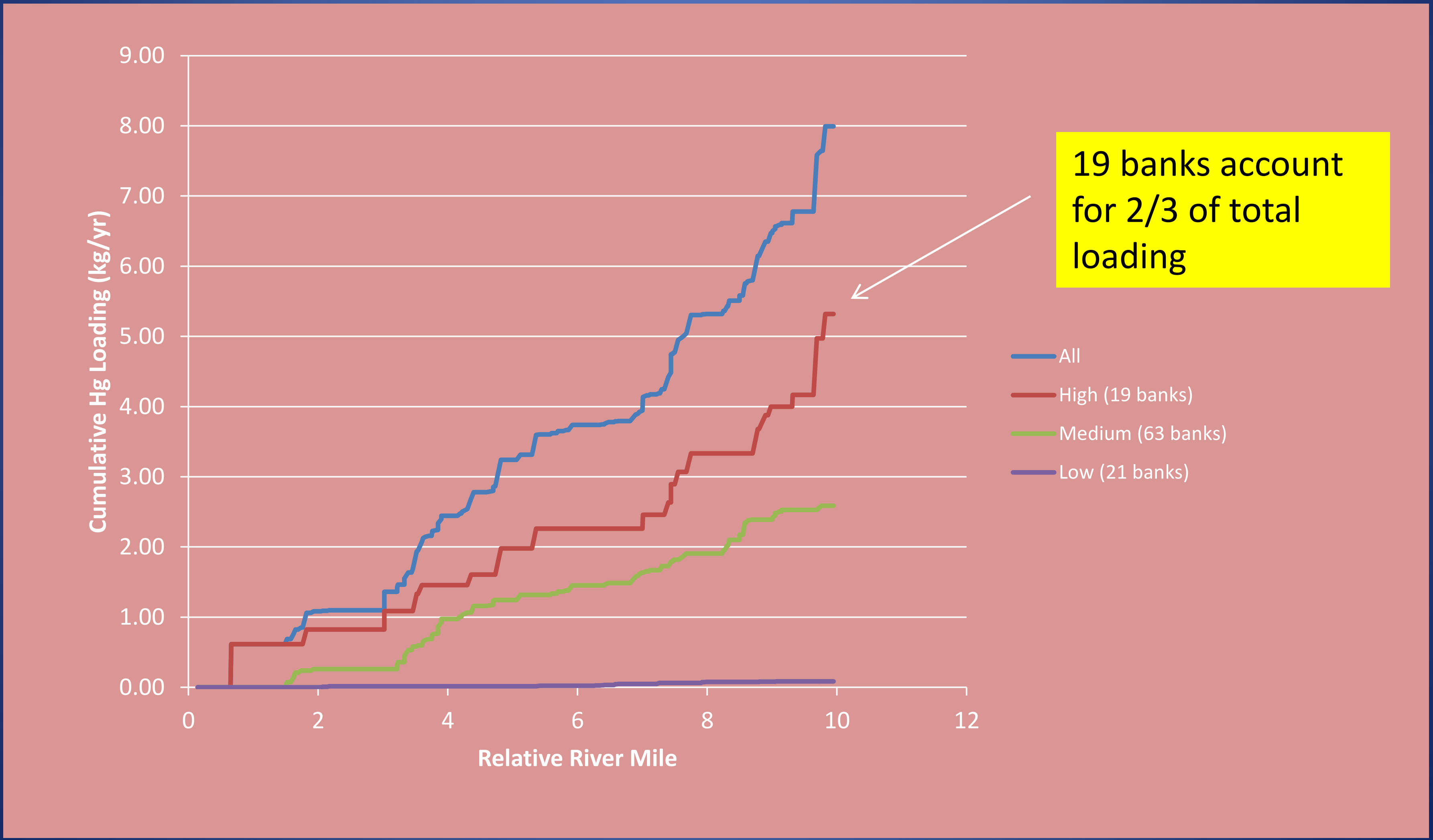
ArcGIS Data Layers..

Bank Loading Binned By RRM

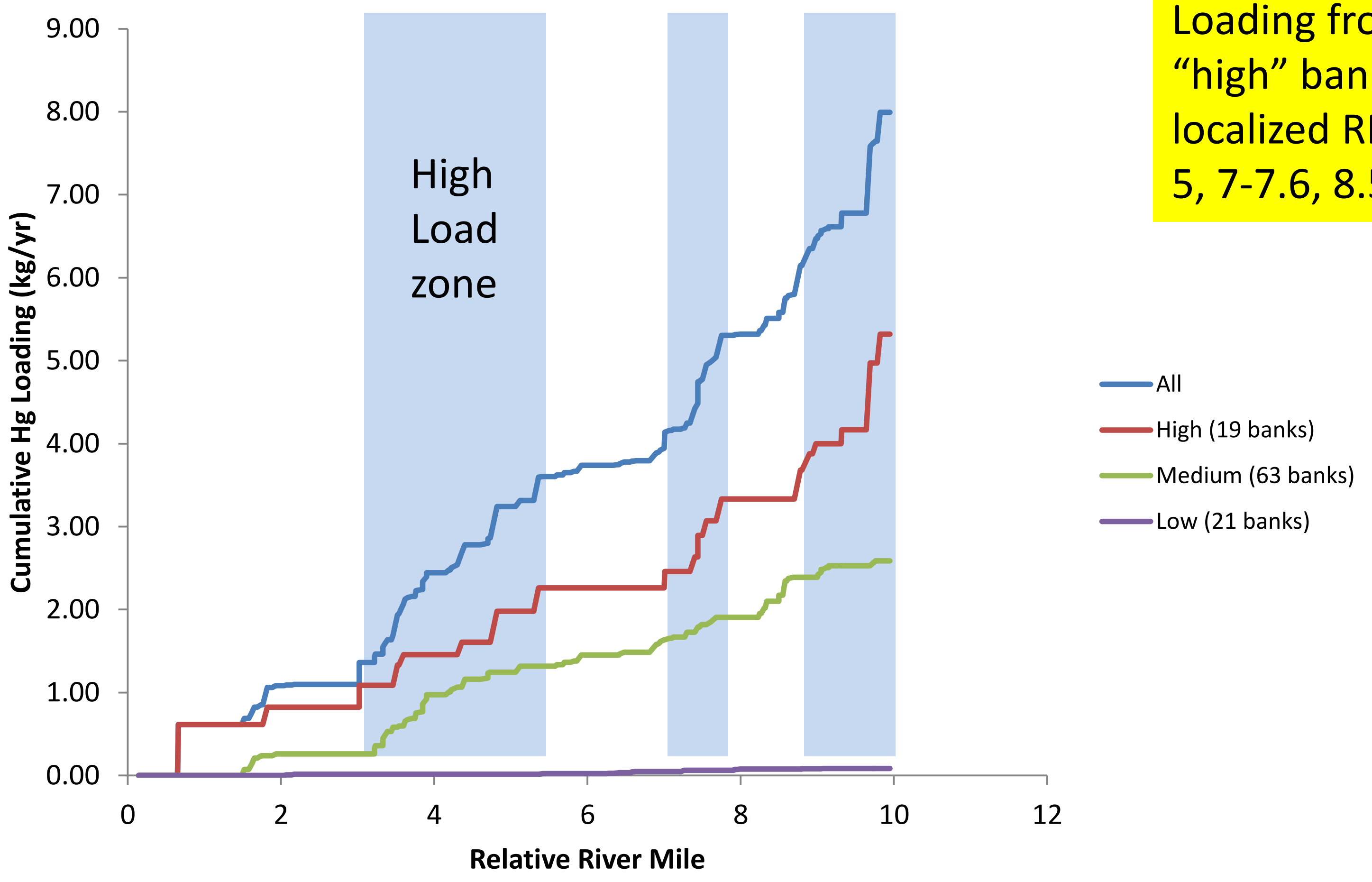
Cum. Loading By RRM, Category



19 "High" Banks Account for 2/3 of Total Loading

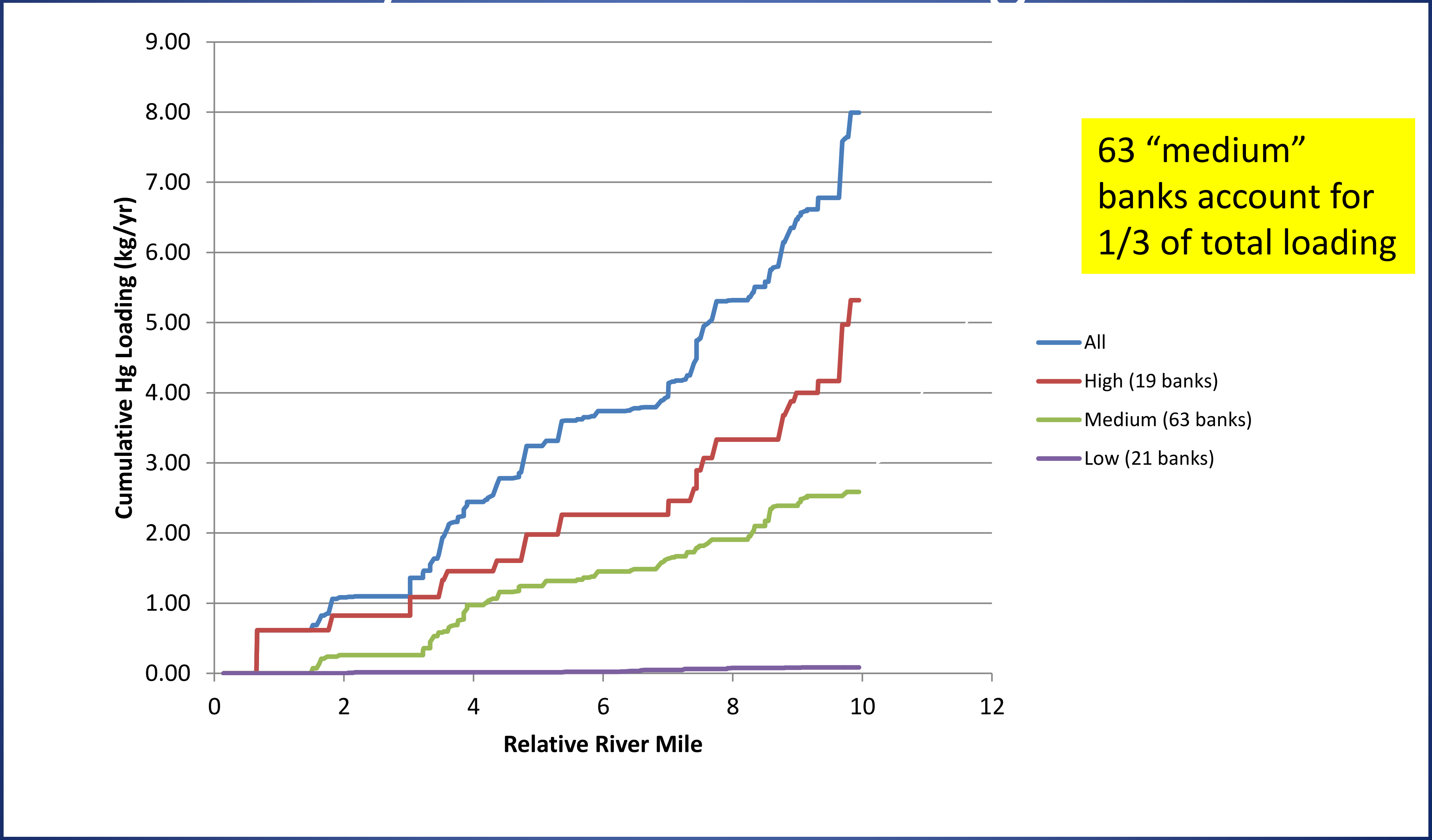


Cum. Loading By RRM, Category

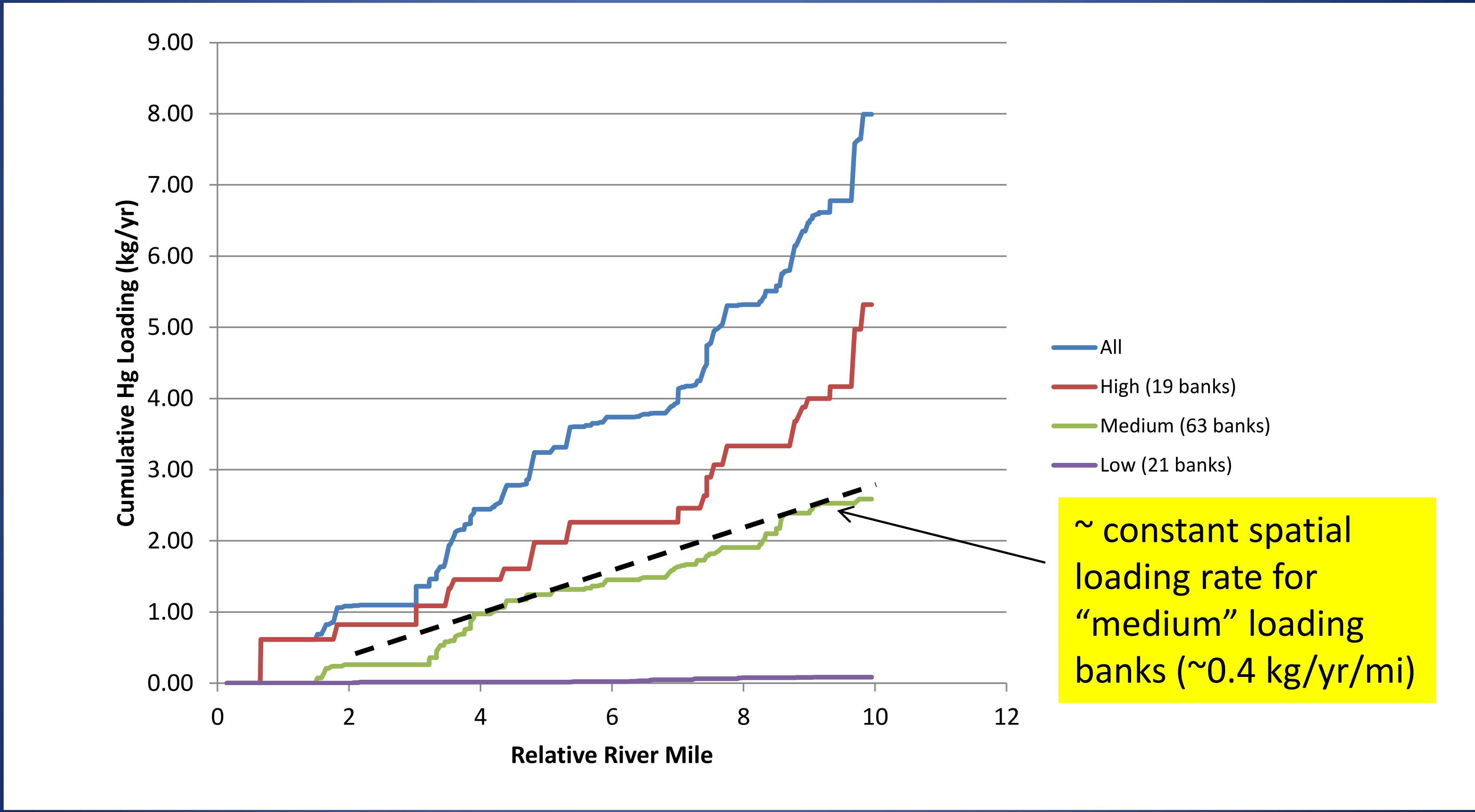


Loading from "high" banks localized RRM 2.5-5, 7-7.6, 8.5-10

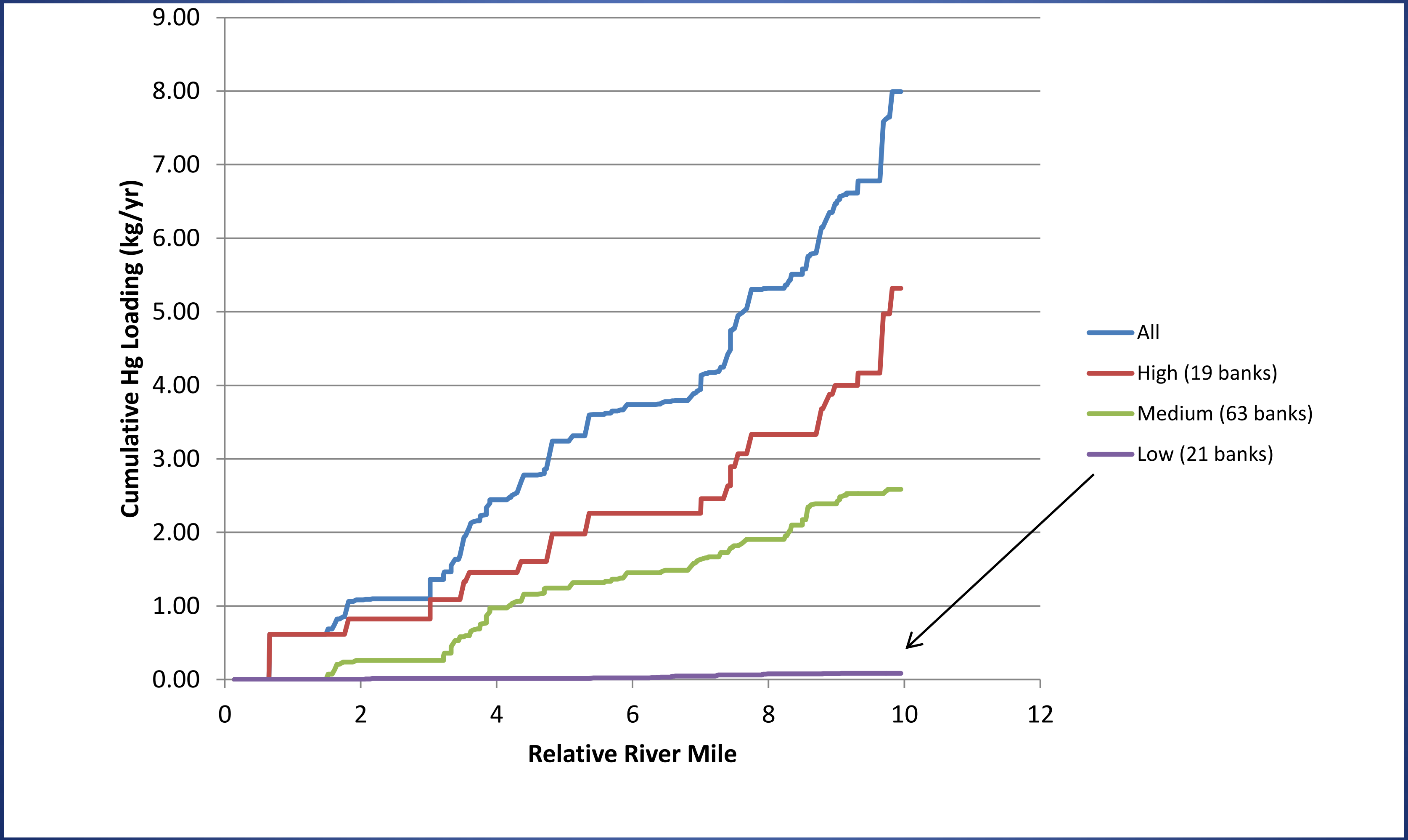
“Medium” Loading Banks Account for 1/3 of Total Loading



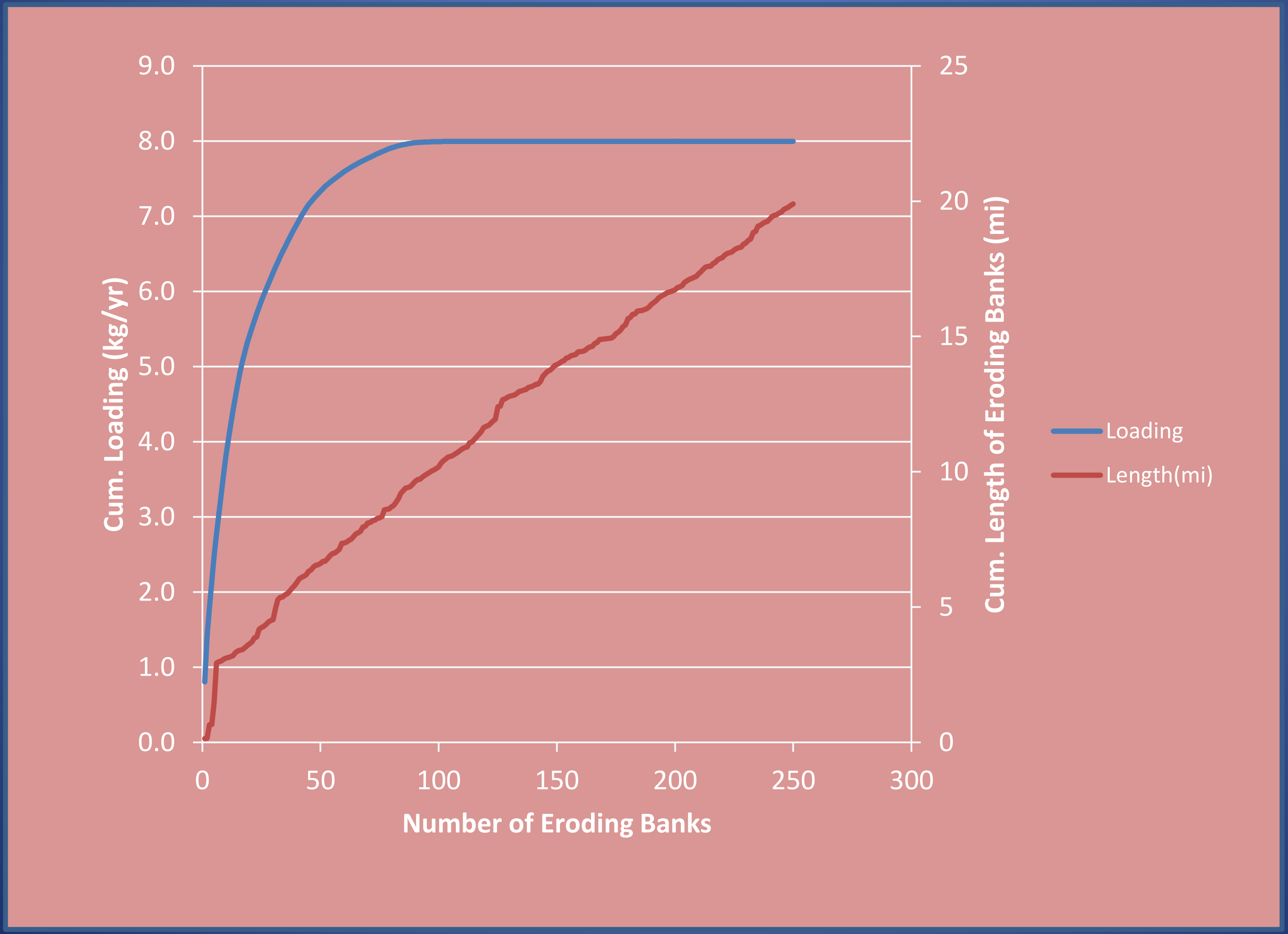
Loading From "Medium" Banks Evenly Distributed vs RRM



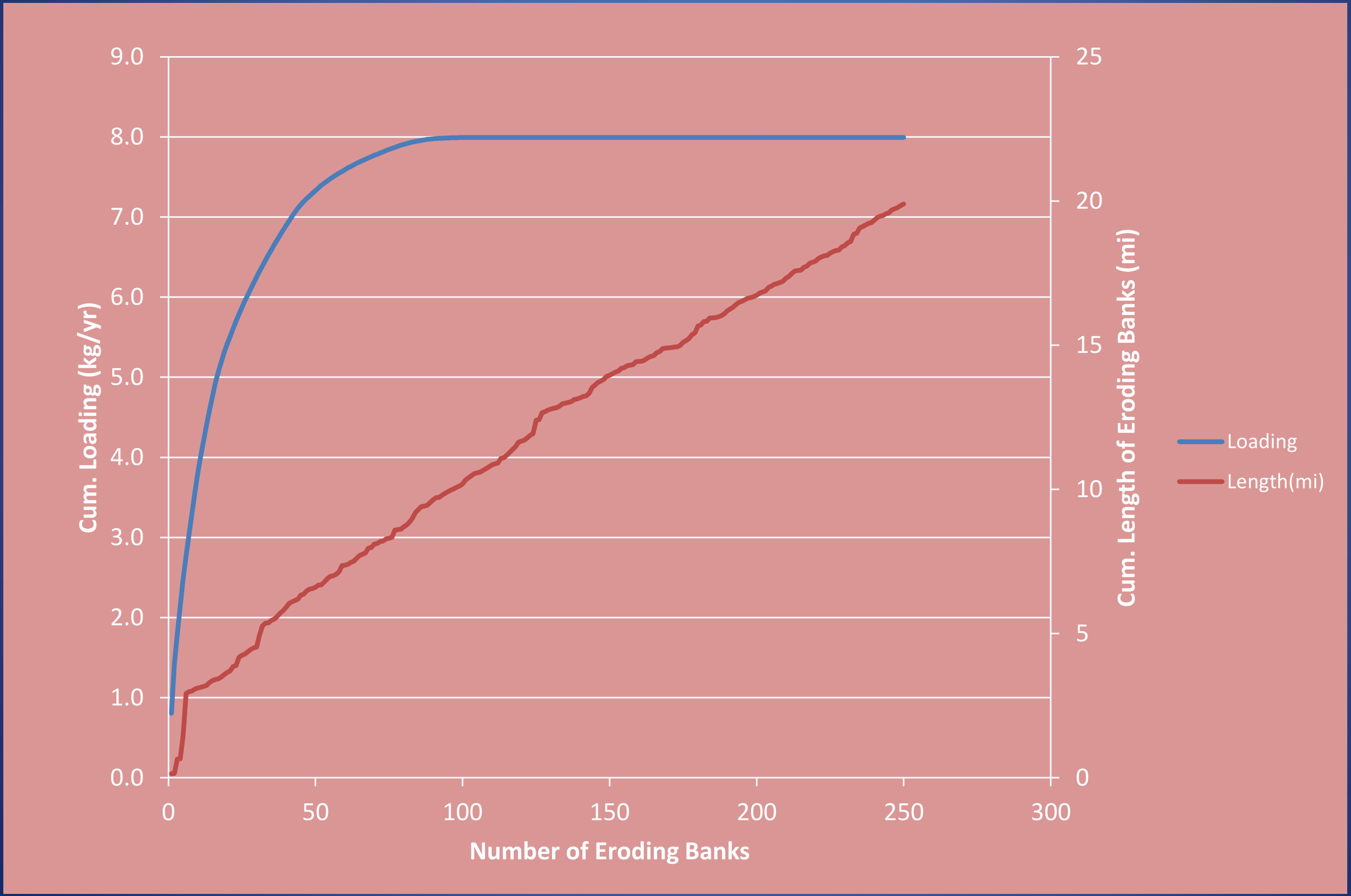
“Low” Loading Banks Contribute Little Total Loading



Eroding Banks Sorted From High to Low Loading, by Cum. #, Length



99% of Loading Accomplished By ~76 Banks with Cumulative Length of ~8.3 miles.
75% of Loading Accomplished by ~24 Banks with Cumulative Length of ~4.2 miles.



Eroding Bank Length Statistics

Average (mi)	0.08
Standard Dev. (mi)	0.12
95th Percentile (mi)	0.2
75th Percentile (mi)	0.09
50th Percentile (mi)	0.06
25th Percentile (mi)	0.03
5th Percentile (mi)	0.01

= ~300 ft

Residence Time of Hyporheic Zone Particles From Radiometric Dating - New Interpretations/Results

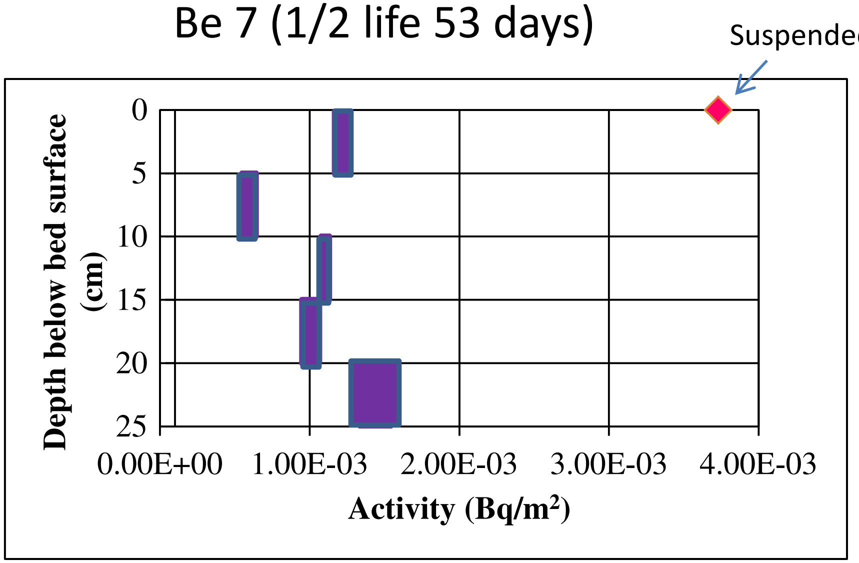
- Use radiometric dating methods utilizing:
  - Pb-210 (half-life – 22.3 years)
  - Be7 (half-life – 53 days)
  - Cs-137 (activity from nuclear testing peaked in 1963)
- Tried to date
  - Sand fraction only (not enough activity)
  - Silt and clay fraction (successful)

Study Location RRM 4.35

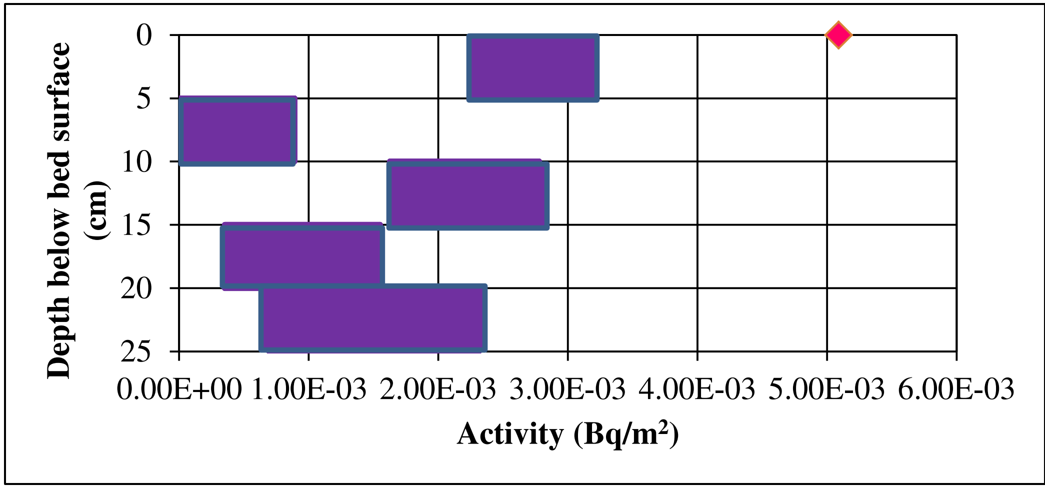
- Typical pool-riffle section
- Bed material mixed sand, cobble that is representative of many areas of the South River

Results

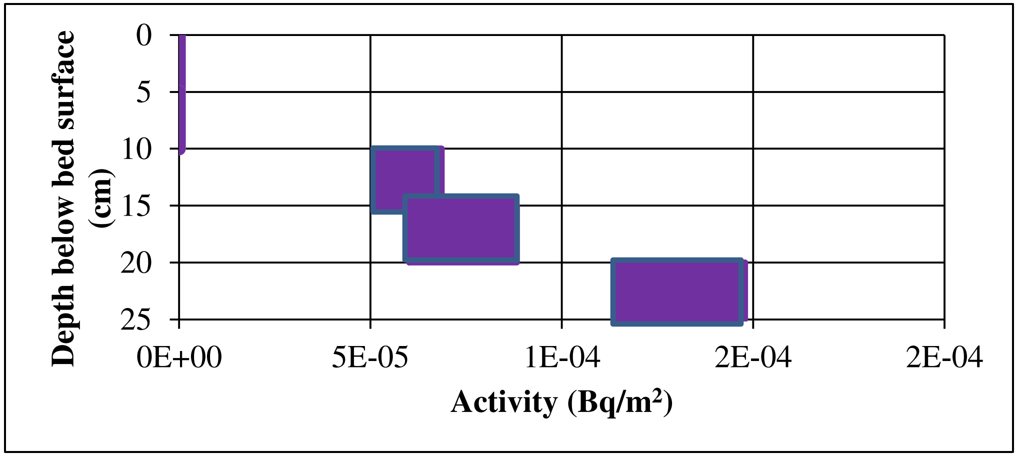
Be 7 (1/2 life 53 days)



Pb 210 (1/2 life 22 years)



Cs137 (Peak in 1963)



Interpretation

- A mixture of “young” and “old” sediment
- From:
  - Contamination during coring?
  - Deposition at depth of small amounts of new sediment during recent events?
  - No way to know which is correct

Fit 2-Age Model To Data

Depth	Fraction of Young Sediment	"Old" Age (years)	"Young" Age (years)
0-5 cm	0.4	6	0
5-10 cm	0.1	55	0
10-15 cm	0.25	15	0
15-20 cm	0.22	42	0
20-25 cm	0.35	32	0

Cumulative “Older” Age Distribution

Mean age = ~ 32 years, Residence time (assuming no net erosion or deposition) = ~36 years

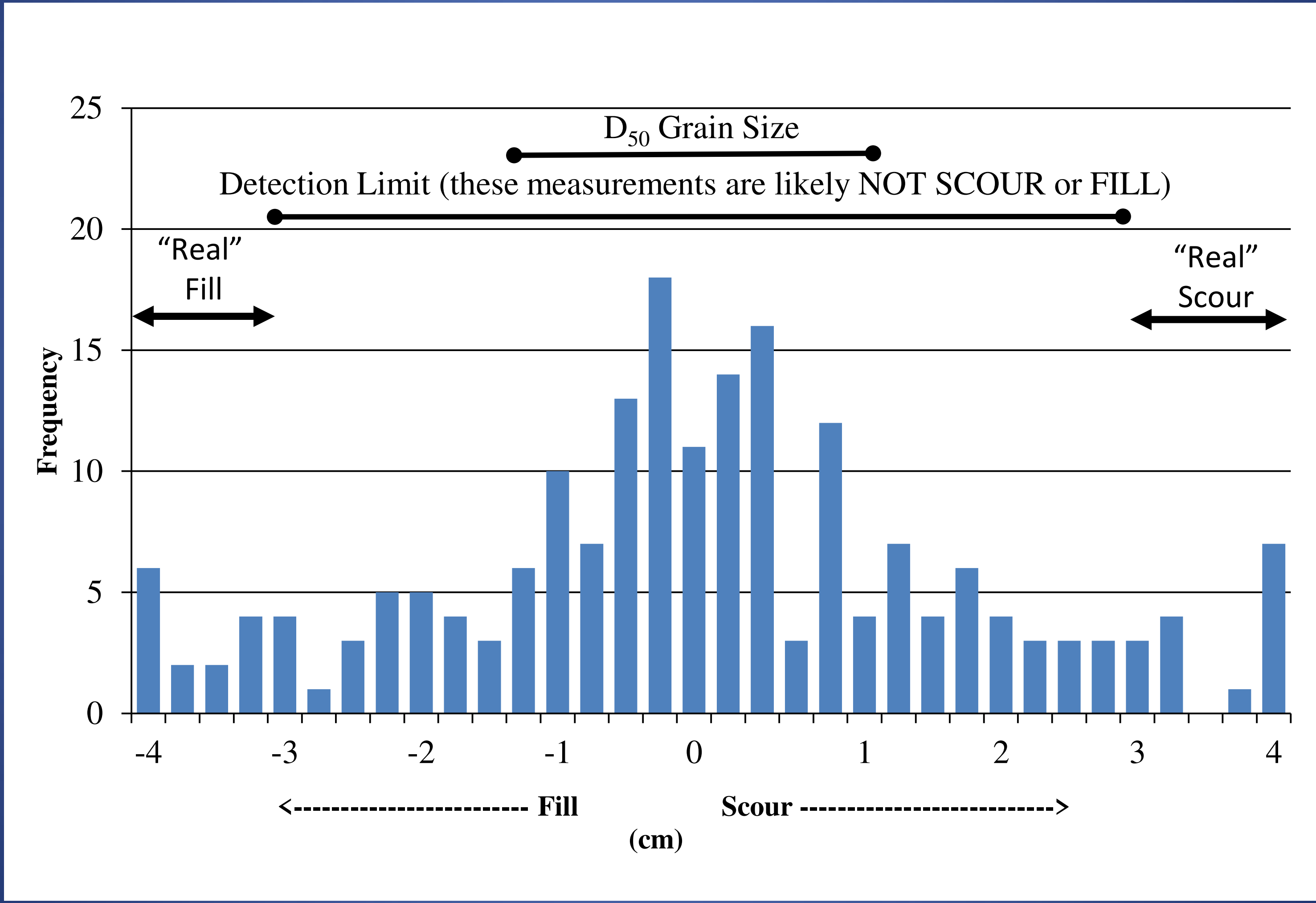
Measurements of Bed Scour using Scour Chains and Repeat Surveys:
Direct Observations of Hyporheic Zone Particle Reworking

Summary of “Scour” Events Monitored

Event Date	Flow (m^3/s)	Recurrence Interval (years)
September 28, 2010	56.6	0.95
December 1, 2010	84.9	2.25
March 10, 2011	45.3	0.61
April 16, 2011	229.4	12.76

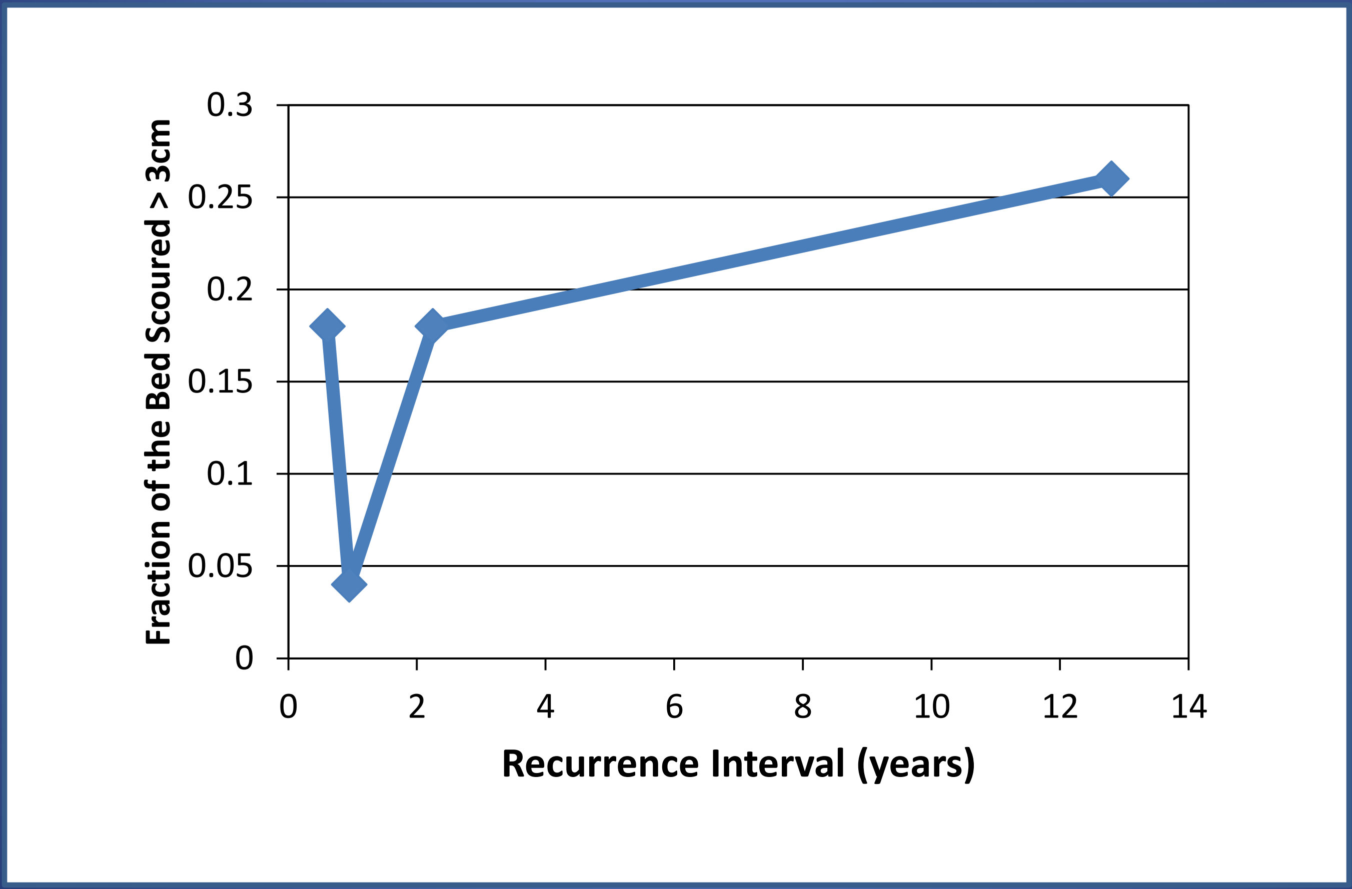
All of these discharges were capable of transporting the bed material!

Summary of All Scour/Fill Data



The overwhelming major of measurements indicate NO SCOUR OR FILL

Areal Frequency of Scour/Fill Events – An Estimate



Several decades are likely needed to scour the entire streambed!

South River Geomorphology: Overview of Processes and History Relevant to Mercury Fate and Transport

What have we learned during the last 6 years?

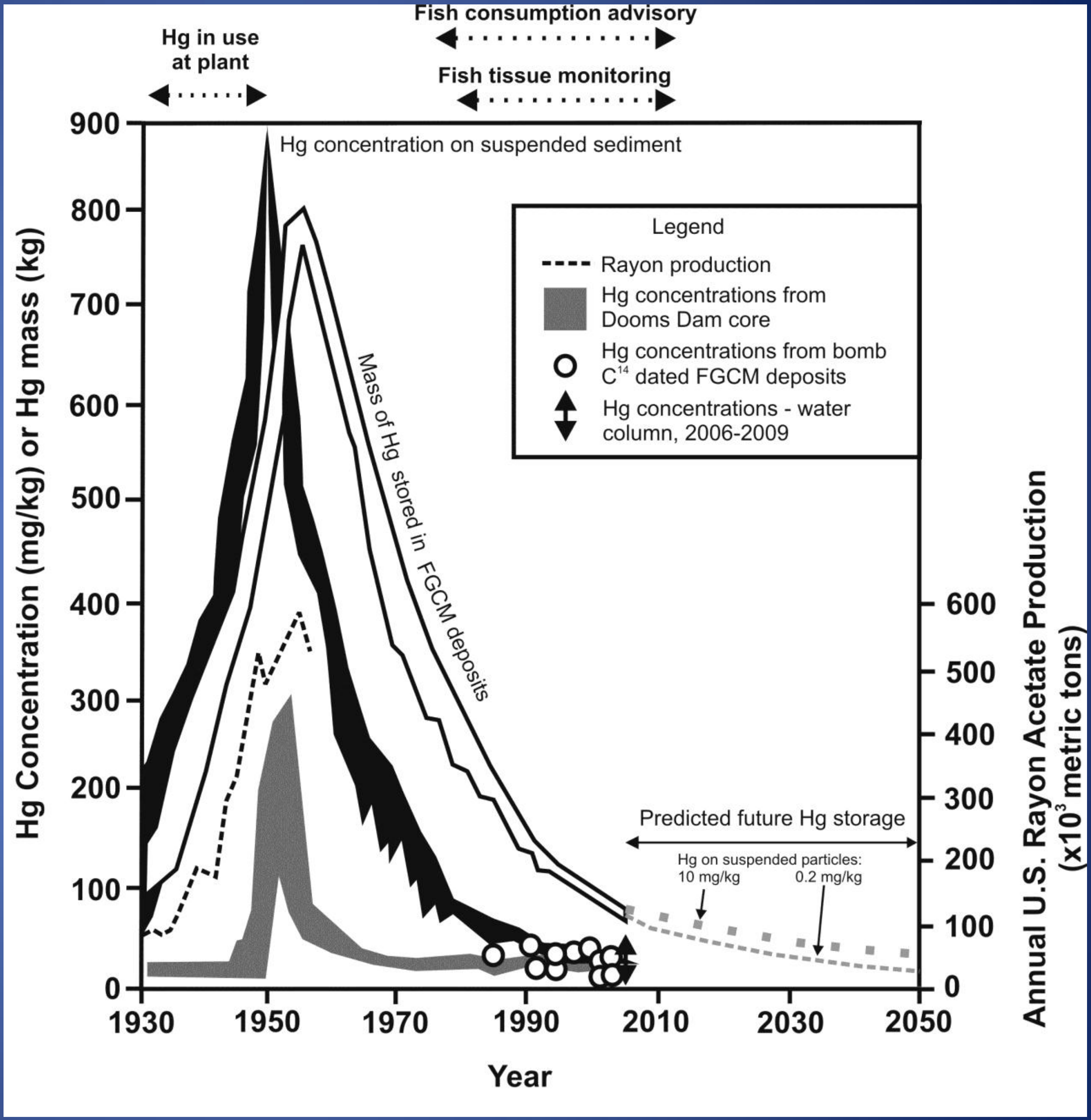
- Description/Classification of the South River
  - Gravel-bed, bedrock river with:
    - Bedrock is exposed every few 100 m along the channel
    - Localized riffle/pool reaches
      - But not a typical alluvial pool/riffle stream
    - ~ Mile long pools related to bedrock (?)/tributary input fan "obstructions"(?)
    - Non-meandering sinuous planform
    - Abundant islands formed by avulsion
      - A new island forms ~ every 5 years between Waynesboro and Port Republic
  - Mixed-load
    - Significant bedload and suspended load transport

Ongoing Influence of Past Events on Mid-Atlantic Streams

- Pleistocene periglacial processes deliver a load of untransportable boulders to stream valleys???
  - A new, but compelling hypothesis
- Catastrophic debris flows destroy alluvial valleys in Virginia every few hundred years
- European settlement
  - Increased sediment yield from deforestation and agriculture
  - Sediment trapping by mill dams
- 20th century
  - Flood control
  - Urbanization
    - Increased runoff
  - Reforestation
- ***Hg release by plant at Waynesboro, into South River, 1929-1950***

History of Mercury Concentration on Particles in the South River

Skalak and Pizzuto, in review

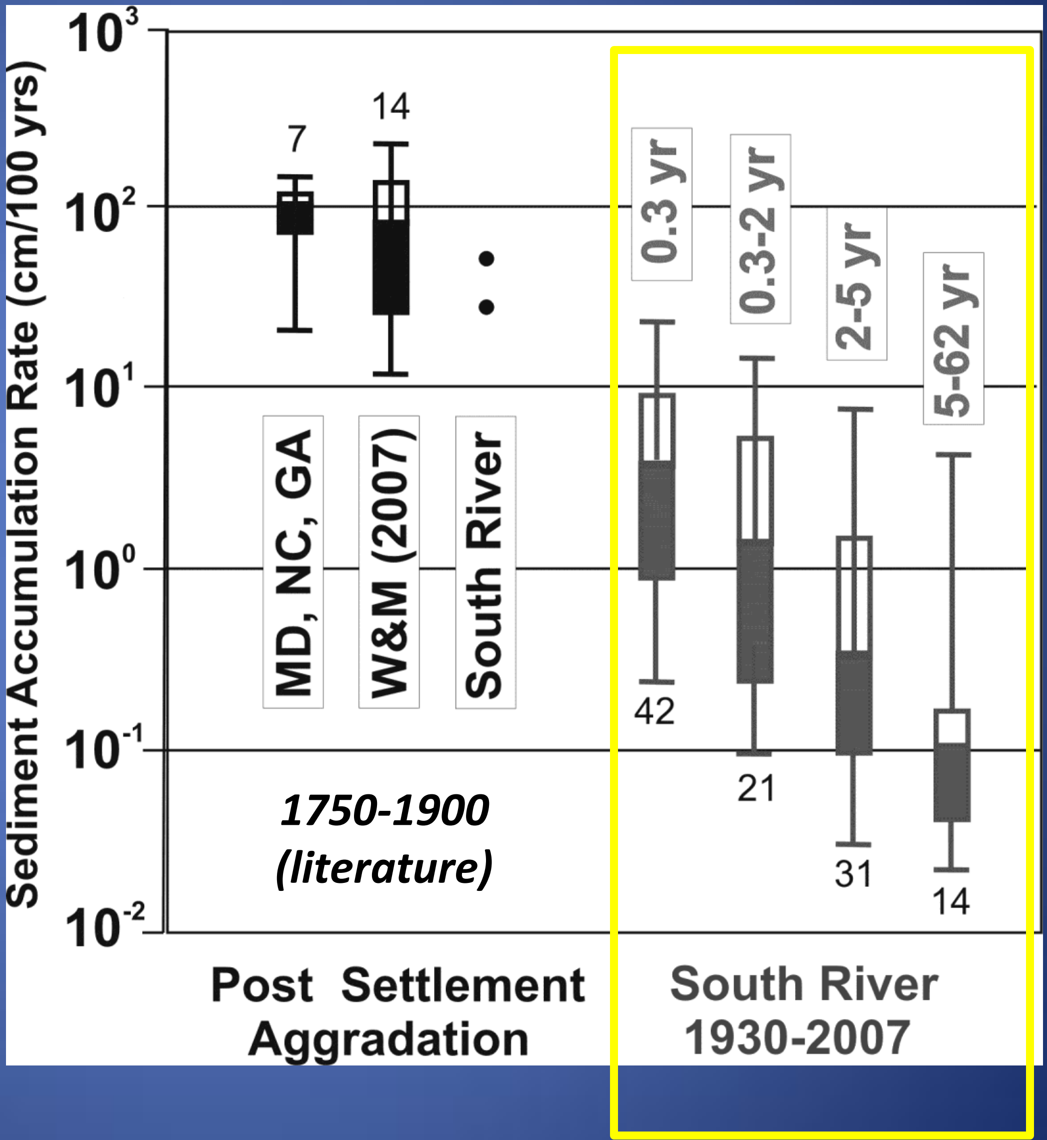


Why Does Hg Persist in the South River Decades After the Initial Release?

- Particles with adsorbed mercury are ***stored***
  - rather than transported downstream
- Stored sediment is released by ***episodic particle erosion***
  - and geochemical processes (?)

Centennial Floodplain Accumulation Rates Determined From Hg Inventories

Pizzuto et al. in review



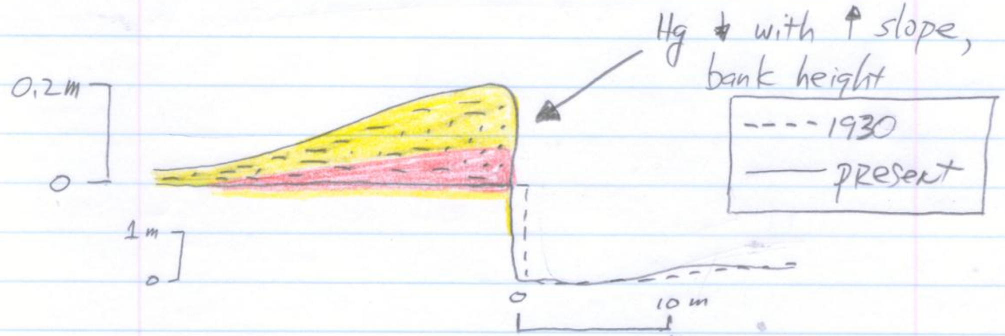
Conceptual Models of Near-Channel Mercury and Sediment Accumulation, 1930-Present, South River, Virginia

Mercury and Sediment Accumulation Settings – Geomorphic Classification

- Floodplain Levee (4 types)
  - Simple
  - Complex
  - Near eroding banks or non eroding banks
- Laterally Accreting Floodplain
- Sandy Point Bar Floodplain
- Mill Dam Bench
- *Tributary Confluence Sedimentation*
- *Islands*
  - *Islands developed from bars*
  - *Islands created by floodplain cutoffs*
- *Deposits related to cattle*

ITALICS - No figures developed as yet for these!

Floodplain Levee Sedimentation
- Eroding Bank



Grain Size

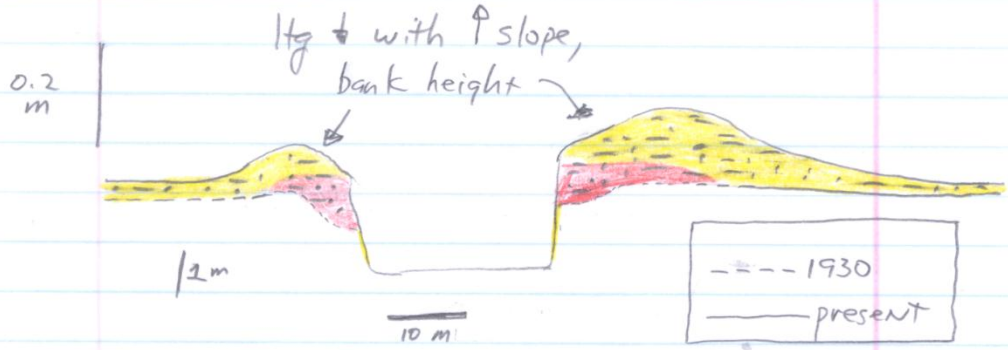
- (lines) silt + clay (< 0.0625 mm
- (dots) Sand (.0625 – 2 mm)
- (circle) Gravel (> 2 mm)

Hg Concentration

- (red) > 20 ppm
- (yellow) 7 – 20 ppm
- (white) < 7 ppm

Examples: RRM 2.9–3.0 (left bank) (high Hg)
RRM 3.22 (Right bank) (low Hg)
RRM 3.50 " "
RRM 8.25 (left bank) "
RRM 9.78 " "
RRM 2.18 (Right) (high Hg)

Floodplain Levee Sedimentation
– Non-Eroding Bank



Grain Size

- silt + clay
- sand
- Gravel

Hg Concentration

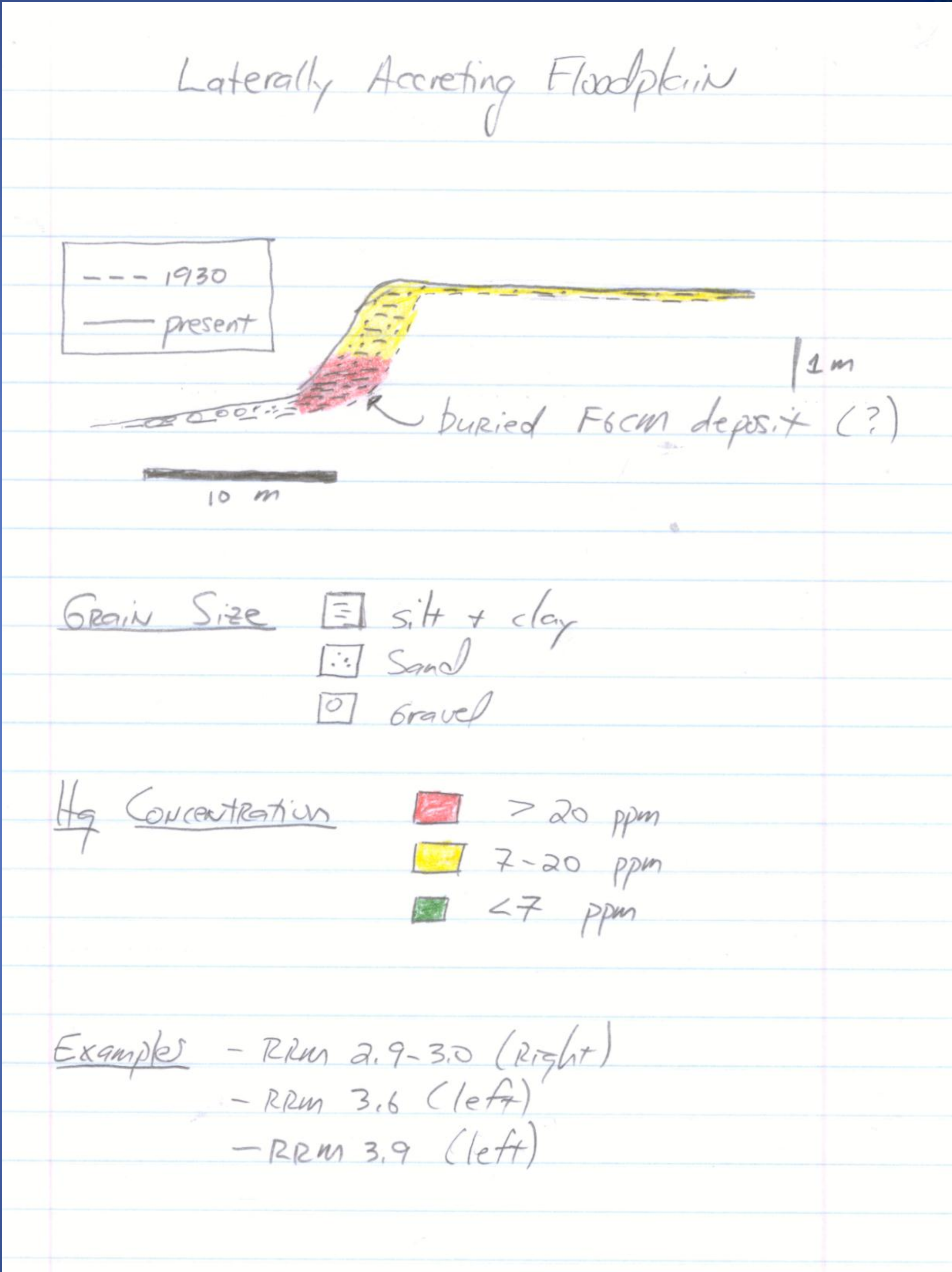
- > 20 ppm
- 7–20 ppm
- < 7 ppm

Examples:

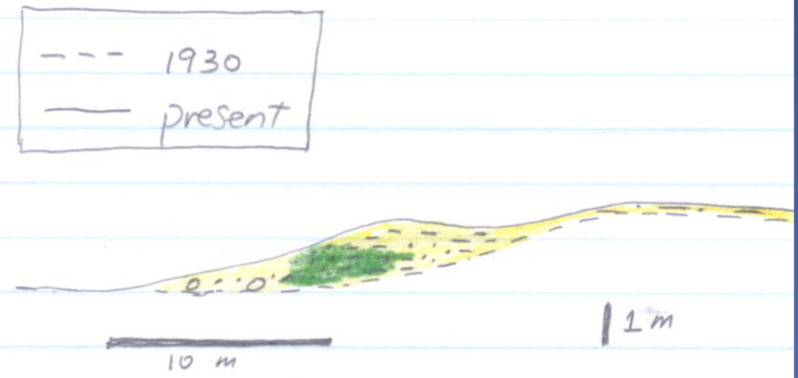
RRM 2.55 (both banks) (high Hg)
RRM 2.22 (Right bank) "
RRM 2.76 (left bank) "
RRM 3.8 (both banks) (Hg - L-low, R-high)
RRM 4.2 " (Low Hg)
etc.

HRADS!!

(Hg Release Age Deposits)



Sandy Point Bar Floodplain

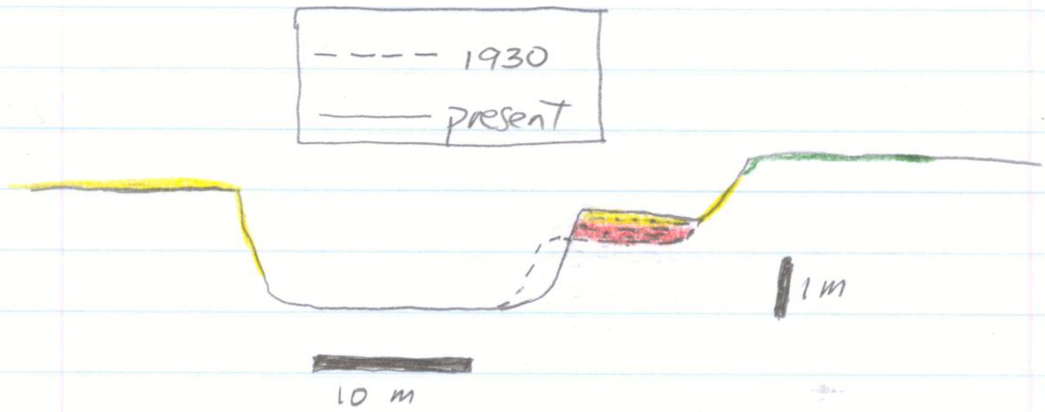


Grain Size: silt + clay; sand; gravel

Hg Concentration:
- > 20 ppm
- 7-20 ppm
- < 7 ppm

Examples:
- RRM 8.25 (Right bank)
- RRM 4.11 (Right bank)
- RRM 5.14 (left bank)
- RRM 3.10 (Right bank)

Mill Dam Bench



Grain Size
- silt + clay
- sand
- gravel

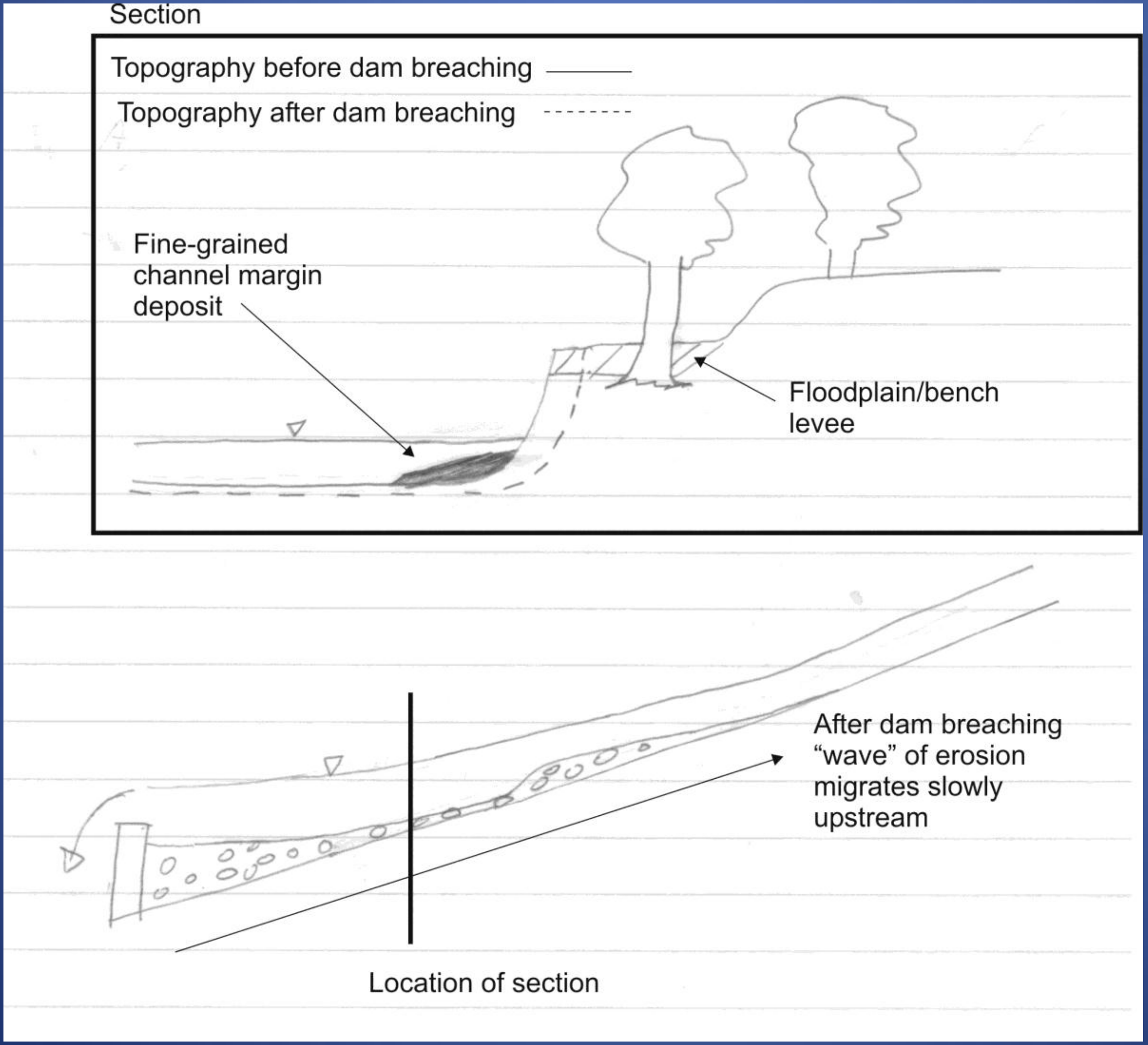
Hg Concentration
- > 20 ppm
- 7-20 ppm
- < 7 ppm

Examples
- RRM 7.4 (right bank)
- RRM 9.5 (Right bank)
- RRM 4.0 (left bank)

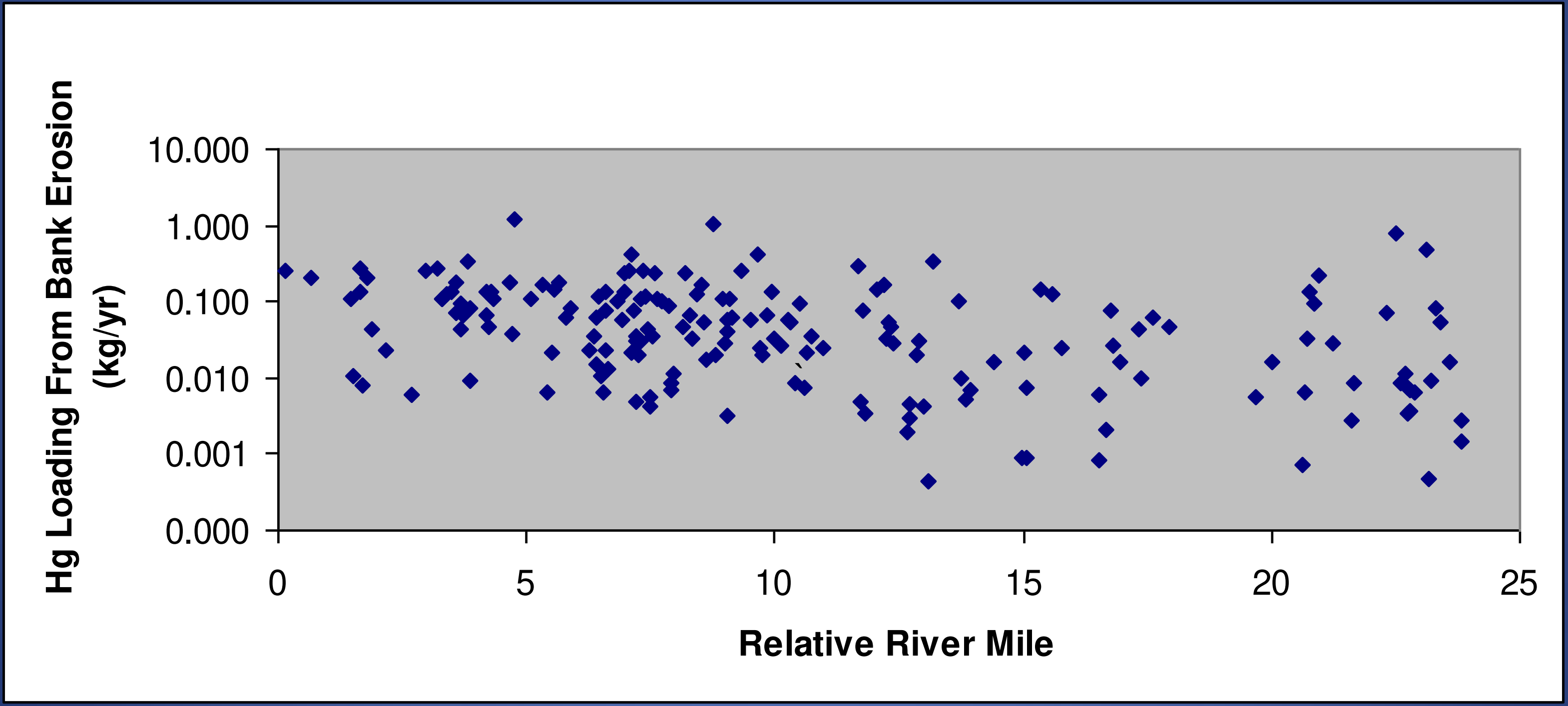
Colonial Mill Dams

- 14 in place from Waynesboro-Port Republic in 1930.
- All breached at present
- These likely enhanced mercury and sediment storage over a short reach upstream of each dam.
- After breaching, some of the stored sediment and mercury has been removed.
- Little data or analysis documents these processes

Conceptual Model of Mill Dam Accumulation and Post-Breaching Incision *(based on little data)*

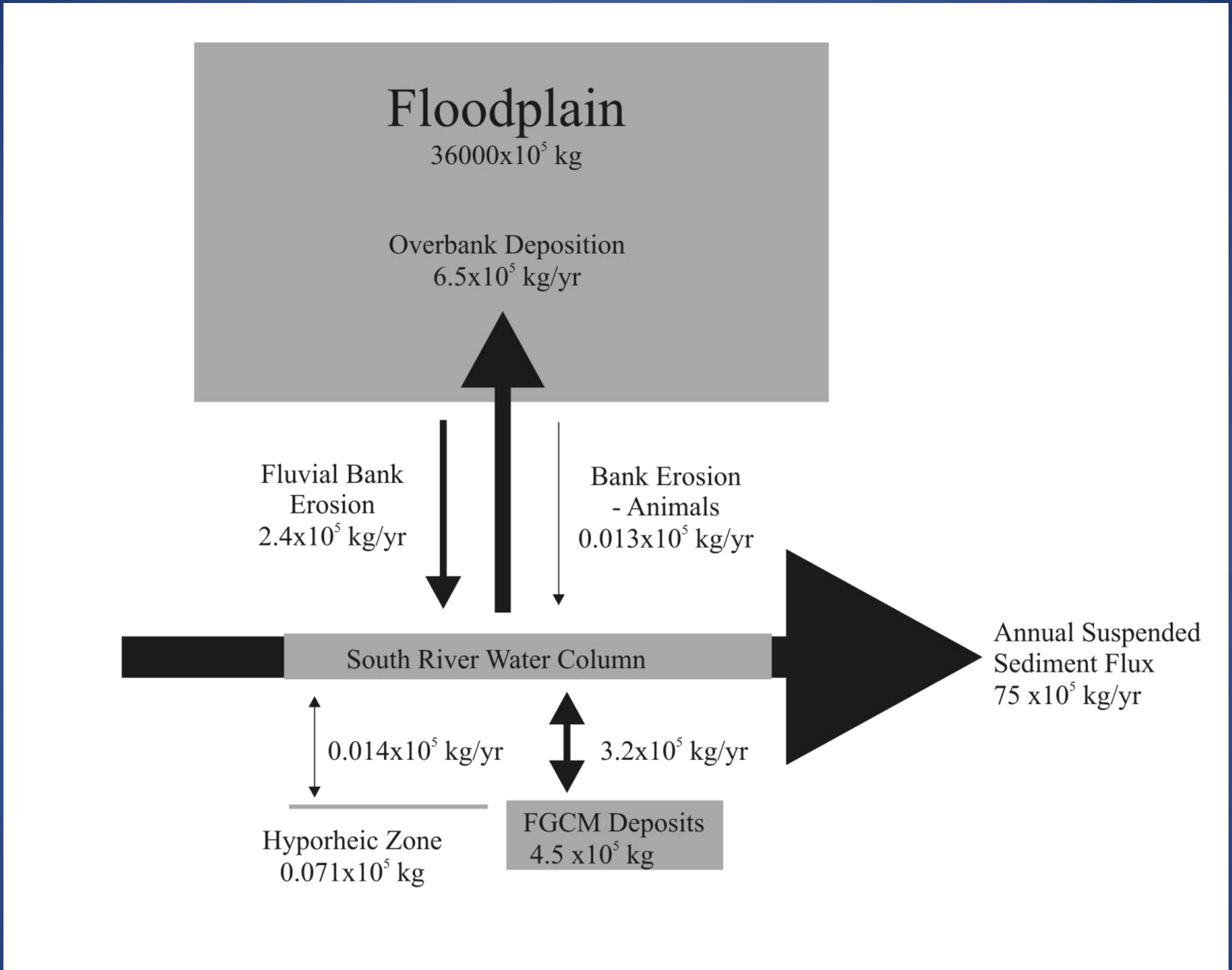


Mercury is Released Into the South River From Bank Erosion



Estimated Hg loading rates from every eroding bank from Waynesboro – Port Republc

A Fine-Grained Sediment Budget Quantifies Particle Transfers Rates and Processes of the South River



Storage

Flux

The Numbers, for the recod

Table 1. Fine-grained (silt, clay, and sand) sediment stored in the floodplain, hyporheic zone, and fine-grained channel margin deposits of the South River, and annual fluxes between these environments and the water column.

Sediment Storage				Transit Time		Annual Sediment Fluxes			
Storage Component	**Mass in Storage (x100 Mg)**	**Storage Mass Uncertainty (x100 Mg)**	**Storage as Fraction of Annual Suspended Load**	**Transit Time (years)**	**Transit Time Uncertainty (years)**	**Flux Component**	**Annual Flux (x100 Mg/yr)**	**Flux Uncertainty (x100 Mg)**	**Fraction of Annual Suspended Load**
Floodplain	36000	13000	493	8165	5436	Suspended sediment	73	19	1.00
FGCM deposits	4.5	2.6	0.06	1.43		Overbank deposition rate	6.4	2.2	0.09
Hyporheic zone	0.07	0.053	0.0010	5.0000		Fluvial bank erosion rate	2.4	1.2	0.03
Total Storage	36005	13003	493	4800	2600	Bank erosion - cattle & beaver	0.013	NA	0.0002
						Mean floodplain exchange rate	4.4	2.5	0.06
						FGCM exchange rate	3.2	1.8	0.04
						Hyporheic zone exchange rate	0.014	0.01	0.0002
						Total exchange rate	7.6	3.1	0.10

Implications

- Particles transported into a reach in suspension by the South River are completely replaced by new particles from storage after an average distance of ***28 +/- 13 km***
- Once in storage, the average particle remains in storage for ***4800 +/- 2800 years***.
- This gives a spatial and temporal average downstream transport velocity for suspended particles of ***6 +/- 4 m/yr***.

Any Questions??