Geomorphology Update – April 26, 2011 S.R. Science Team Meeting

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Outline

- Measurements of Bed Scour From RRM 4.3
- New Topographic Data – USGS LiDAR from Jan. 2010
- Estimates of Hg Concentrations and Loading on S.R. Streambanks – RRM 0-10
  - Review of model
  - How to apply the model
  - Preliminary results

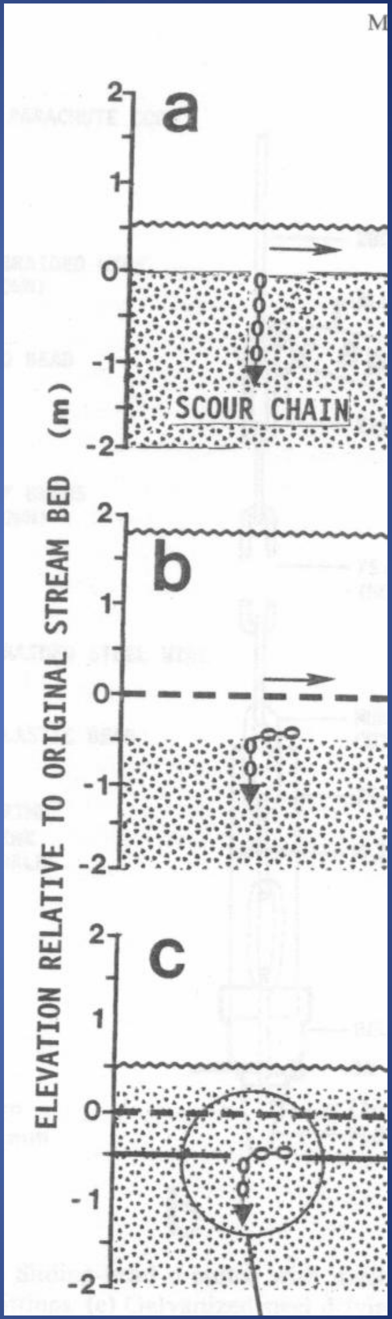
Bed Scour Measurements

- Why?
  - Provides useful independent estimate of frequency of bed reworking
  - Related to timescales required to remove contaminated particles from the hyporheic zone by erosion
    - Radiometric dating suggests that ~20 years required to "clean out" the hyporheic zone

Methods

- 2 cross-sections established near RRM 4.3 (Downstream side of “Schifflett Bend)
- 5 “scour chains” installed at each cross-section

Cartoon Illustrating How Scour Chains Provide a Reference For Measuring Changes in River Bed Elevation



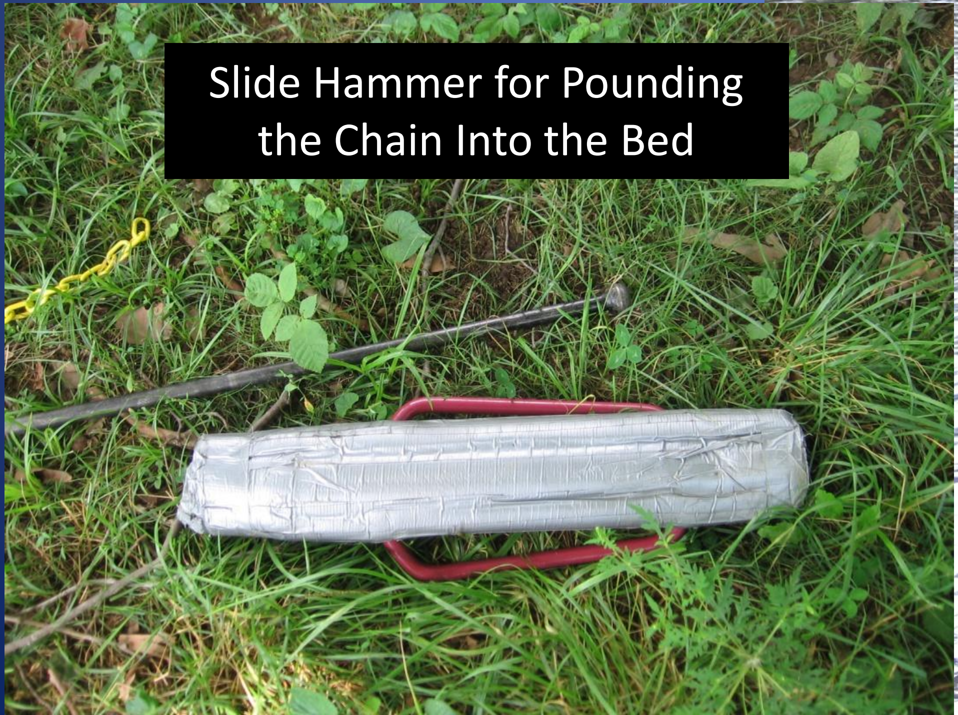
Scour Chain With Anchor

Close up of Anchor

Scour Chain with “Insertion Rod”

Insertion Rod Placed in Anchor – Close up

Ready to Install



Slide Hammer for Pounding the Chain Into the Bed


Scour Chain in Place
Flow Direction

Approach

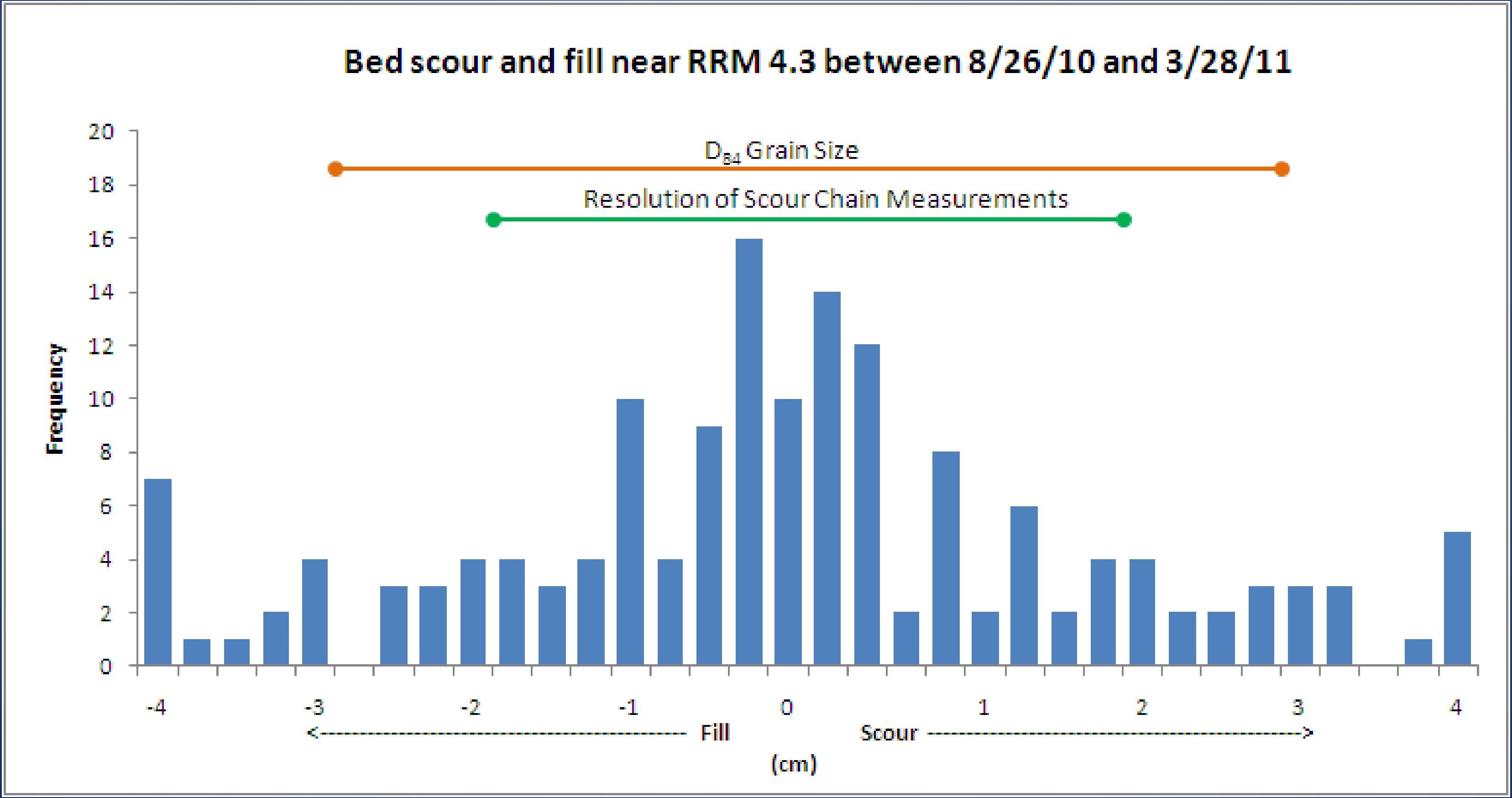
- After every significant discharge event:
  - Survey cross-section at 1 m intervals with mm resolution
    - Change in bed elevation related to NET scour and fill during the event
  - Measure length (or extent of burial) of scour chains

August 2010 – March 2011

- ~ 4 1-year recurrence interval discharges
  - ~2,000 cfs at Waynesboro
- Take home message:
  - Virtually 0 scour
    - Changes in bed elevation mostly within resolution of measurement error/variability.

All Scour Data From Surveys and Scour Chains

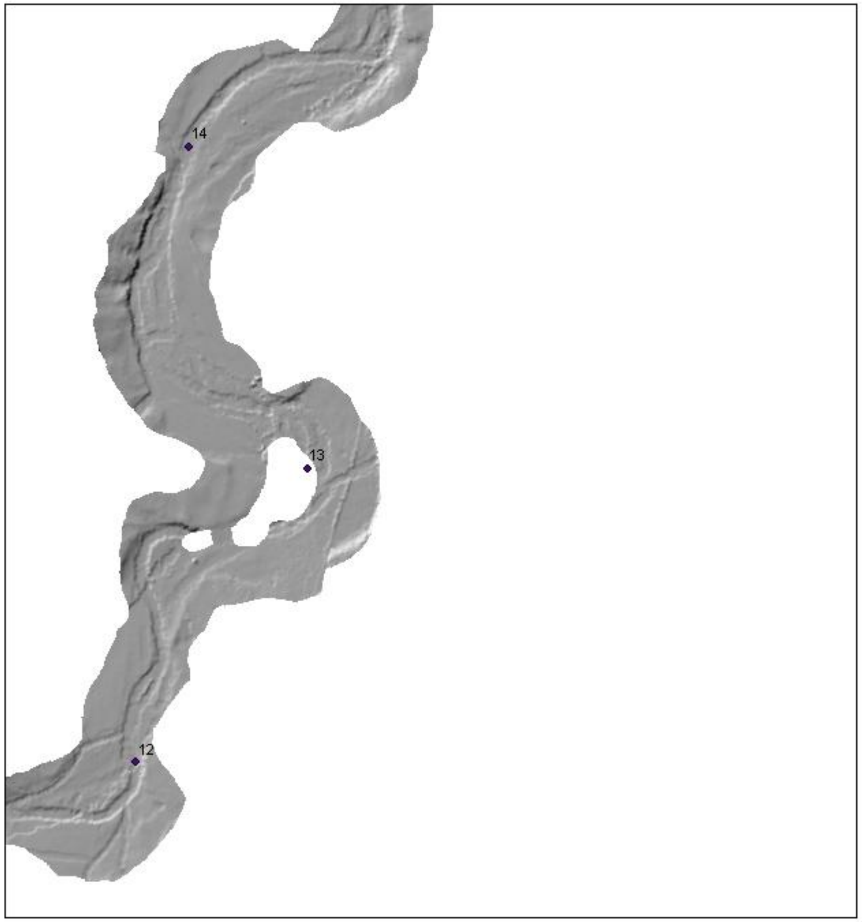
nearly all measurements can be explained as variability related to irregularities of the bed surface related to protrusion of large particles, because most measurements are smaller than the characteristic grain diameter D_{84}



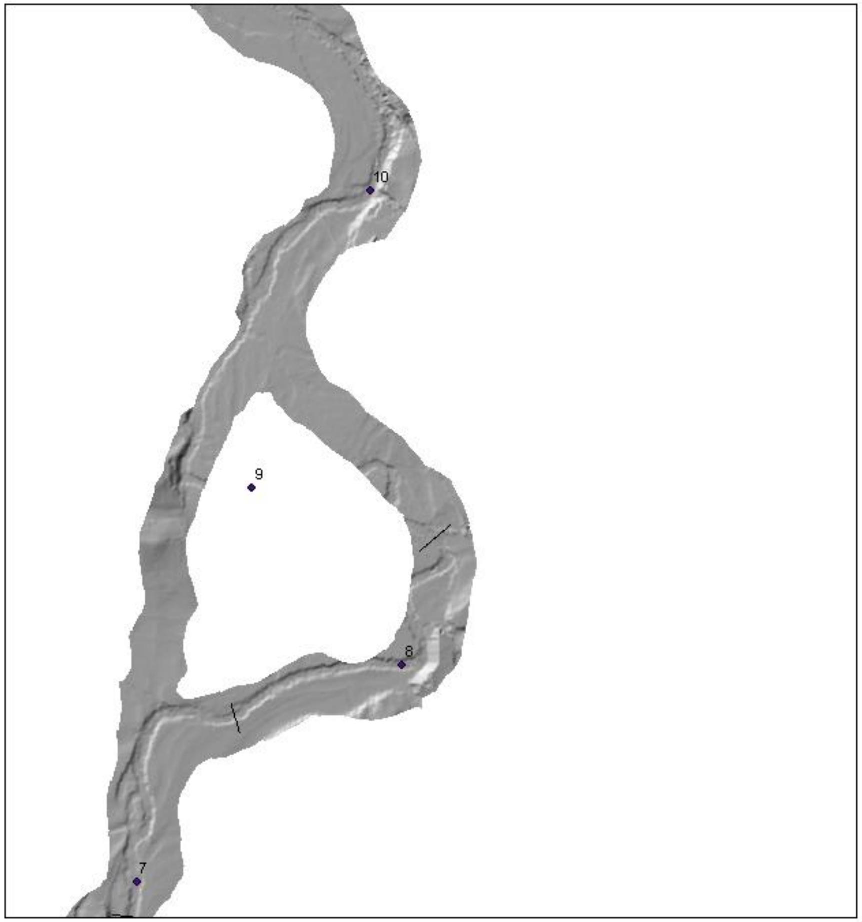
New Topographic Data From Jan 2010 USGS “Green” Lidar

- Data are incomplete, noisy and difficult to interpret …
  - But still useful
- 5 m DEM
- Point cloud useful for defining
  - Cross-sections
  - Other features of interest
    - Longitudinal profile
- River bed AND water surface “imaged” in places
  - But difficult to extract each unambiguously

5 m DEM RRM 12-14



5 m DEM RRM 7-10

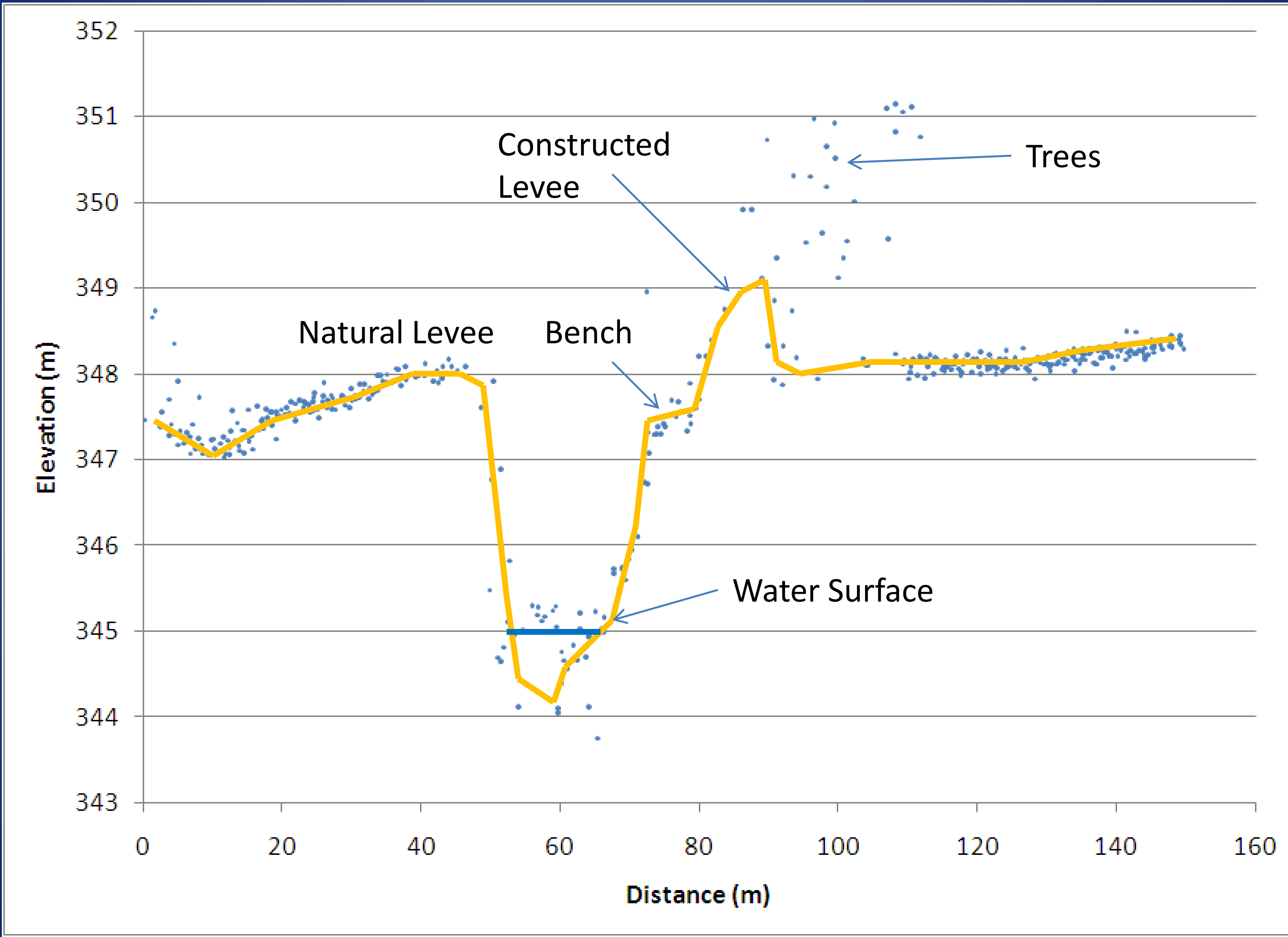


Oops – note parts of river not imaged

Cross-Sections From USGS Jan. 2010 LiDAR Point Clouds

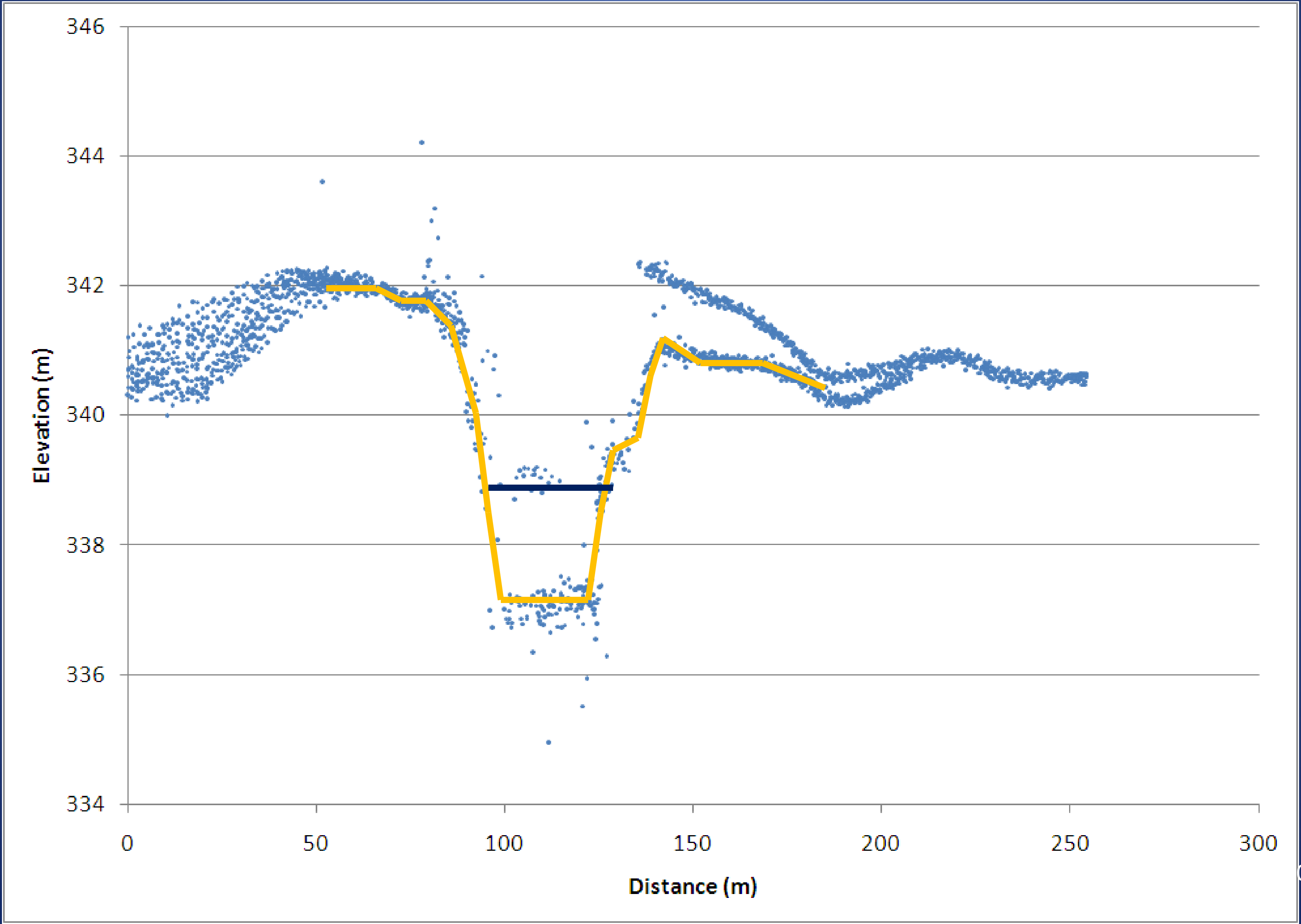
- Needed because only a few field surveyed cross-sections are available
- Noisy data requires time-consuming manual analysis!

RRM 3.0



Constructed Levee
Trees
Natural Levee
Bench
Water Surface
Elevation (m)
Distance (m)
352
351
350
349
348
347
346
345
344
343
0
20
40
60
80
100
120
140
160

RRM 7.4



346
344
342
340
338
336
334
Elevation (m)
0
50
100
150
200
250
300
Distance (m)

Estimates of Hg Concentrations and Loading on S.R. Streambanks – RRM 0-10

- Review of the process
- Note:
  - Conceptually identical to our estimates of loading from eroding banks
    - No new data for bank erosion rates are used
- What IS new:
  - Where data are unavailable, a modeling approach is used to estimate extent of legacy mercury contamination, 1930-present
  - More field measurements of mercury concentrations are used
  - Estimates of average mercury concentration are provided for nearly all the river's banks

Review – Modeling Approach to Assess Legacy Mercury Contamination

The Model is Applied to "Surfaces" Adjacent to the River Channel

"Surfaces are classified as either low elevation "benches" or higher elevation "levees"

Site Classification - Vegetation

PASTURE

FOREST

The Model

- Represents mercury accumulation from 1930-2007 as a sedimentation process
- A simple analytical model….
  - Facilitates calibration

Model Assumptions

- Contaminated particles are deposited at a constant rate when a surface is inundated during high water events
- All sites have experienced the same history of mercury concentrations on suspended particles through time
  - i.e. upstream-downstream variations in mercury concentration are neglected
- Deposition on occurs when the depth of overbank flow is less than a threshold value
  - To be determined through calibration
  - i.e. only relatively shallow overbank flows deposit mercury and sediment

Determining the Inundation Frequency at Each Site

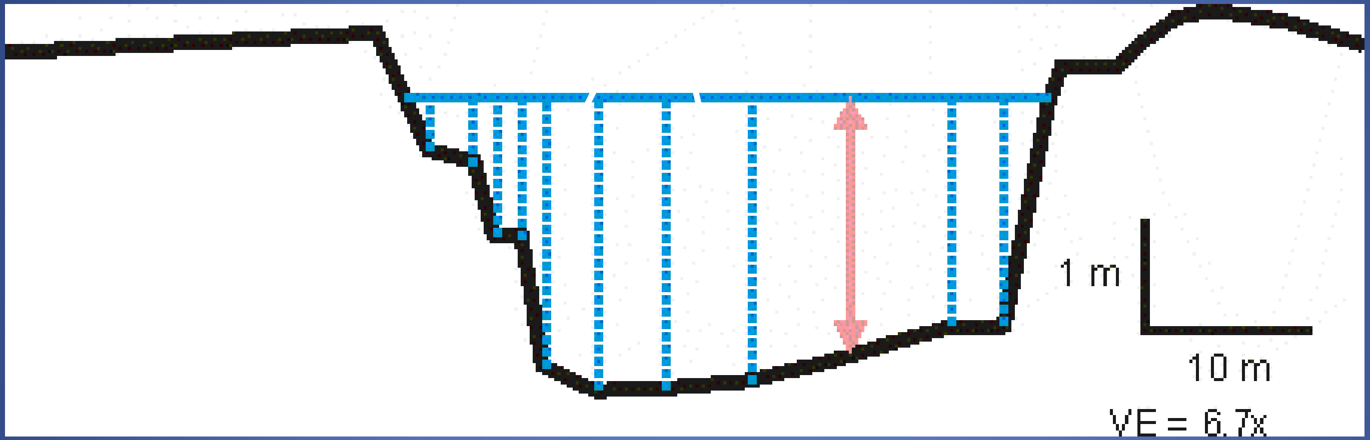
- How OFTEN do different flows occur?
- What is the water surface elevation of each flow?

To Determine the FREQUENCY of Flows at a Site....

- Linearly interpolate discharges of varying return period
  - Between 3 U.S.G.S. gaging stations
    - Located above, below, and in the middle of the study reach

Determine Water Surface Elevations From 1-D Streamtube Hydraulic Model

n streamtubes

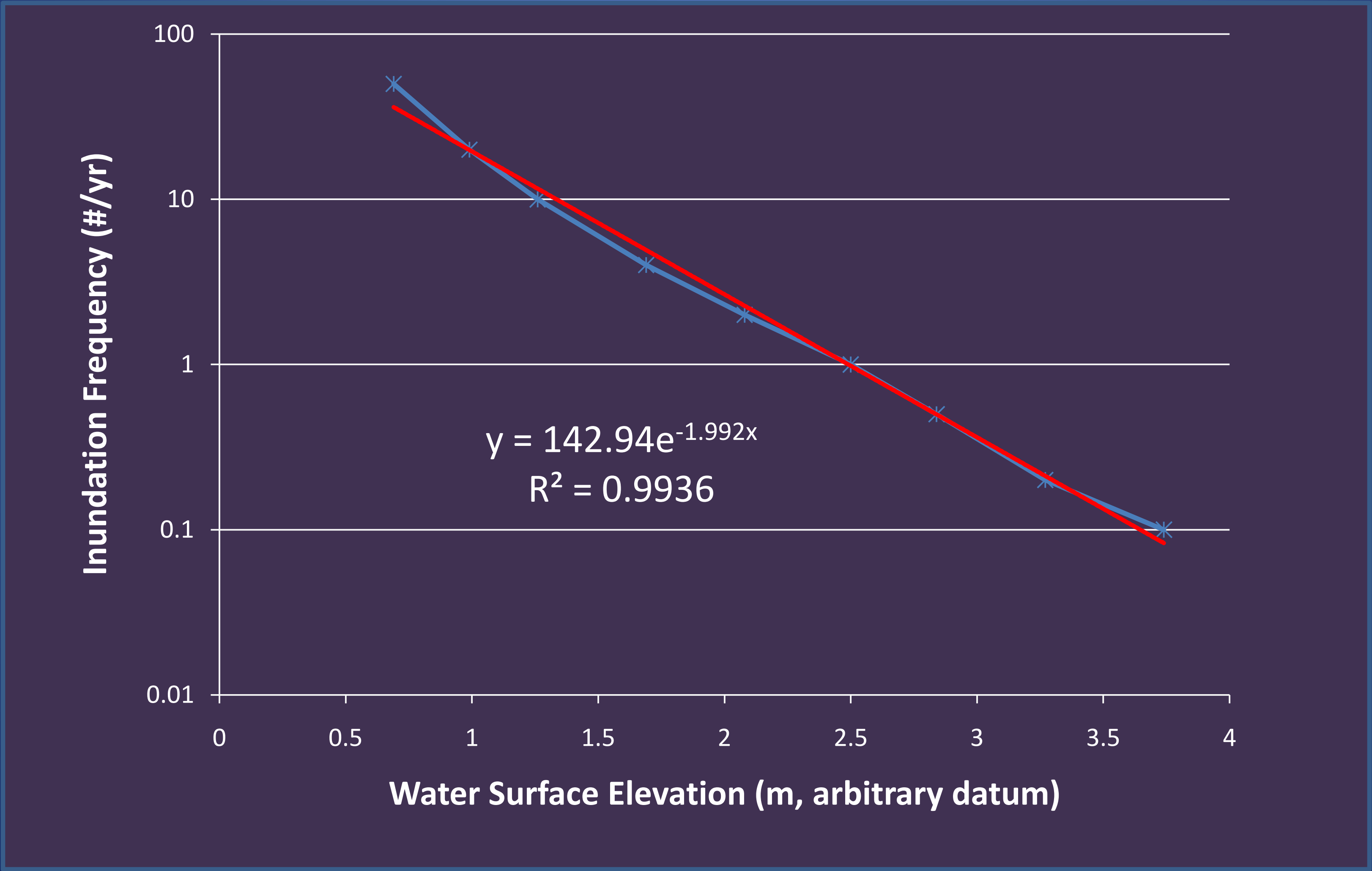


$$q_i = V_i h_i$$

$$Q_{calc} = \sum_{i=1}^{n} q_i$$

Vary water surface elevation until $Q_{calc} = Q_{measured}$

The Exceedence Frequency of Water Surface Elevation is Exponentially Distributed! *(leads to simple math!)*



The Model Equation (no accretion)

$$T_t = (t_f - t_1) I \sigma_D \left(e^{-\lambda z_{cf}} - e^{-\lambda (z_{cf} + h_D)}\right)$$

The Model Equation (no accretion)

$$T_t = (t_f - t_1) I \sigma_D (e^{-\lambda z_{cf}} - e^{-\lambda (z_{cf} + h_D)})$$

Mercury inventory

The Model Equation (no accretion)

$$T_t = (t_f - t_1) I \sigma_D (e^{-\lambda z_{cf}} - e^{-\lambda (z_{cf} + h_D)})$$

Mercury inventory

Elapsed time

The Model Equation (no accretion)

$$T_t = (t_f - t_1) I \sigma_D (e^{-\lambda z_{cf}} - e^{-\lambda (z_{cf} + h_D)})$$

Mercury inventory

Elapsed time

Accumulation Rate Parameter

The Model Equation (no accretion)

$$T_t = (t_f - t_1) I \sigma_D \left(e^{-\lambda z_{cf}} - e^{-\lambda (z_{cf} + h_D)}\right)$$

Mercury inventory

Elapsed time

Accumulation
Rate Parameter

Vegetation density
(forest/pasture ratio)

The Model Equation (no accretion)

Probability of flooding to max. depth h_D (z is elevation of the coring site)

$$T_t = (t_f - t_1) I \sigma_D \left(e^{-\lambda z_{cf}} - e^{-\lambda(z_{cf}+h_D)}\right)$$

Mercury inventory

Elapsed time

Accumulation Rate Parameter

Vegetation density (forest/pasture ratio)

The Model Equation

$$T_t = (t_f - t_1) I \sigma_D \left(e^{-\lambda z_{cf}} - e^{-\lambda(z_{cf} + z_{hD})}\right)$$

$$+ I \sigma_D \left[\frac{\left(e^{-\lambda z_{c0}} - e^{-\lambda z_{cf}}\right)}{\lambda m} - t_1 e^{-\lambda z_{cf}} \right]$$

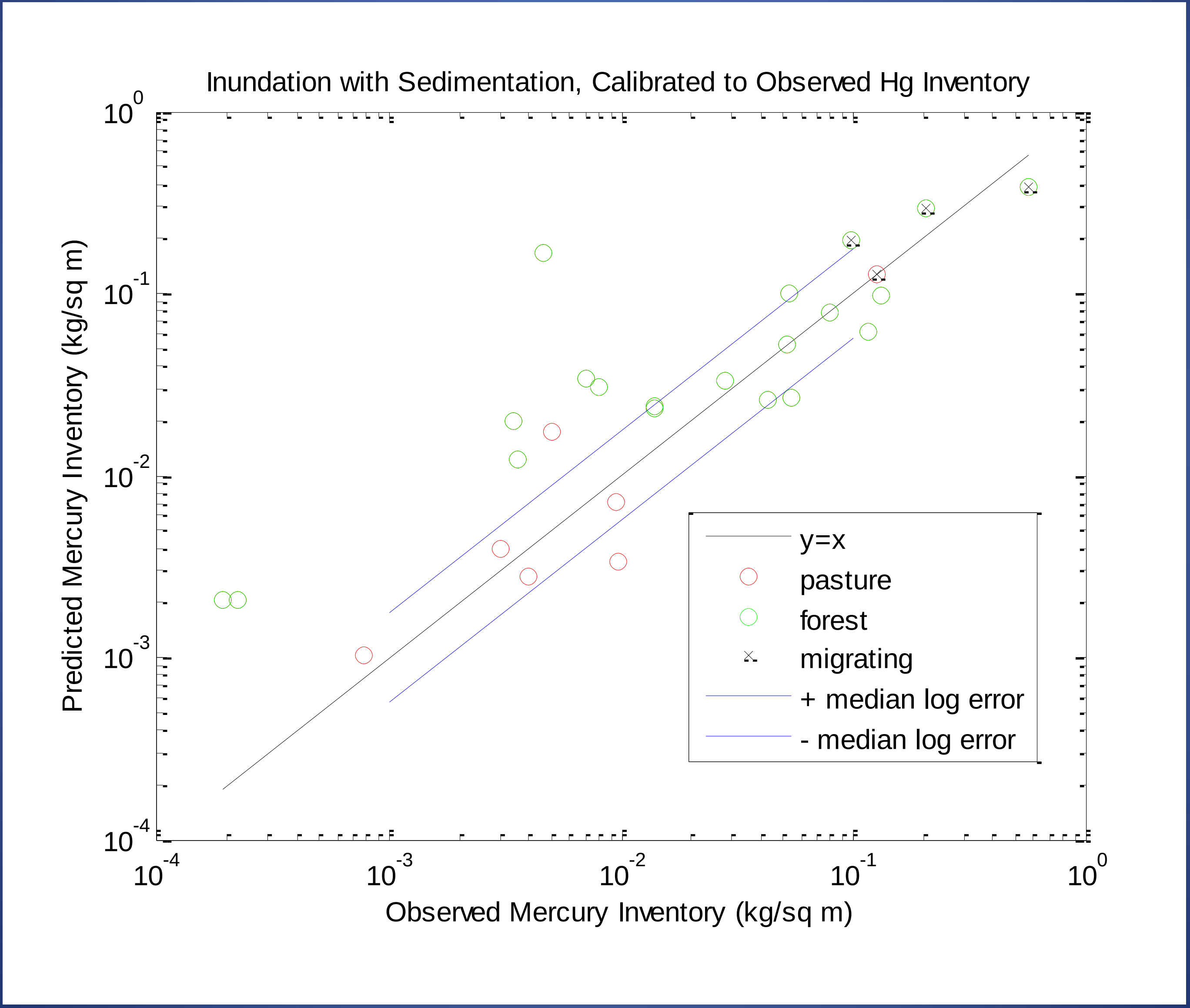
This term corrects inundation frequency for sediment accretion

Calibration

- Brute force evaluation to determine model parameters
  - Minimize rms error between observed and predicted mercury inventories
- Parameter confidence intervals from Monte Carlo methods

The Calibrated Model

explains ~ 2/3 of the variance in observed mercury inventories



Calibrated Parameters

Parameter	Calibrated Value	95% Confidence Interval	Range of Parameter Values
Hg Deposition Rate (kg/m²/yr)	**0.049**	**0.0219-0.0760**	**0.004-0.45**
Forest-Pasture Veg. Density Parameter	**2.9**	**2.0-3.6**	**0.2-59**
Accretion Time (years)	**4**	**1.8 – 5.4**	**0-77**
Max. depth for deposition (m)	**0.06**	**0-0.1**	**0.006-5**

Note – forests increase rates of mercury (and sediment!) accumulation by 3x

To Apply the Model RRM 0-12

- First classify banks
  - Identify banks where model use is inappropriate or inaccurate
    - Bedrock banks
    - Banks modified by humans
    - Banks dominated by erosion or sand/gravel transport
      - Point bars, etc

The Bank Classification

- Benches
- 2-yr Floodplain
- > 2-yr Floodplain
- Anthropogenic
- Bedrock
- Sandy point bars
- Terraces

Divide Banks Into "Segments"

- A "segment" is defined by:
  - A length of bank with a single classification
  - A length of bank with a documented average erosion rate
- Bank segments are therefore highly variable in length!

The Model is Only Needed Where Measurements of Hg Concentration are Unavailable

- For RRM 0-10
  - 248 bank “segments”
  - ~40% have measured Hg concentration
    - At the bank segment itself or “nearby”
      - For example, mercury samples from the 2007 floodplain survey are used if they are “close” to the bank
  - Model is used for ~40%
  - No estimate made for remaining 20%

How to Apply The Model to Estimate Average Bank Hg Concentration

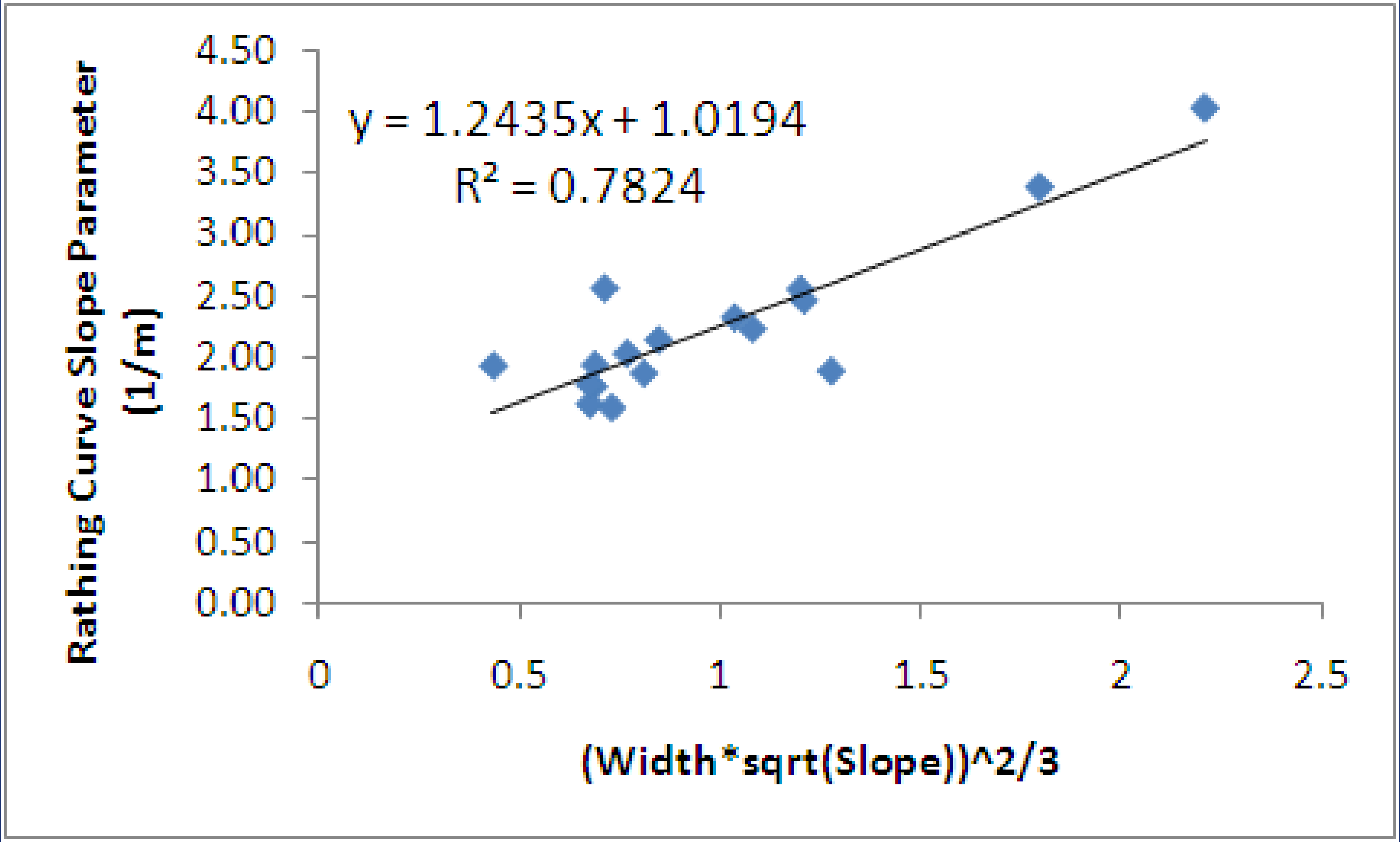
- Steps Required a single bank segment
  - 1. Map topographic cross-section and local channel slope
  - 2. Identify elevation of "surfaces" where mercury can accumulate
  - 3. Determine parameter (λ) that defines frequency of inundation
    - Use Pizzuto's stage-discharge model for this
    - Or, estimate λ from calibration data set (see following..)
  - 4. Is site forested or in pasture?

A Shortcut to Determine Inundation Frequency (λ)

- Applying the model to RRM 0-10 requires ~100 cross-sections!
- Can also use "calibration data set" to determine λ (next slide)
  - Where detailed field surveyed cross-sections are available

Estimating Inundation Frequency Parameter λ From Calibration Data Set

(so detailed cross-sections are not needed)



Note: large λ implies infrequent inundation, which would be expected for wide, steep channels)

Where Cross-sections are Not Available

- Estimate elevation of depositional surfaces in the field
  - Rapid measurements using laser rangefinder

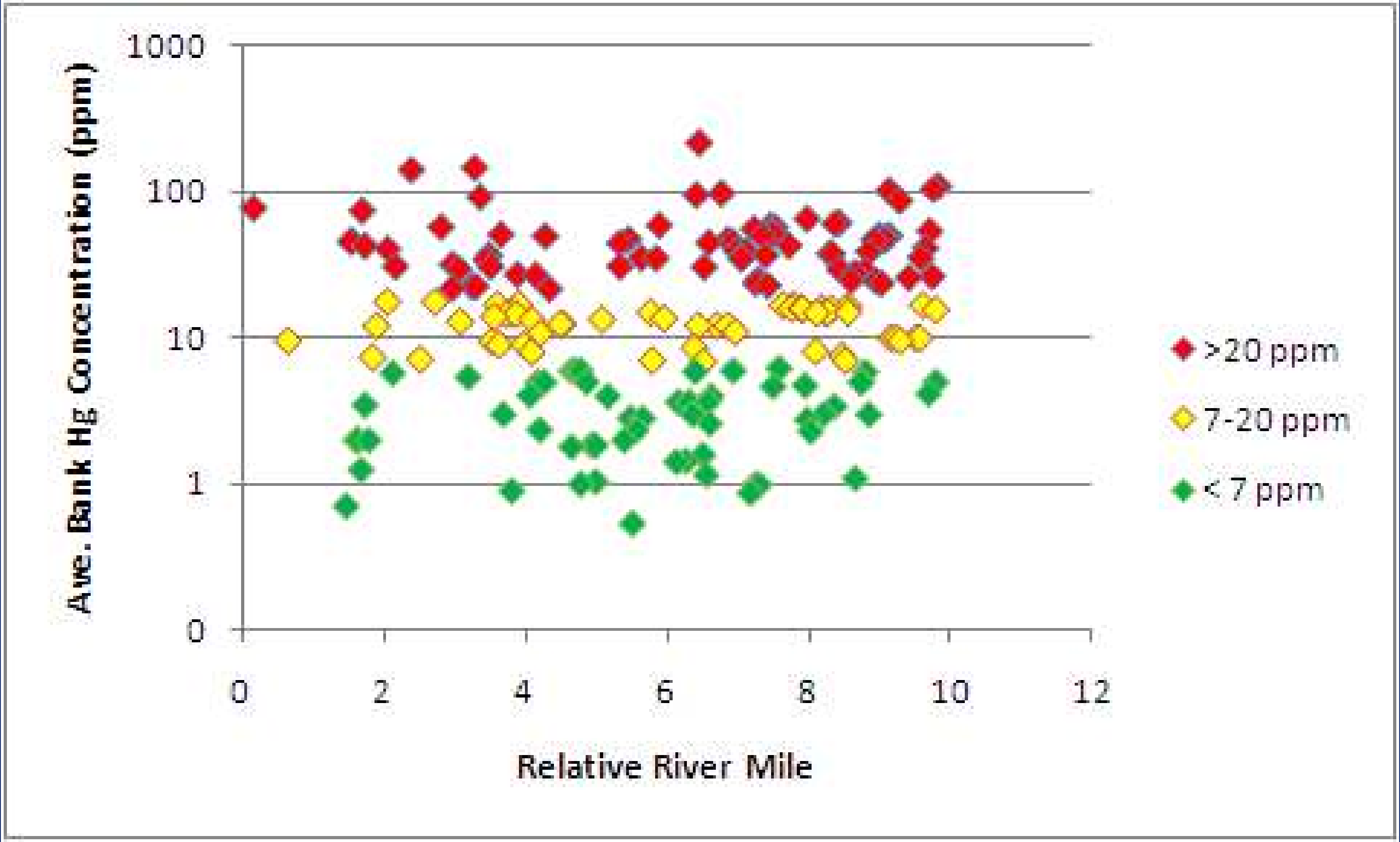
To Compute Loading Once Average Hg Concentration is Known

- Use previous estimates of annual bank erosion rates from:
  - Aerial photo analysis
  - Terrestrial (tripod-mounted) LiDAR surveys
  - Hydraulic modeling of bend-induced bank erosion
  - Field mapping (visual) for sites below resolution of other methods
    - Assume bank migration of 1 m (4.9 feet) over 77 years

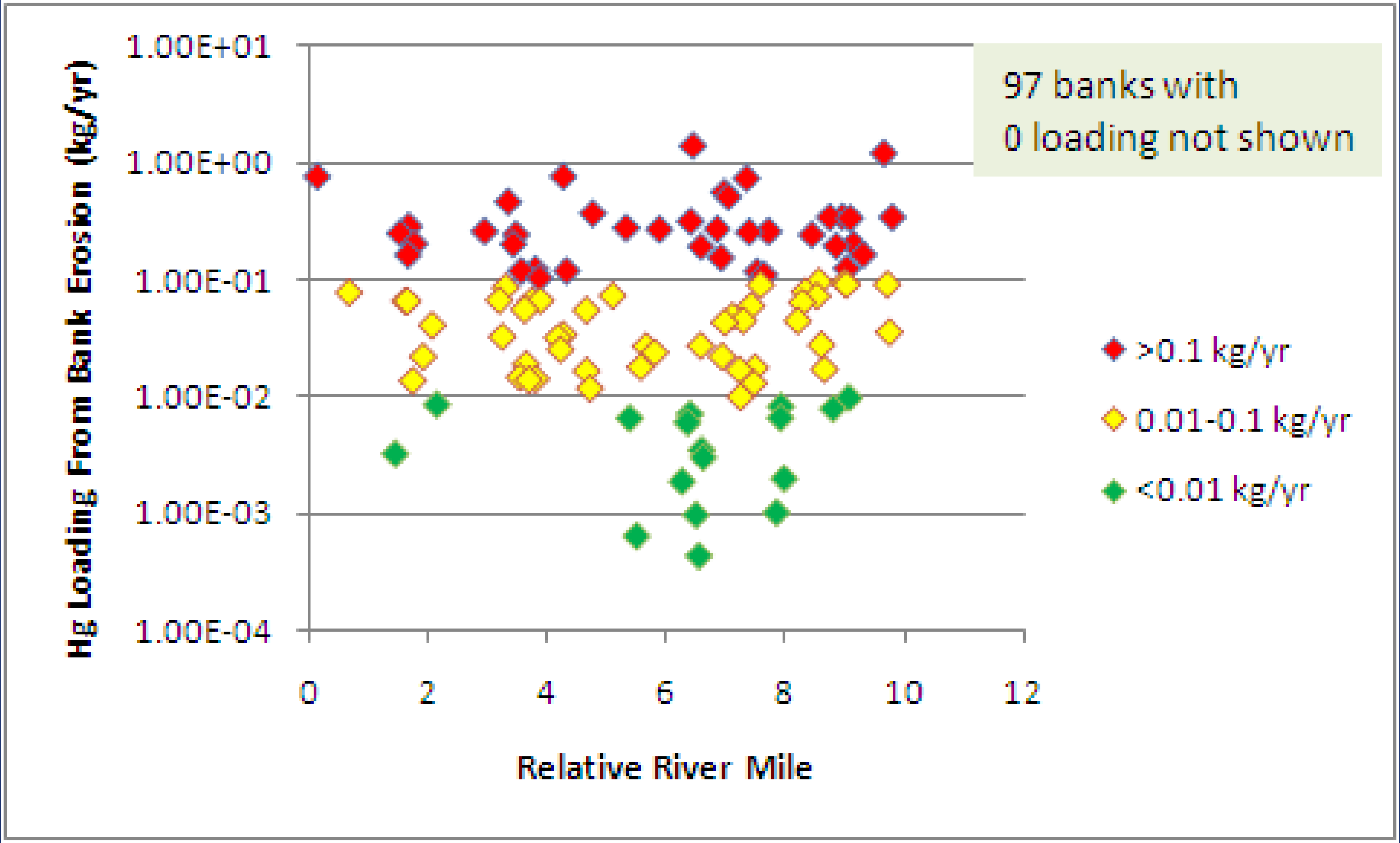
Some Example Tabulated Results

Side of River (R or L, facing downstream)	RRM Start	RRM End	Classification	Ave Hg Conc. (ppm)	Hg loading rate (kg/yr)
R	0	0.14	Anthropogenic	0	ND
R	0.14	0.15	Anthropogenic	77	7.72E-01
R	0.15	0.65	Anthropogenic	ND	ND
R	0.65	0.66	Anthropogenic	10	7.96E-02
R	0.66	1.49	Anthropogenic	ND	ND
L	0	1.44	Anthropogenic	ND	ND
L	1.44	1.49	Anthropogenic	1	3.20E-03
R	1.49	1.58	2-yr	46	2.54E-01
R	1.58	1.62	>2-yr	2	6.71E-02
R	1.62	1.65	2-yr	2	6.71E-02
L	1.49	1.55	2-yr	46	0.00E+00
L	1.55	1.655	Sandy	ND	ND
R	1.65	1.715	2-yr	74	2.92E-01
L	1.655	1.69	>2-yr	1	1.66E-01
R	1.715	1.74	>2-yr	3	1.38E-02
L	1.69	1.76	2-yr	43	0.00E+00
R	1.74	1.82	2-yr	2	2.07E-01
L	1.76	1.83	Sandy	ND	ND

Illustrating the Concentration Estimates – Classify Banks as High, Medium, or Low Concentration



Illustrating the Loading Estimates – Classify Banks as High, Medium, or Low Loading



ArcGIS Data Layers..

Status

- Finalized estimates in progress
  - All estimates of concentration and loading need to be revised
  - And checked
- Finished in May