Results of Geomorphological Studies

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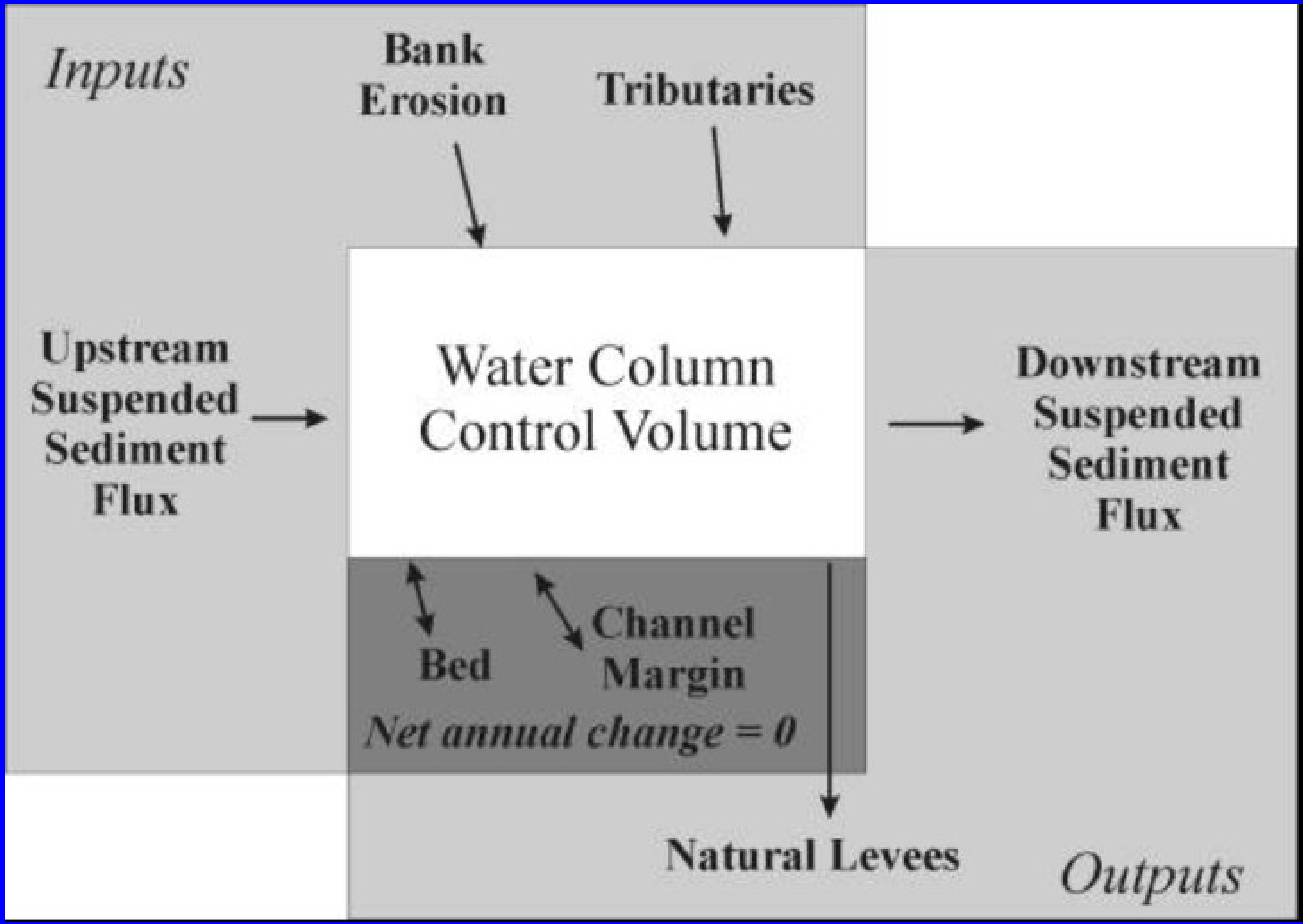
Purpose of our study

- Goal: develop an understanding of processes and rates of sediment erosion, deposition, and storage from Waynesboro-Port Republic, 1930s – present.
- Focus on silt and clay transport
  - Finer sediment movement closely related to Hg movement
- Emphasis on an *annual budget* for silt and clay

The Annual Silt and Clay Budget Components

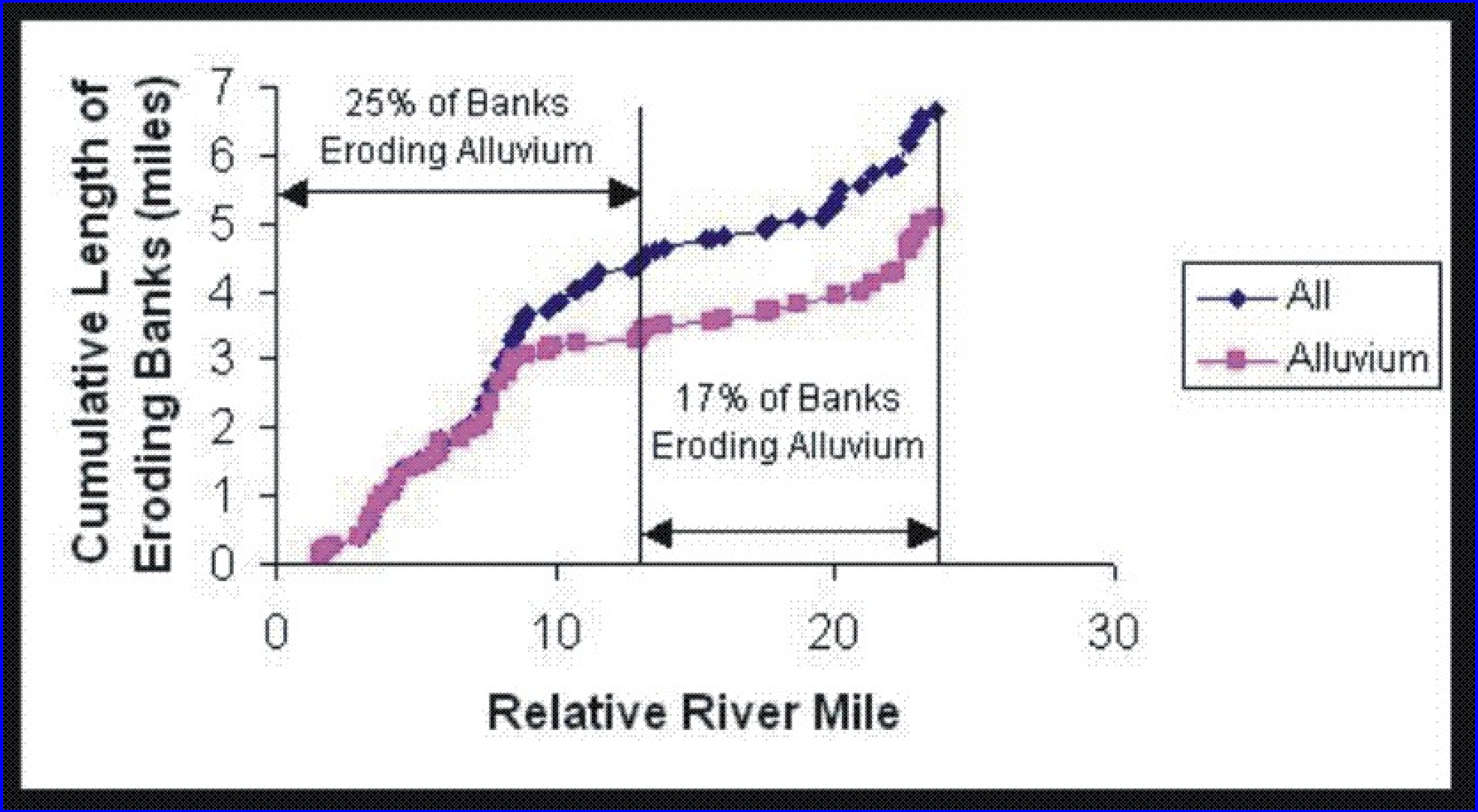


Bank Erosion

- Observations of currently eroding banks
- Historic rates of bank erosion 1937-2005
- Lidar surveys of contemporary eroding banks

Mapping Currently Eroding Banks

(note – *41% of banks are eroding between RRM 21-24*)

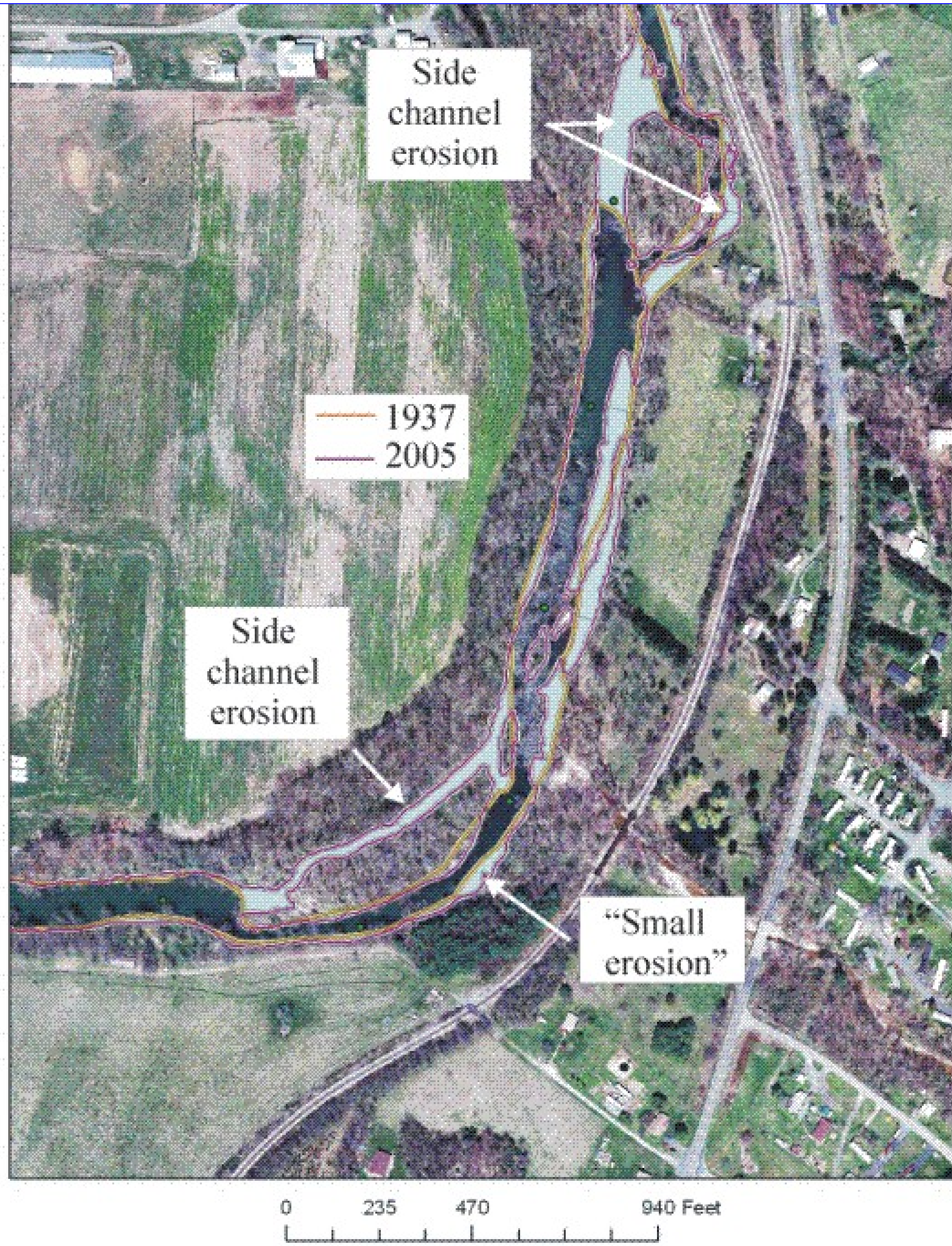


Bank Erosion 1937-2005 From Aerial Photographs

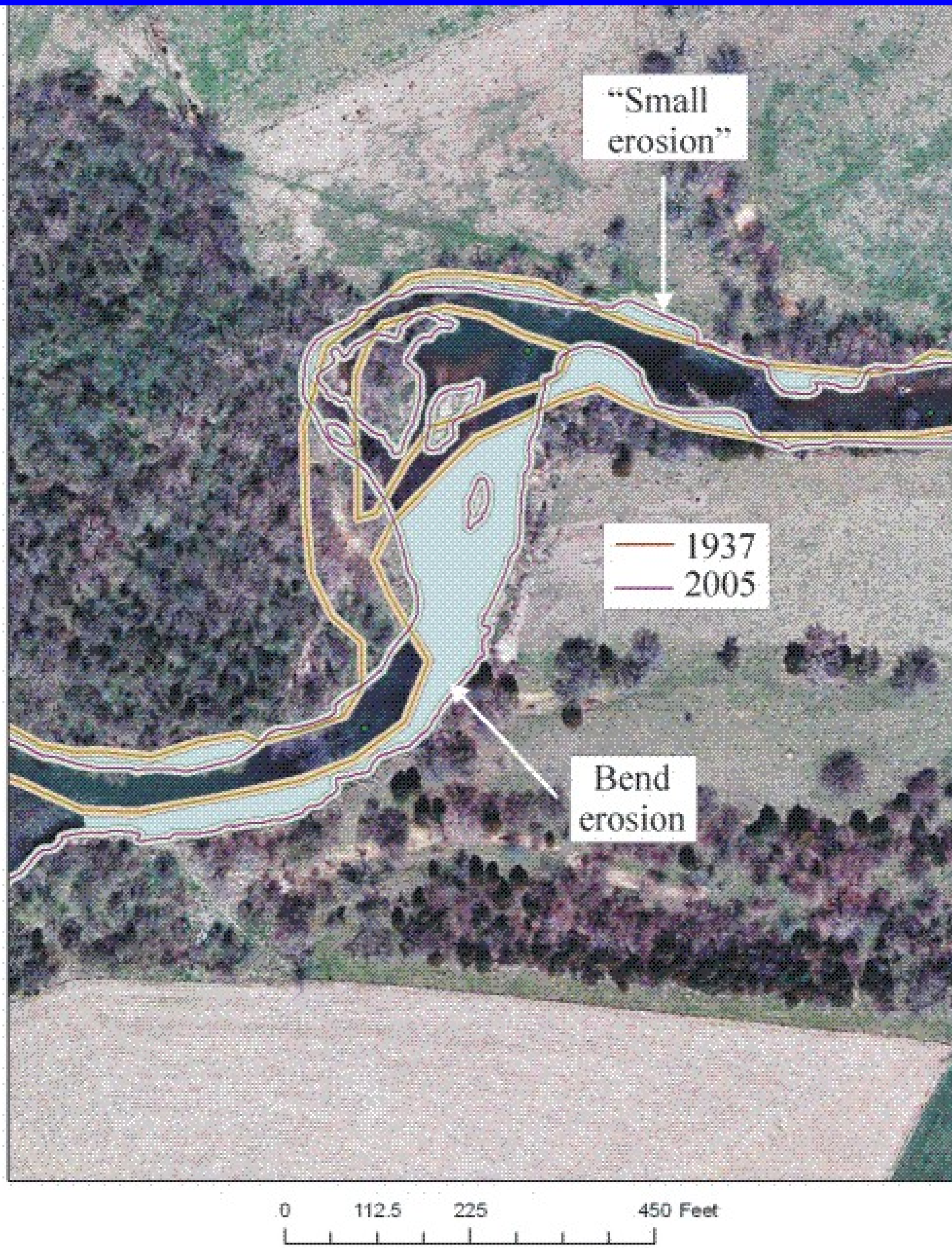
Several Examples….
(note LOW RATES)

RRM	Figure	Type	Area (m^2)	Length (m)	Nominal Bank Erosion Rate (cm/yr)	
2.15	6.8	"small"	92	97	3	
9.25	6.9	related to dam removal	1151	318	11	
9.4	6.9	bend	1387	433	9	
9.5	6.9	bend or related to bridge	1158	324	10	
10.45	6.10	"small"	397	194	6	
15.68	6.11	"small"	321	188	5	
15.68	6.11	side channel	2104	696	NA	
16.0	6.11	side channel	2620	329	NA	
16.0	6.11	side channel	510	303	NA	
22.5	6.12	bend	3082	604	15	
22.62	6.12	"small"	71	61	3	

1937
2005
"Small erosion"
0
60
120
240 Feet

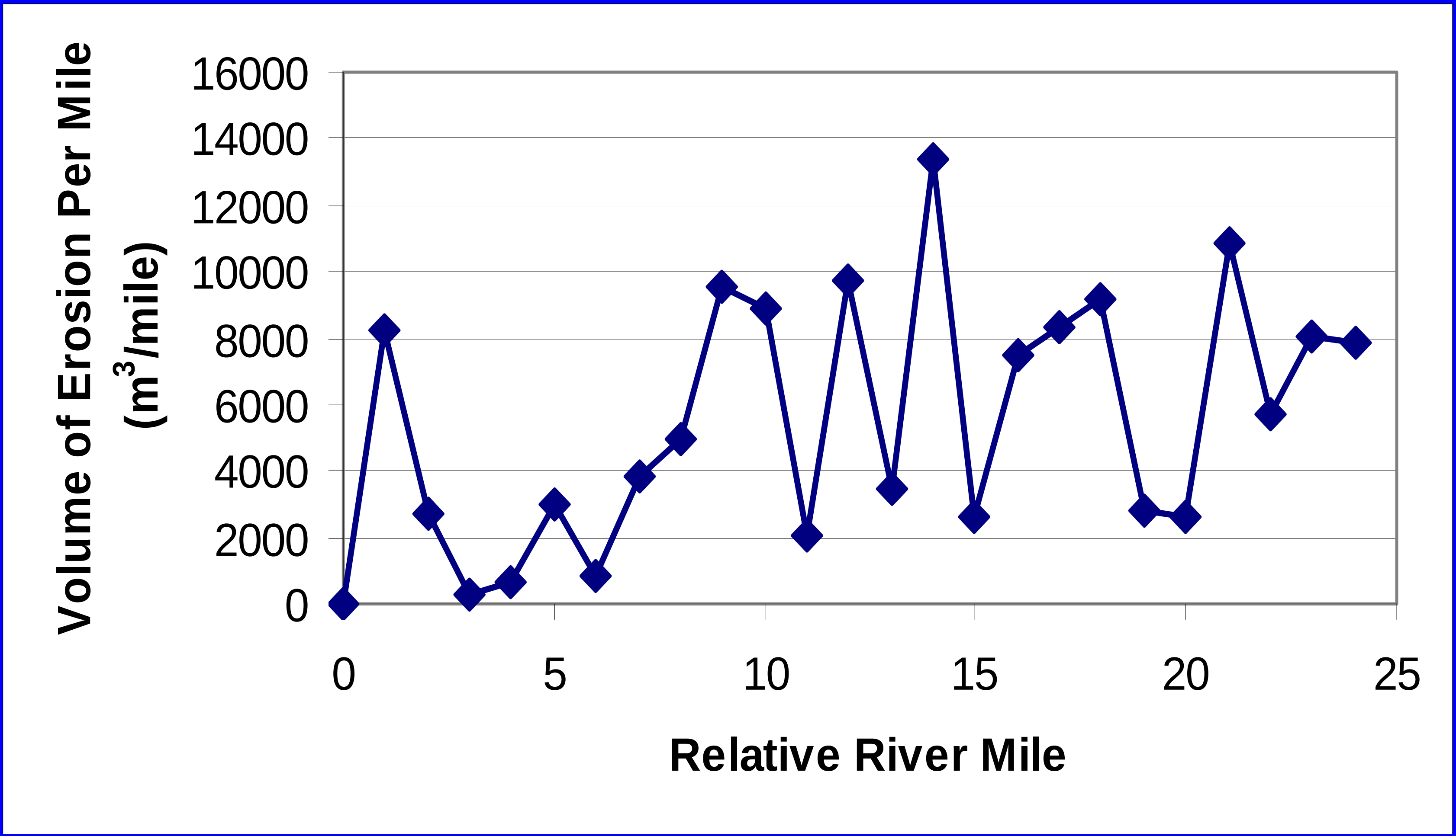


Side channel erosion
1937
2005
Side channel erosion
"Small erosion"
0
235
470
940 Feet



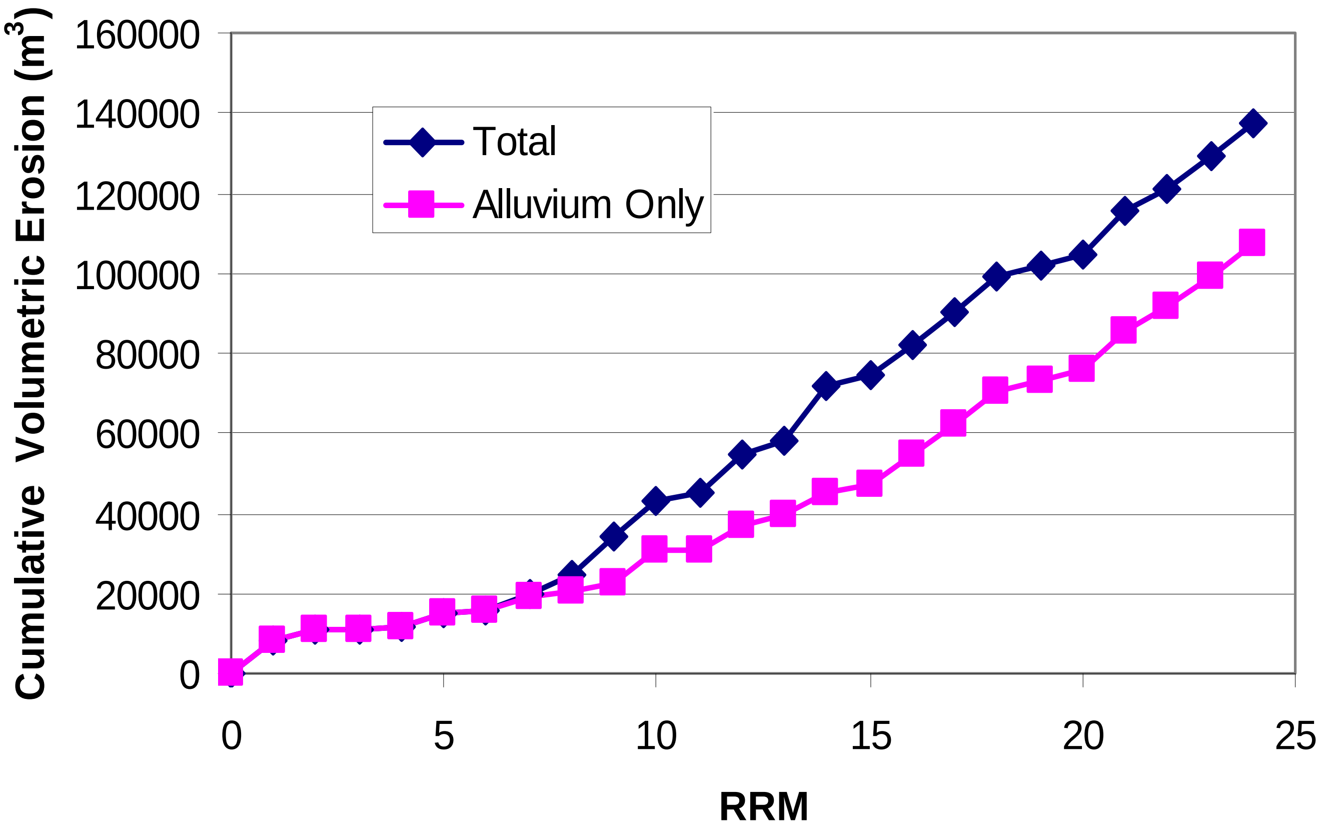
"Small erosion"
1937
2005
Bend erosion
0
112.5
225
450 Feet

Volume of Bank Erosion Per Mile

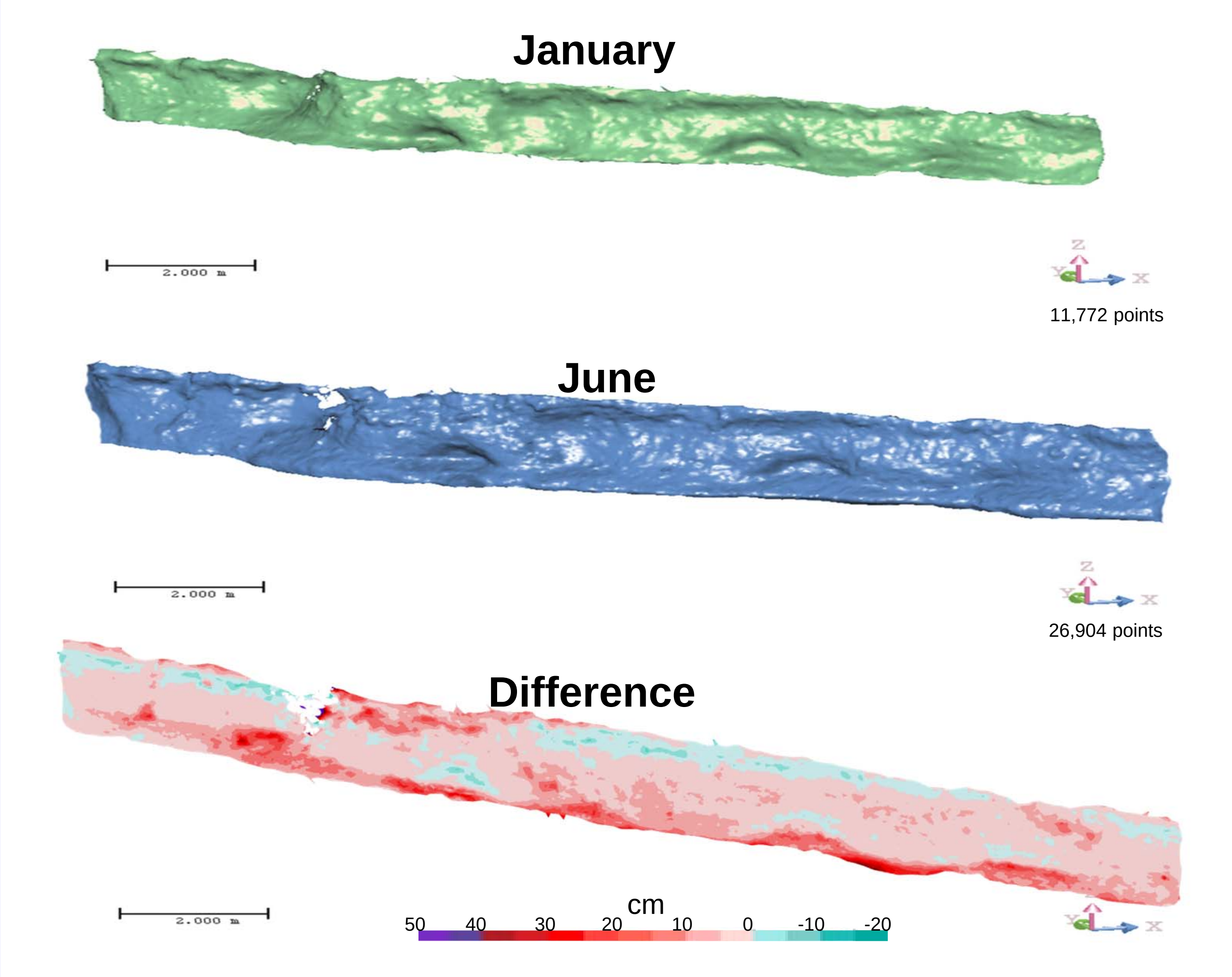


Cumulative Bank Erosion vs RRM

Note – more erosion downstream – likely caused by influxes of gravel from tributaries via confluence bar and island development



Bank Erosion From Lidar Surveys, Jan-June 2006 @ Allied Ready Mix Site



The Big Picture: Overall, few changes between 1937 & 2005

Take Home Points – Bank Erosion Studies

- Bank erosion rates along South River are typically very low, often < 10 cm/yr
  - Effects of riparian trees, bedrock, cohesive bank sediments
  - More rapid rates occur when channel is forced to “digest” gravel inputs from tributaries
- Short term erosion could favor the upper parts of banks with high Hg concentrations

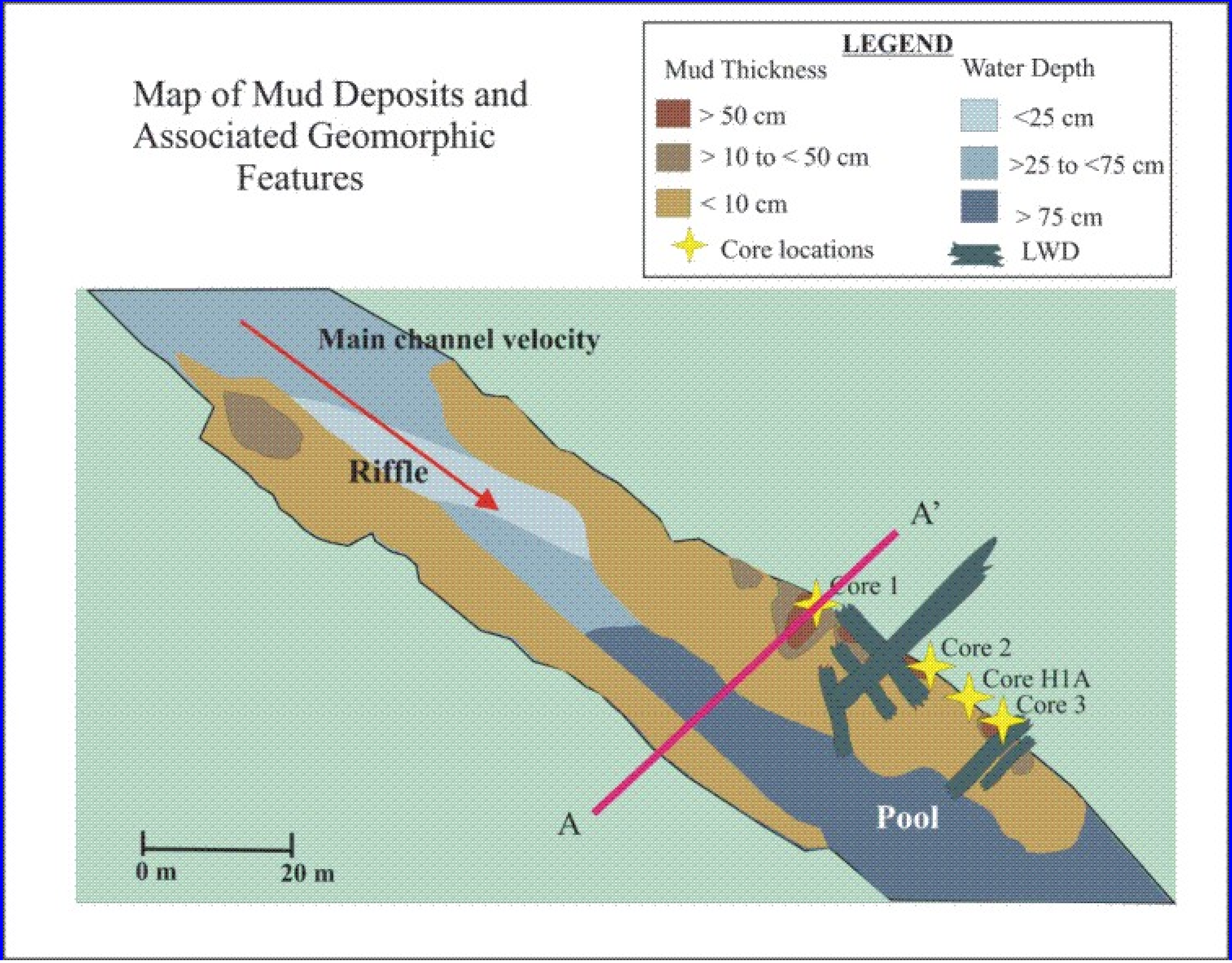
Silt and Clay Deposition/Storage in The Channel

- Within the pores of the gravel….
  - Volumetrically unimportant
  - Results not presented here
- Behind piles of large woody debris (LWD)

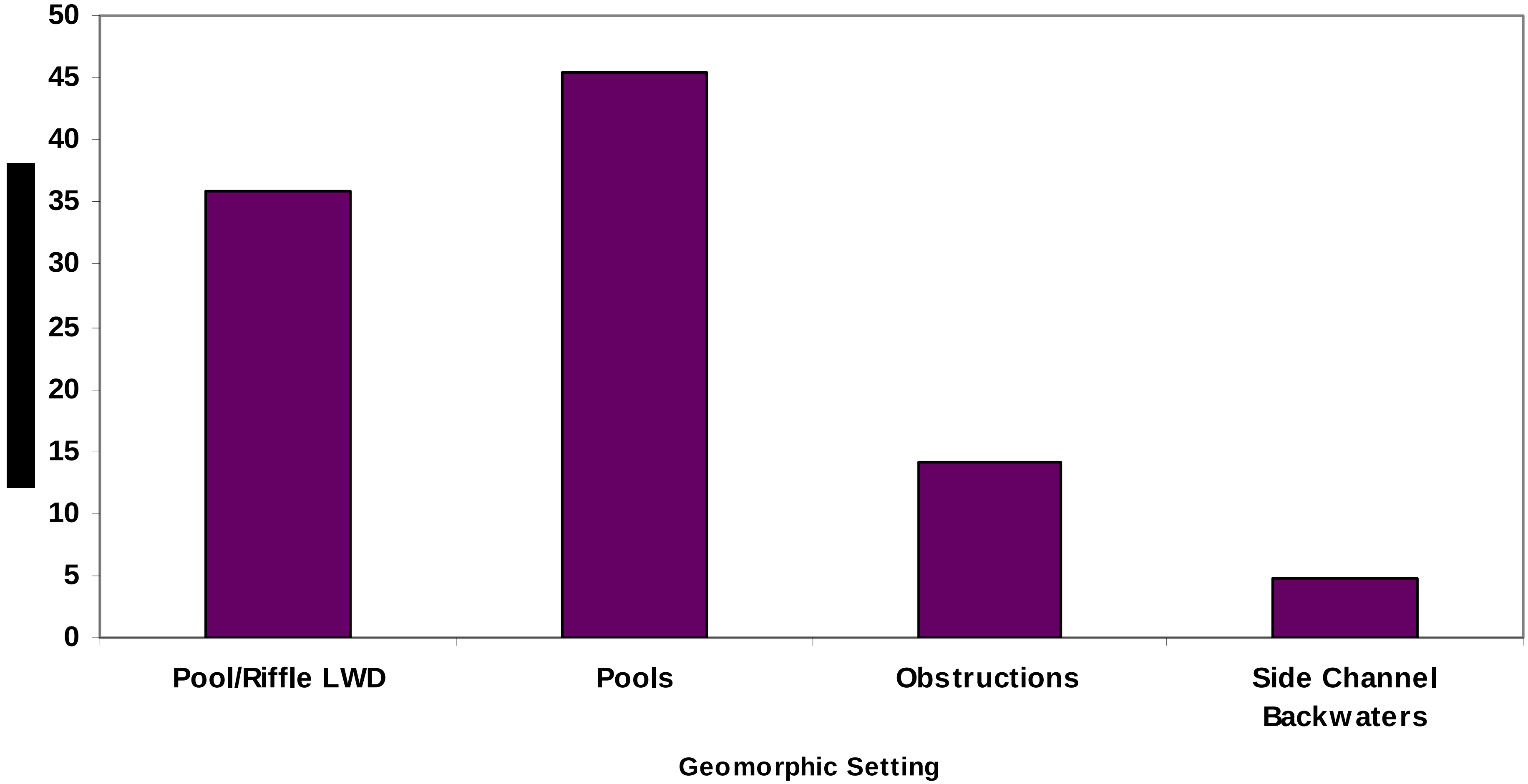
“Fine-Grained Channel Margin” Mud Deposits

- Mud deposits within the channel perimeter initially proved difficult to locate;
- We found mud deposited on the channel margins, typically associated with large woody debris

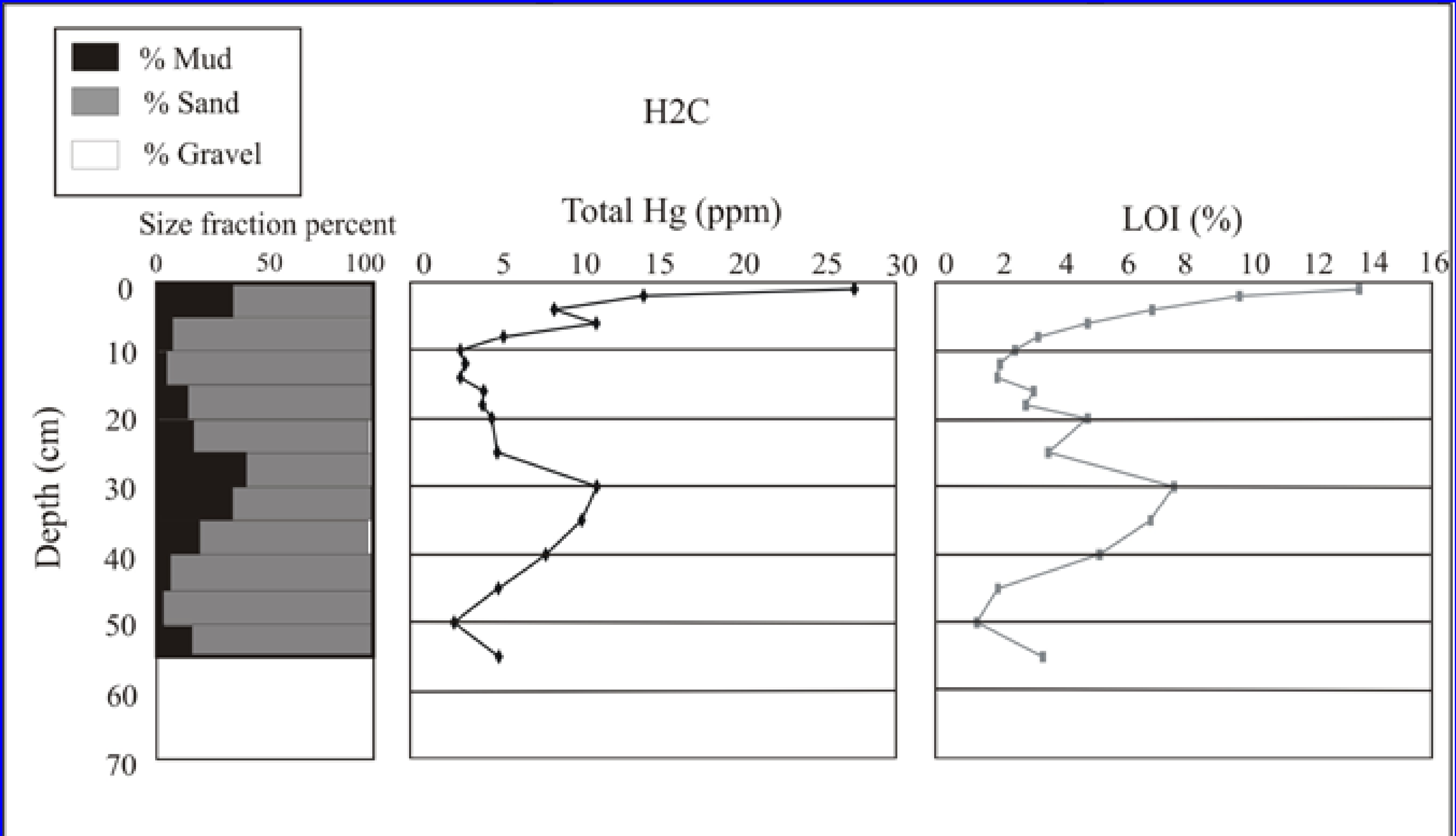
Map of Pool/Riffle Channel Margin Fine-Grained Deposit H1A (Core 1 – 600 ppm Hg at base)



Occurrence – 4 Different Geomorphic Settings



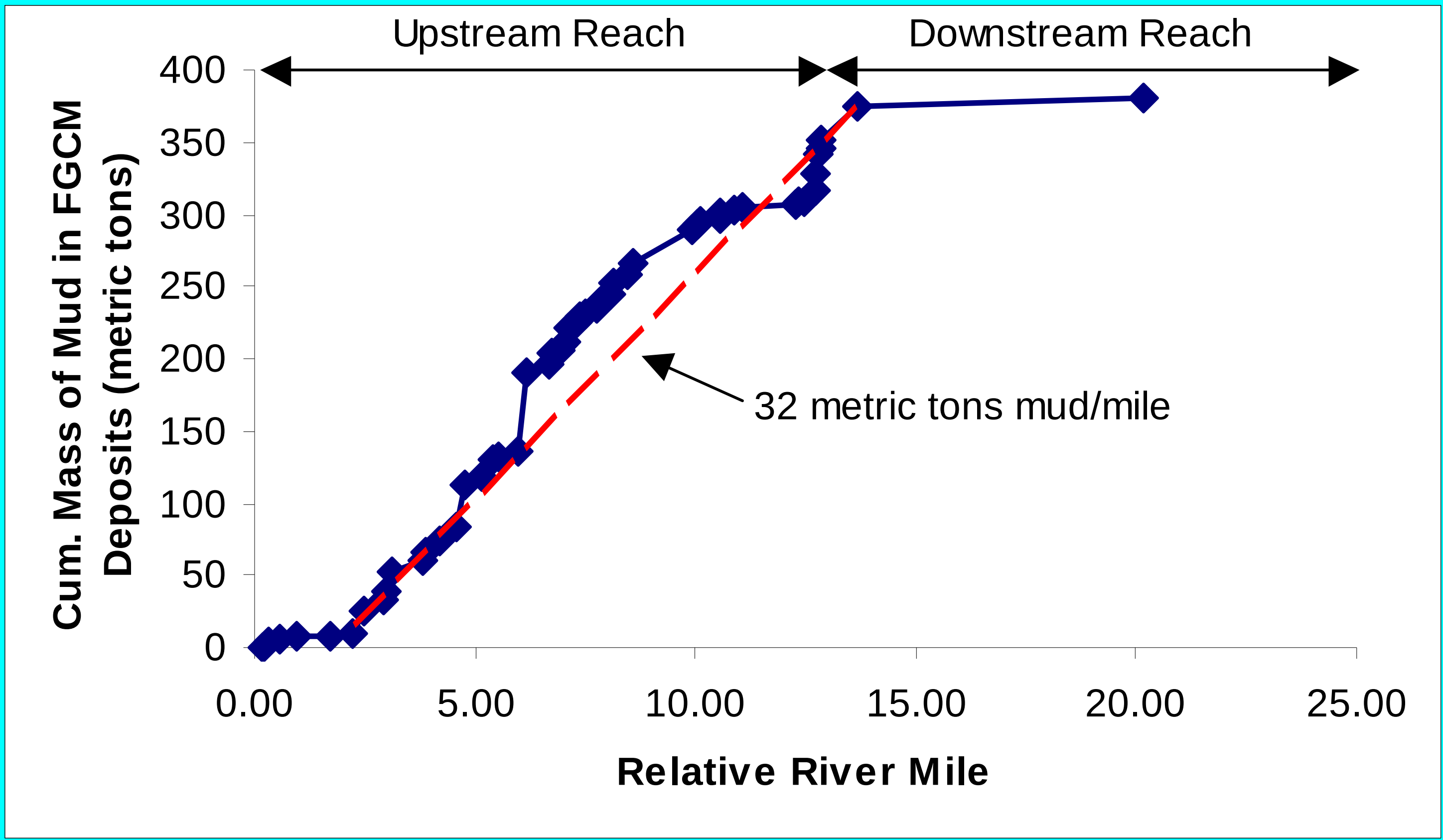
Example Results – Core H2C RRM 3.12



Average THg

Name	Total Hg		Hg (ppm)
	as rec'd	dry	
	ng g^{-1}		
H1A	15209.92	27128.93	**27.13**
H2A	3876.68	5962.64	**5.96**
H2C	4061.24	7848.73	**7.85**
D5A	6836.17	13726.25	**13.73**
D7A	4834.39	11410.96	**11.41**
Core 1	73538.49	133576.06	**133.58**
Core 3	12923.08	20972.40	**20.97**

Mapping…



Upstream Reach
Downstream Reach
400
350
300
250
200
150
100
50
0
Cum. Mass of Mud in FGCM Deposits (metric tons)
32 metric tons mud/mile
0.00
5.00
10.00
15.00
20.00
25.00
Relative River Mile

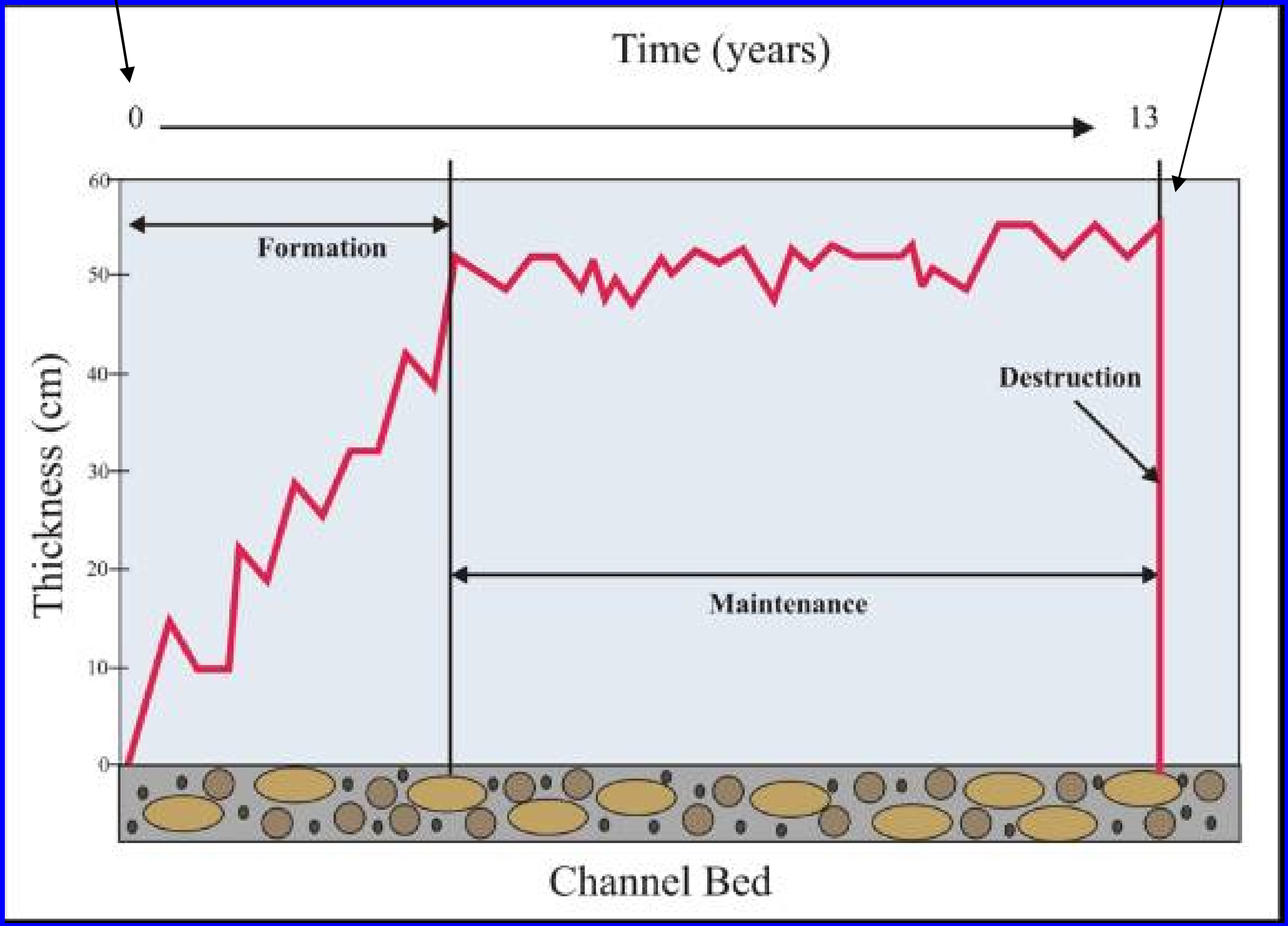
Maximum ages of FGCM Deposits From ^{14}C Dating

Core	Age at Base (years)
Core 1	> 55
H1A	19
H2A	14
H2C	13
D5A	10
D7A	11

“Life Cycle” of A Representative FGCM Deposit

Deposition begins after LWD trapped on channel margins

Destruction during whopping flood



Summary: FGCM Deposits

- Volume of mud stored equivalent to 16% of annual suspended sediment load
- FGCM deposits average about 70% sand and 30ppm total Hg
- FGCM deposits have a typical lifespan of 10-20 years
  - Probably do not contribute significantly to an annual sediment budget

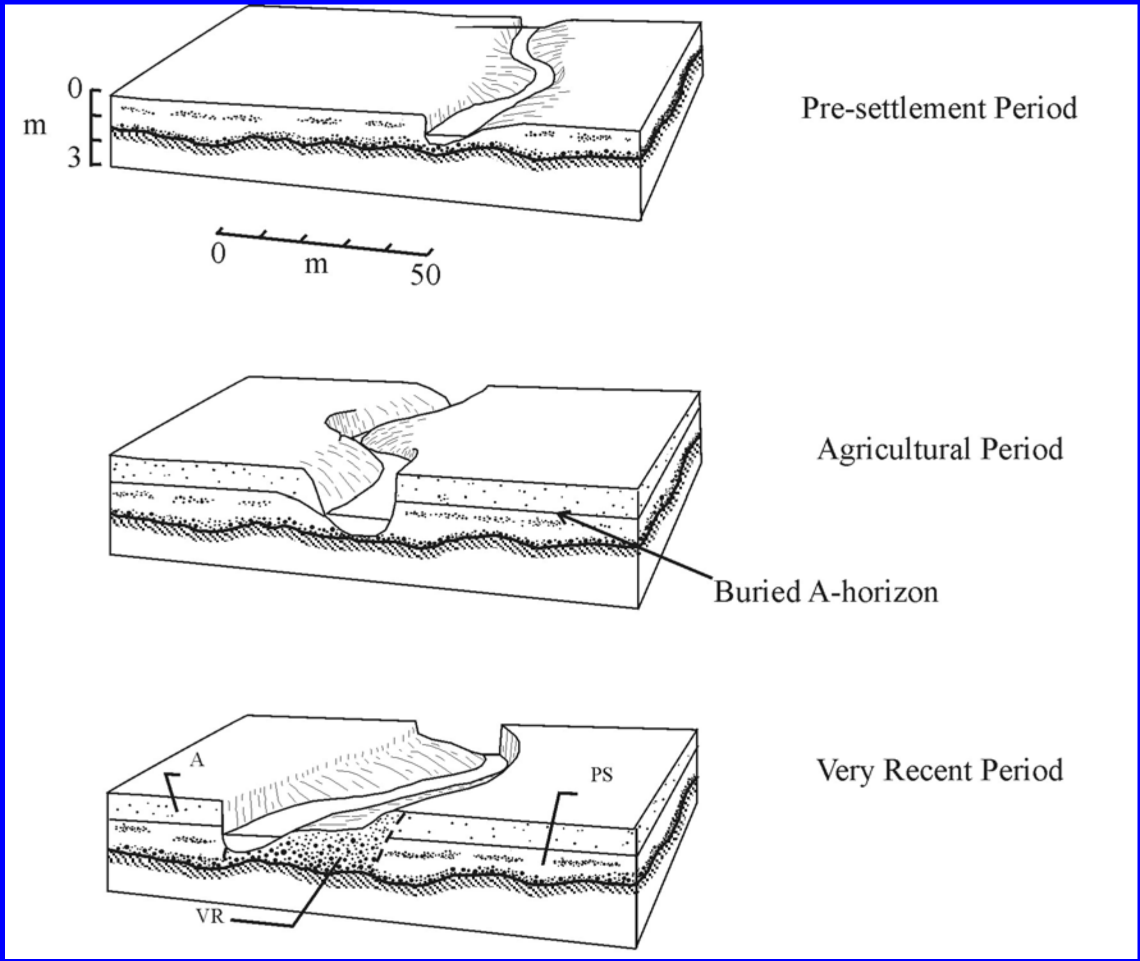
Floodplain Deposition

- Centennial history of floodplain evolution
- Recent deposition and erosion during last few decades

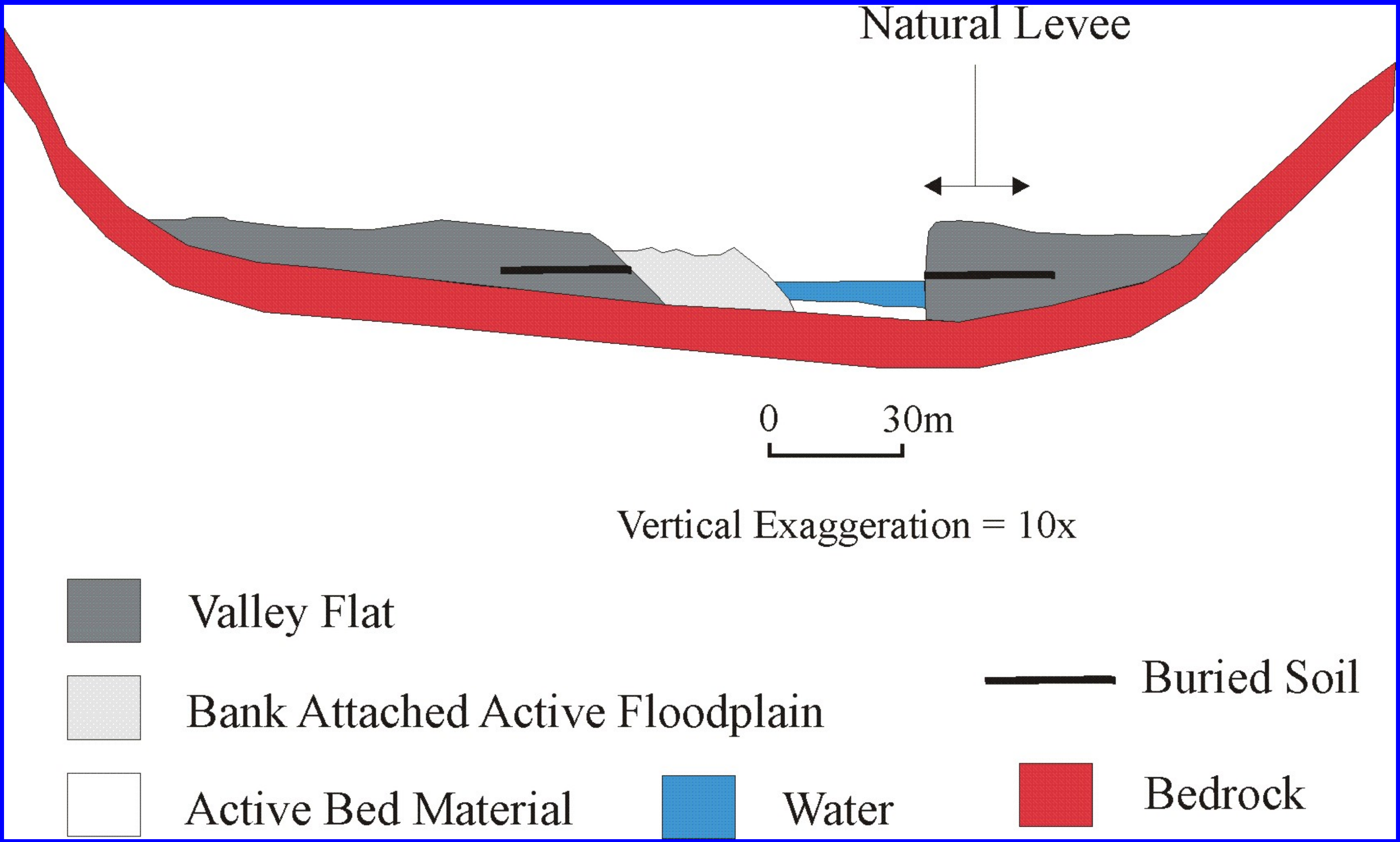
Long-term (Centennial) History of Floodplain Evolution

- 1750-early 1900s(?)
  - Several meters of floodplain deposition as a result of post-colonial land clearing and soil erosion, construction of mill dams.
- Early 1900s – present
  - Early deposits eroding through bank erosion
  - Some deposition on “natural levees”
  - Some deposition of sandy “point bar” floodplains

Jacobson and Coleman, 1986

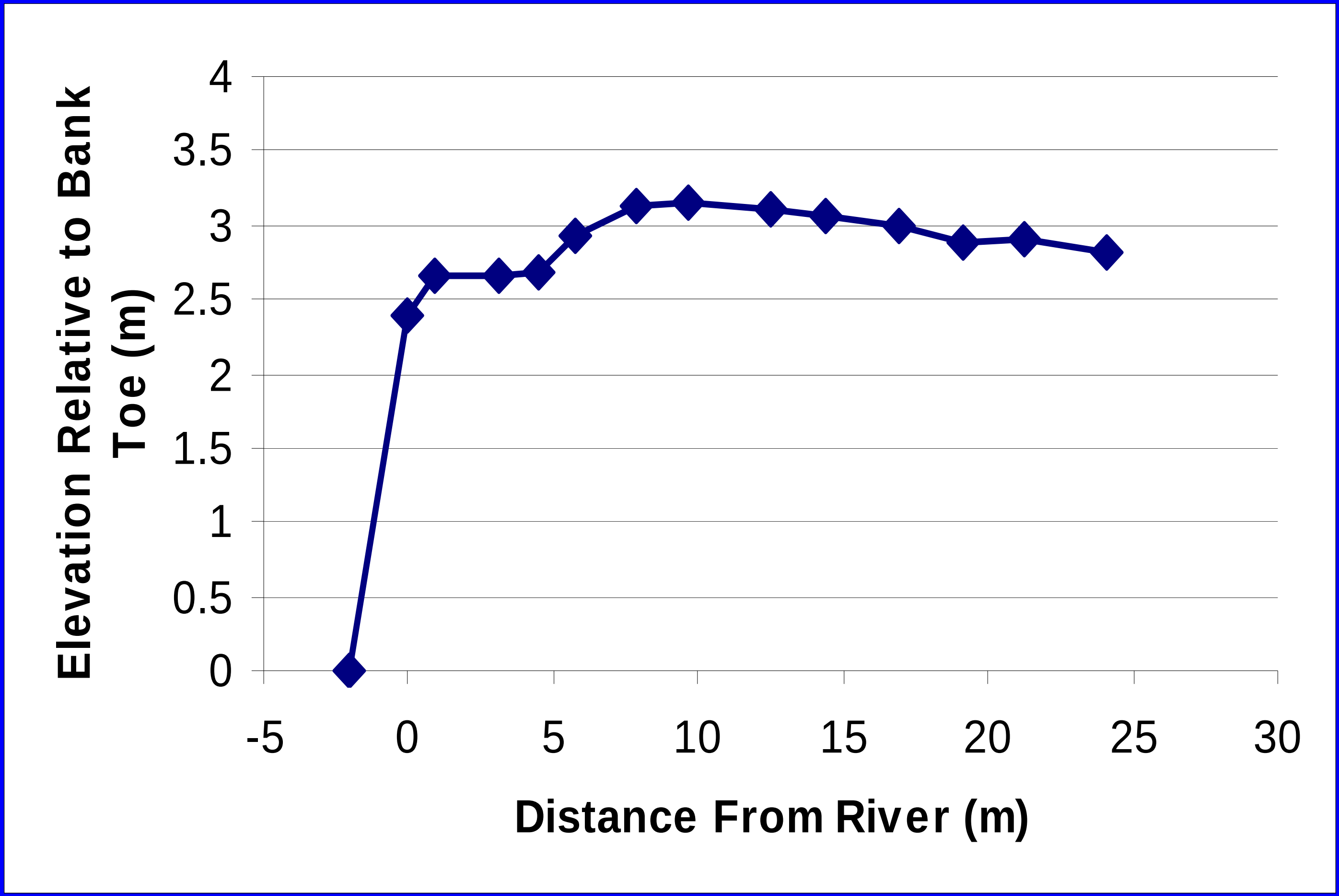


Conceptual Model of South River Floodplains

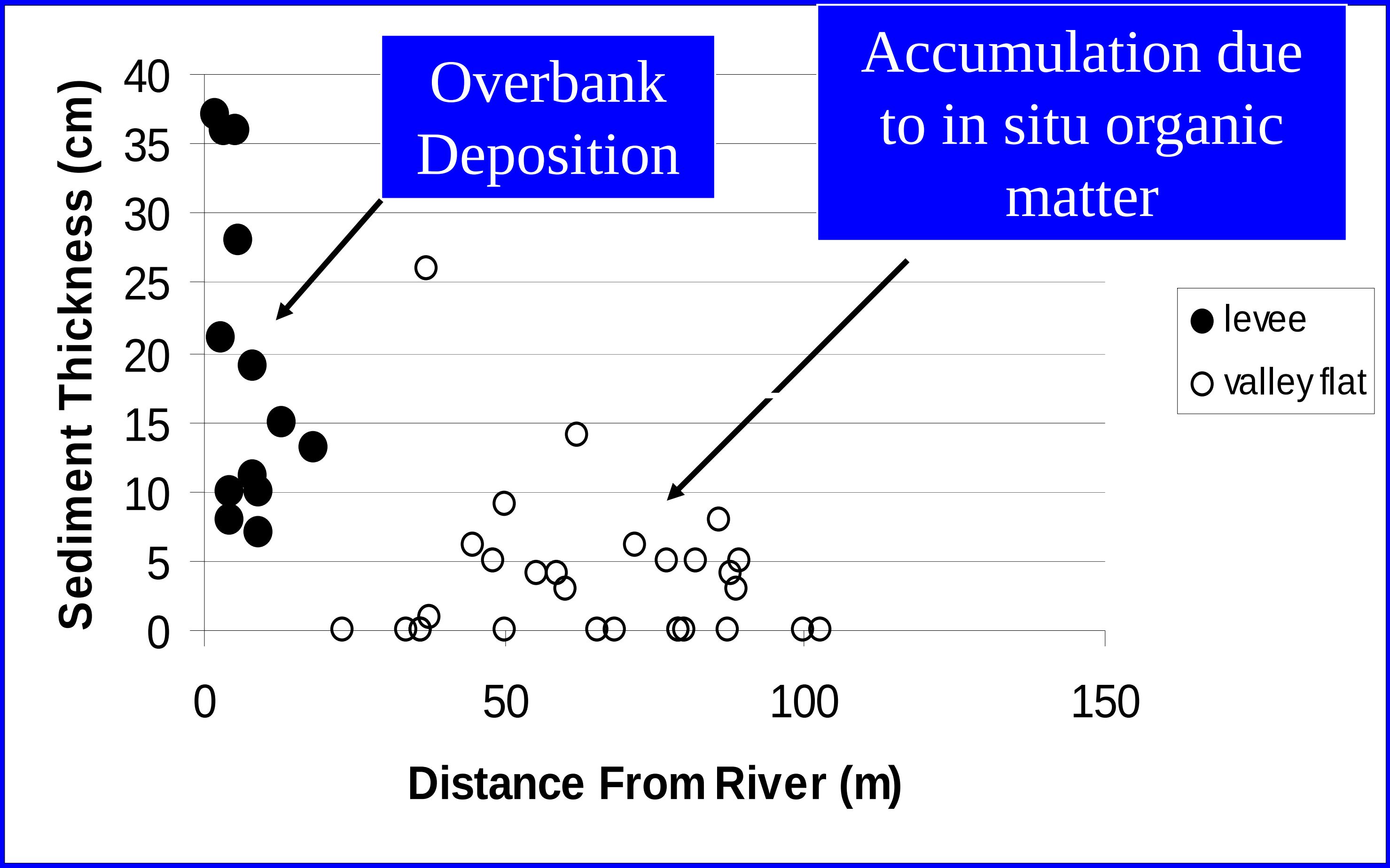


Overbank Accumulation During the last ~30 years below Hopeman Parkway

A Well-developed "Natural Levee"….



Total Accumulation



Total Mass and Some Hg Data For Natural Levees

Annual mud accumulation per unit channel length	26 kg/m/yr
Total length of apparent natural levees in the study area	6800 m
Total annual apparent natural levee mud accumulation	**1.76×10^5 kg/yr**

Table 9.8. Summary of Hg analyses for natural levee deposits discussed in the text.

Source	Location	Depth Range (cm)	Average Hg (ppm)
Jensen et al. (2004)	Hopeman Pkway	0-15	6
Cocking et al. (1991)	Hopeman Pkway	0-15	22
Jensen et al. (2004)	Forestry Station	0-15	12
Overall Average			**13**

BAAF Study Site ('37 shoreline – blue, '05 shoreline-yellow) below Dooms

Evidence of Recent Erosion

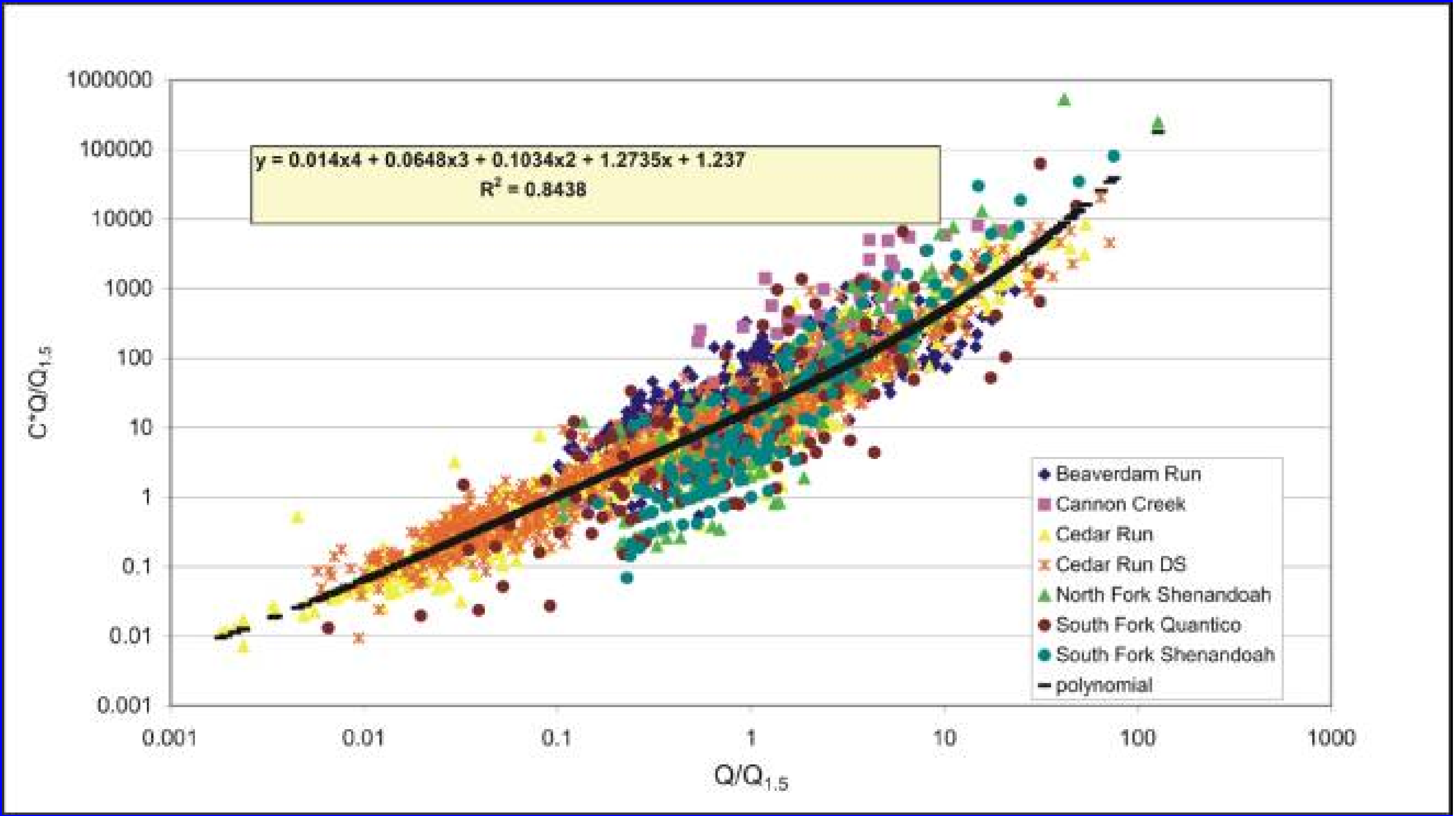
Summary of Floodplain Studies

- Negligible accumulation on valley flat outside of natural levees during the last 30-40 years
- Levee accumulation averages 0.5 cm/yr, and totals 1.5×10^5 kg/yr from Waynesboro to Port Republic
- BAAF deposits likely formed after a period of valley alluviation before the 20th century
  - These deposits are not storing silt and clay in significant amounts today, and may be neglected in a silt and clay budget for the study area
- Silty alluvium of the valley flat is gradually being removed, to be replaced by sand and gravel of the BAAF deposits

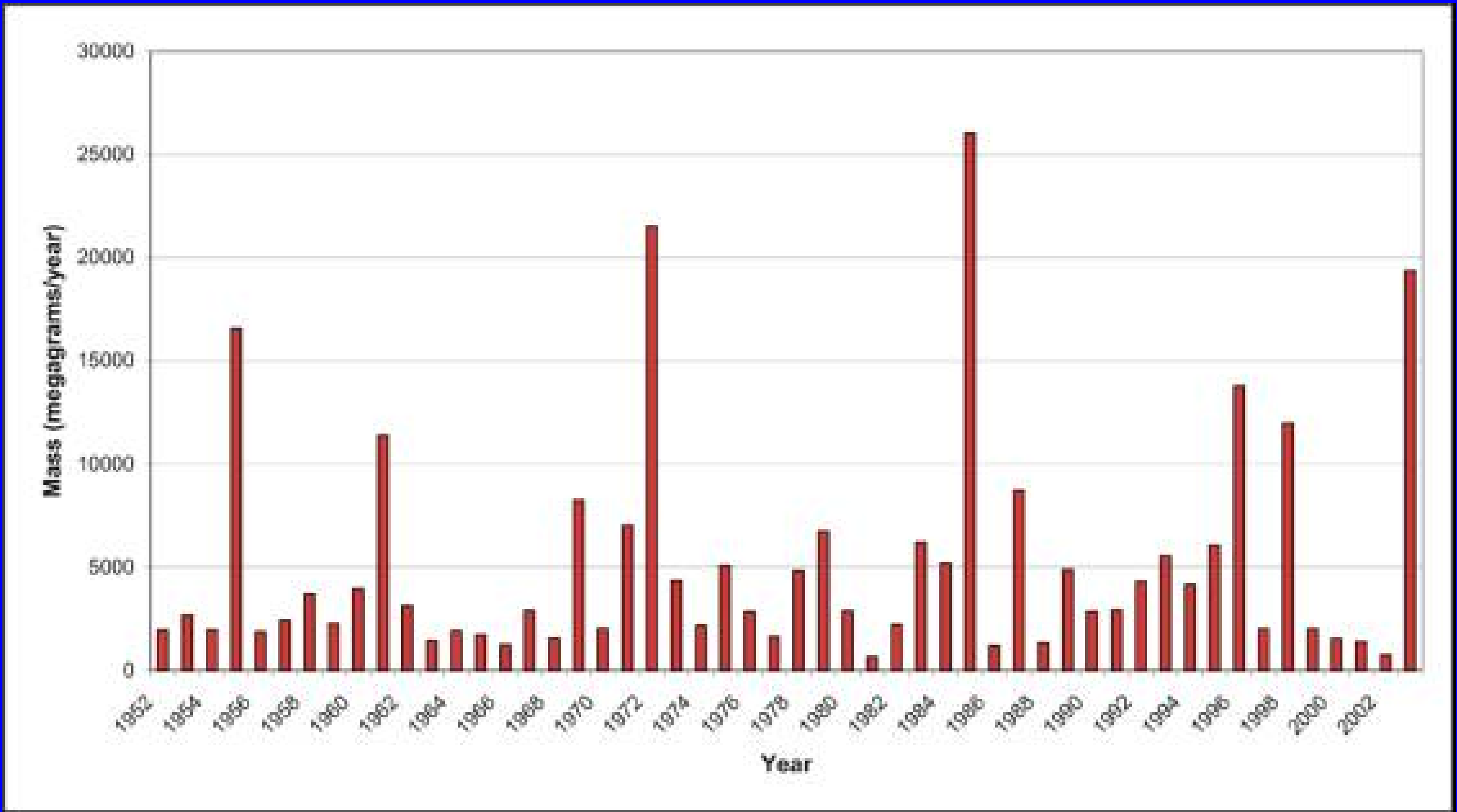
Suspended Sediment Transport From Regionalized Rating Curves

- Used to compute
  - Input from upstream
  - Input from tributaries
  - Output from the study reach

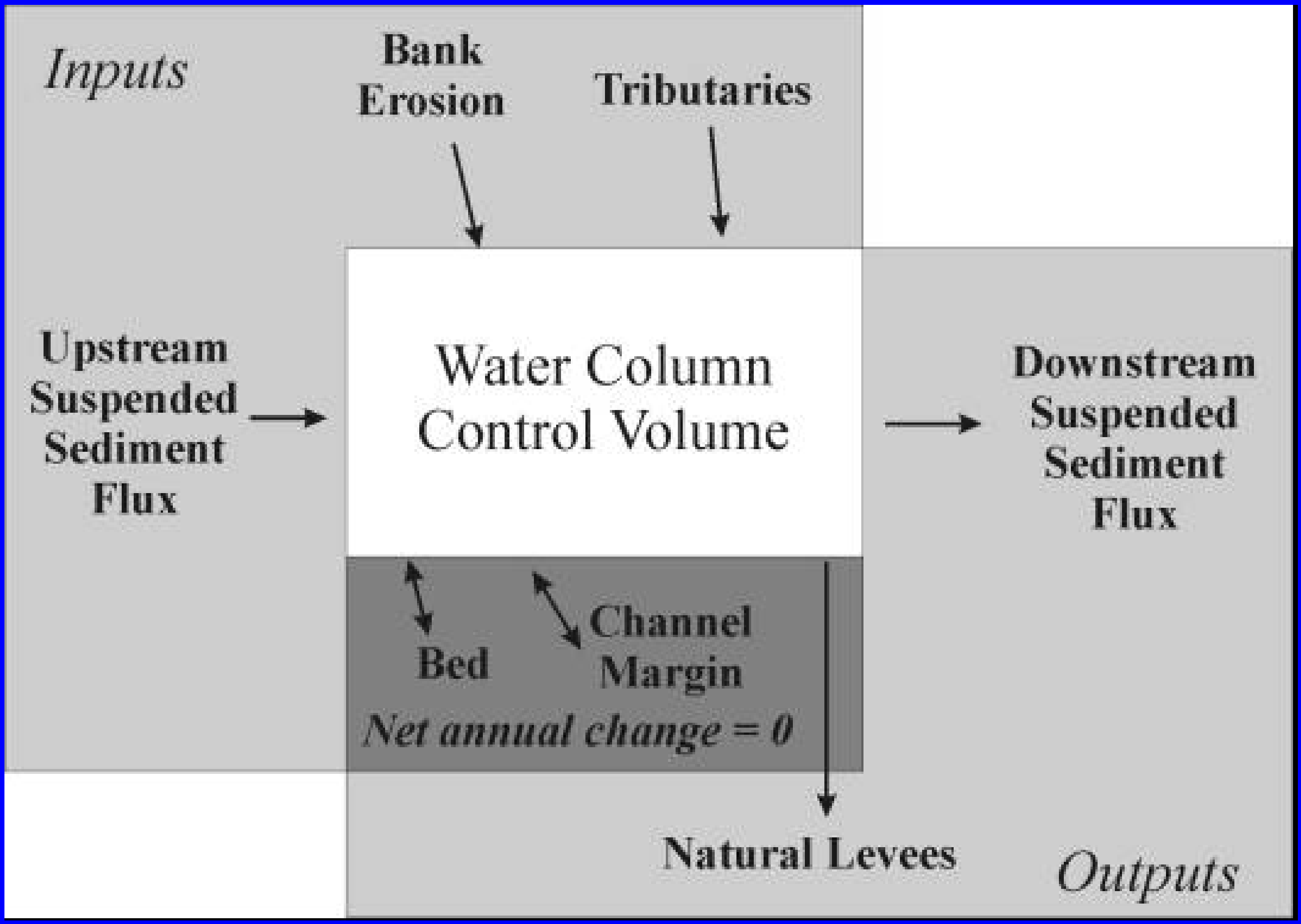
The Regional Rating Curve



Annual Suspended Sediment Fluxes At Waynesboro – a few "big years" dominate transport!



The Annual Silt and Clay Budget Components



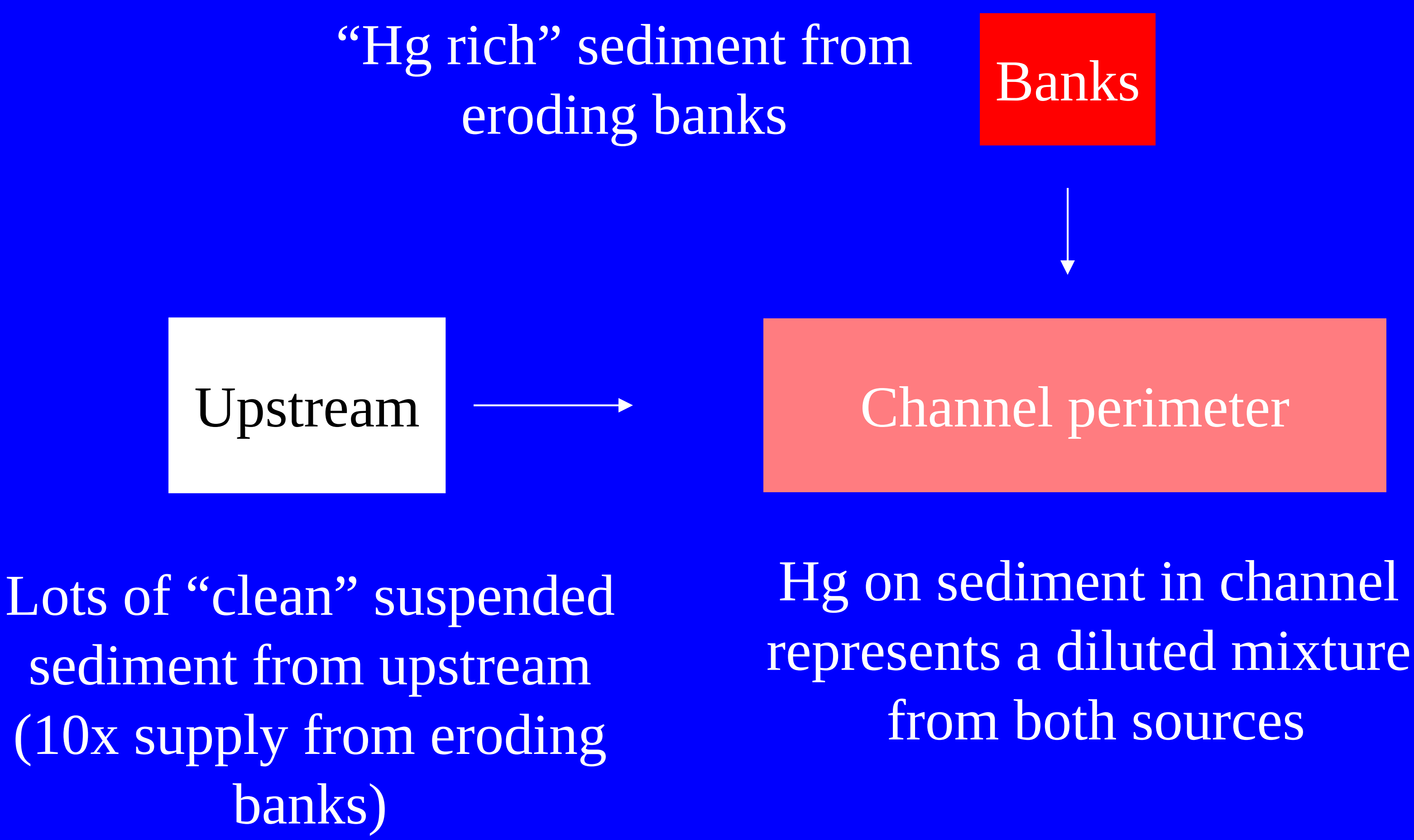
Annual Silt and Clay Budget, Waynesboro-Harriston

INPUTS	Metric tons/year	% of suspended sediment output
Upstream	5200	57
Bank erosion	850	9
Tributaries	3330	36
Total input	9380	102
OUTPUTS		
FGCM deposition	0	0
Deposition on streambed	0	0
Deposition on natural levees	180	2
Downstream	9200	100
Total output	9380	102

Mass of Mud Stored in Channel Components as % of Annual Suspended Sediment Load at Harriston

Category	% of Annual Load at Harriston
Mud Stored in Pores of Gravel Bed	0.2
Fine-Grained Channel Margin Deposits	4

Testing a Simple Box Model of Sediment-Related Hg in South River Channel Perimeter



Predicted Hg Concentrations Based on the "Well-mixed" Hypothesis

Sources	Annual Mass of Sediment (kg/yr)	Ave. Hg concentration (ppm)	Annual Mass of Hg (kg/yr)
Upstream Suspended Sediment Flux	5.2E+06	0.2	1.0
Bank Erosion	8.5E+05	10.0	8.5
Tributaries	3.3E+06	0.2	0.7
Total input (final result rounded)	**9.3E+06**	**1.1**	**10**

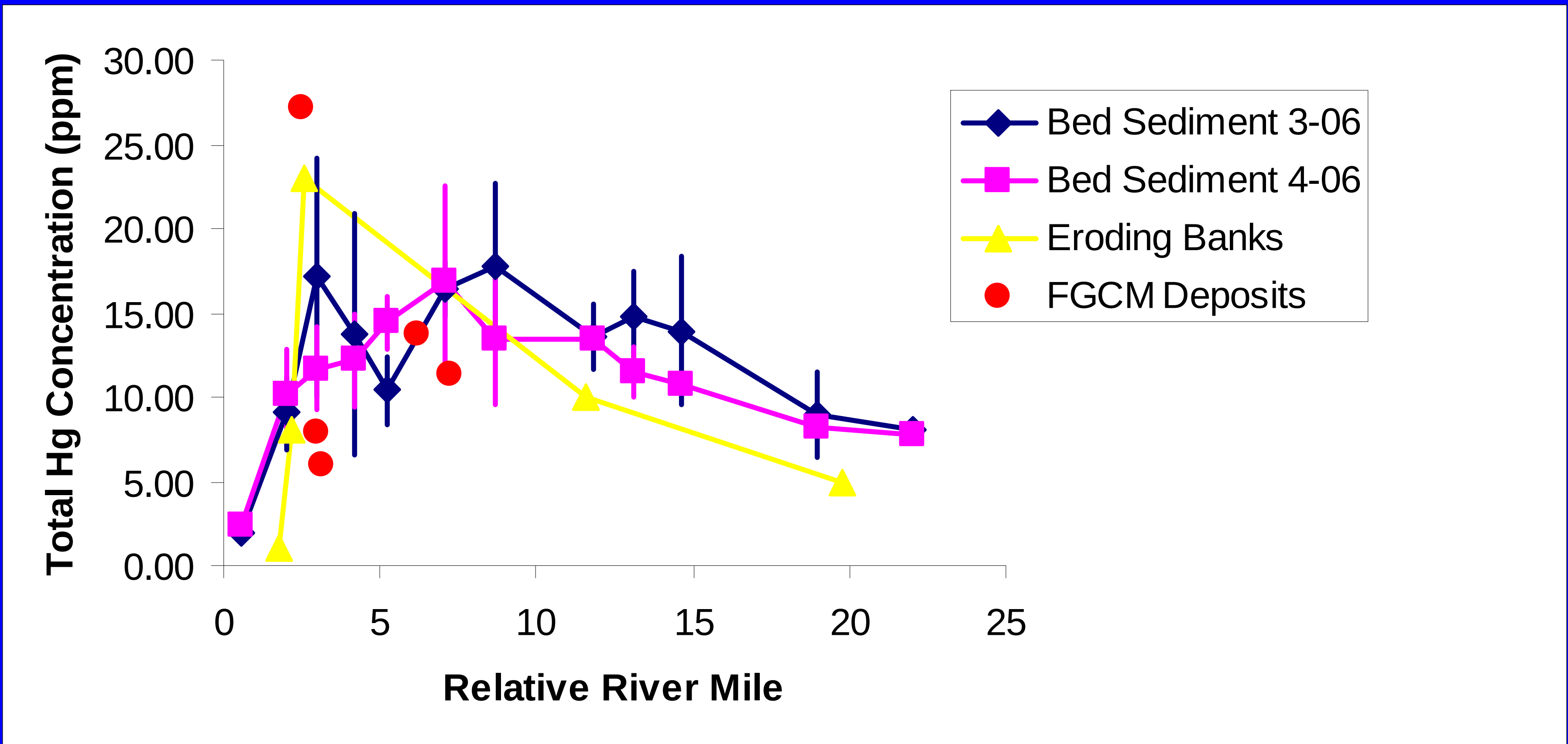
Predicted "source-weighted" water column Hg concentration
On solid suspended material

Predicted vs Observed Hg Concentrations

Component	Predicted Hg concentration (ppm)	Actual Hg concentration (ppm)
Water Column	1	NA
FGCM deposits	1	30
Natural levees	1	13
Channel bed	1	12

Mean Eroding Bank Hg Similar to Mean Hg in Mud Sampled on Bed, FGCM Deposits

NO DILUTION FROM UPSTREAM SEDIMENT SOURCES



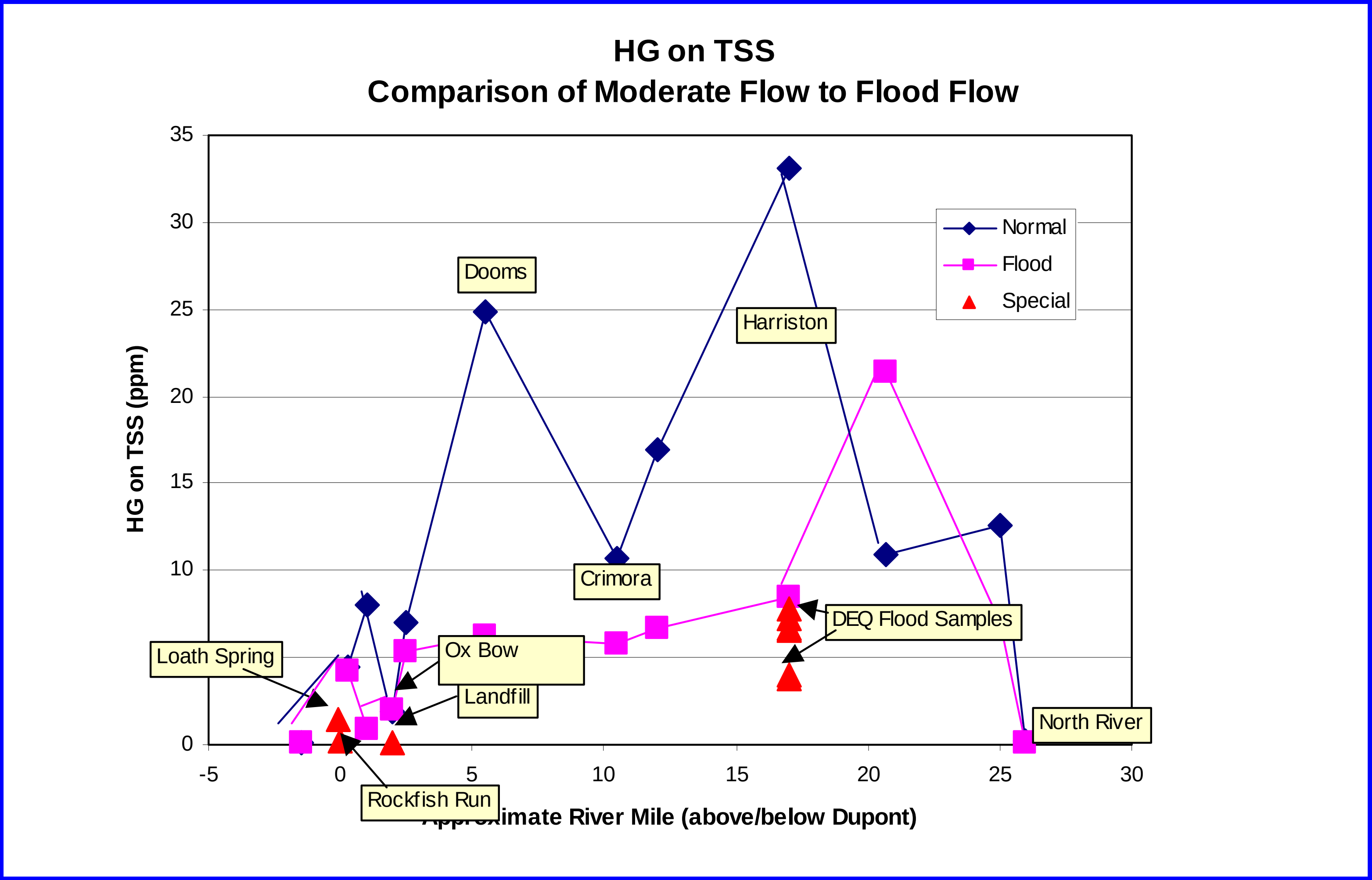
Observation

- Hg concentration from sediments within the channel similar to average Hg concentration of sediments in eroding banks
- Material stored in the channel is transported directly from the banks WITHOUT DILUTION from “clean” sediment supplied from upstream

Observation

- Hg concentration of suspended solids DECREASES during very high discharges
- DILUTION from “clean” sediment supplied from upstream occurs!!

Flood Hg on TSS is lower than at "moderate" flow (Jensen and Turner…)



USGS Flood Samples

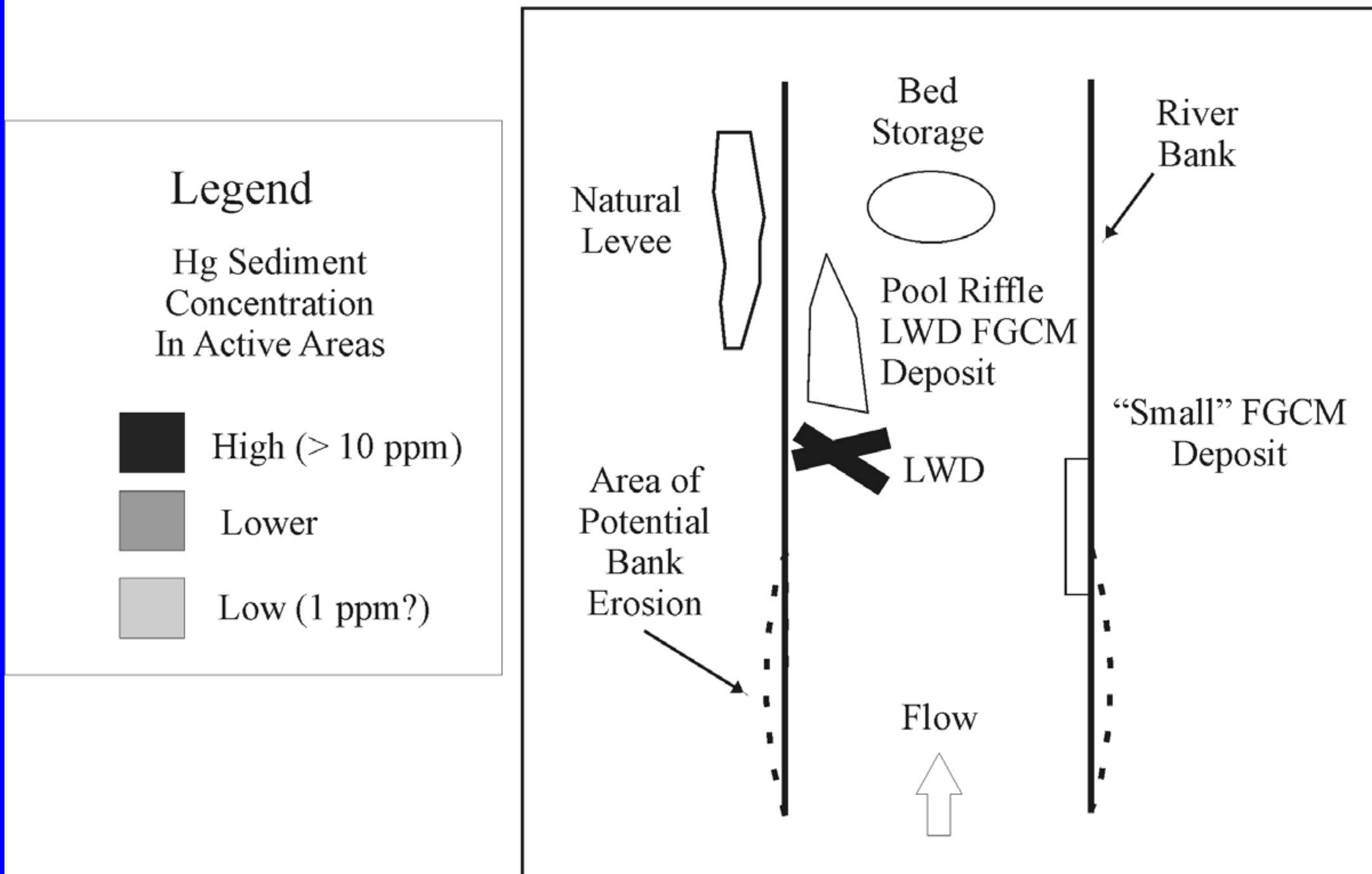
Date	Time	Discharge (ft^3/s)	Discharge (m^3/s)	Suspended Solids Concentration (mg/L)	Particulate Total Hg (ng/L)	Hg on TSS (ppm)
11/29/05	11:30 AM	2765	78	377	4022	11
11/30/05	12:30 AM	11776	333	277	1346	5
11/30/05	04:30 AM	9143	259	227	817	4
11/30/05	11:00 AM	5795	164	118	416	4

Working Hypothesis

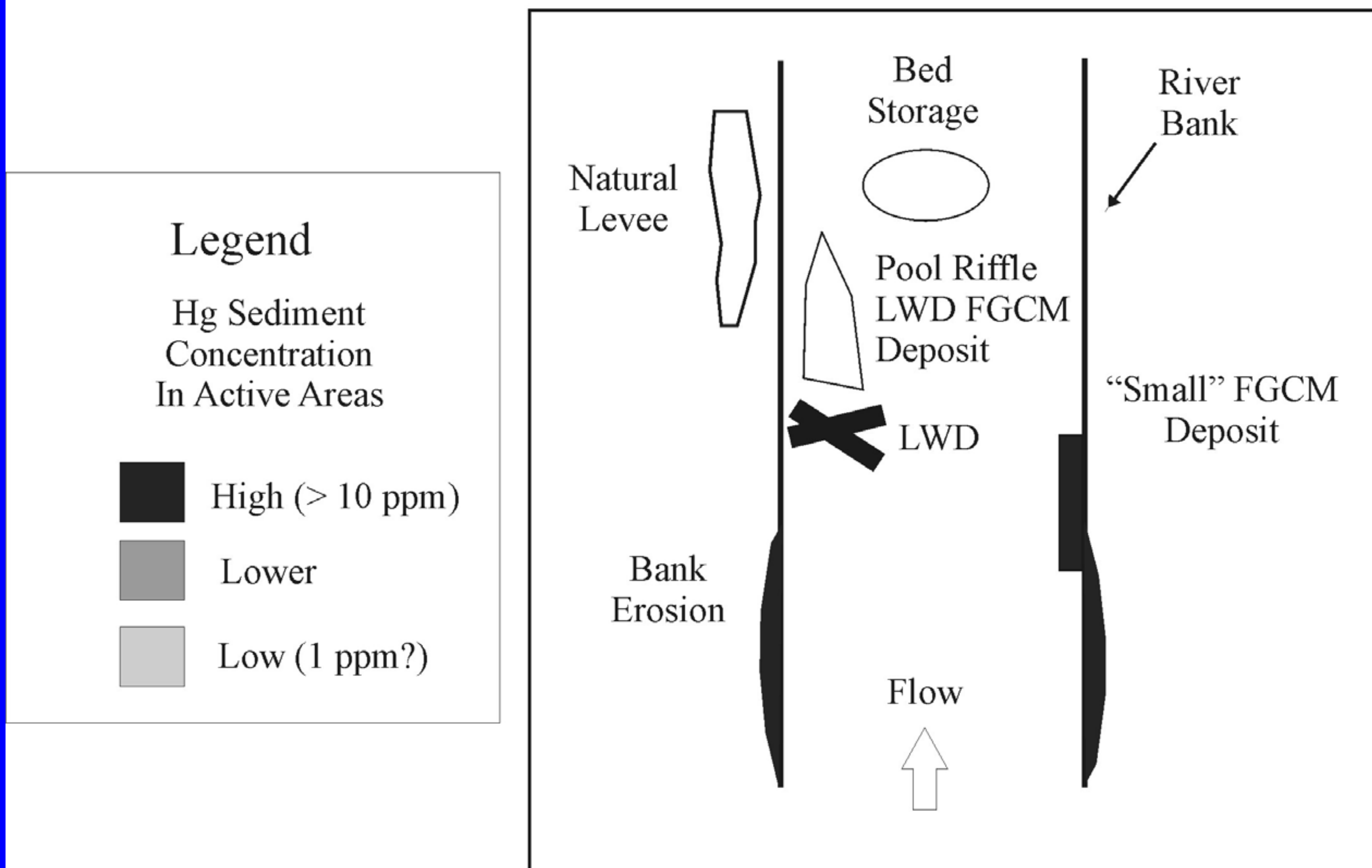
- Hg contaminated sediment in the channel is supplied from the banks by small, frequent discharges rather by than large storms
- Large storms that transport most of the suspended material simply transport fine sediment and Hg through the watershed without storage

Some Conceptual Models of Particulate and Hg Transfer Between Sediment Budget Components at Different Discharges

1 Day of Base Flow Conditions



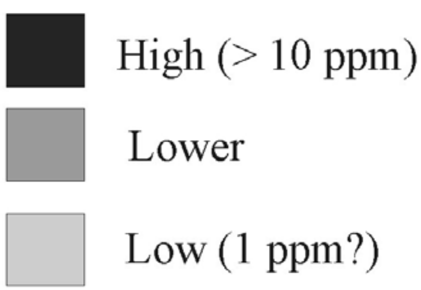
Feb.-April, w/o Significant Flows

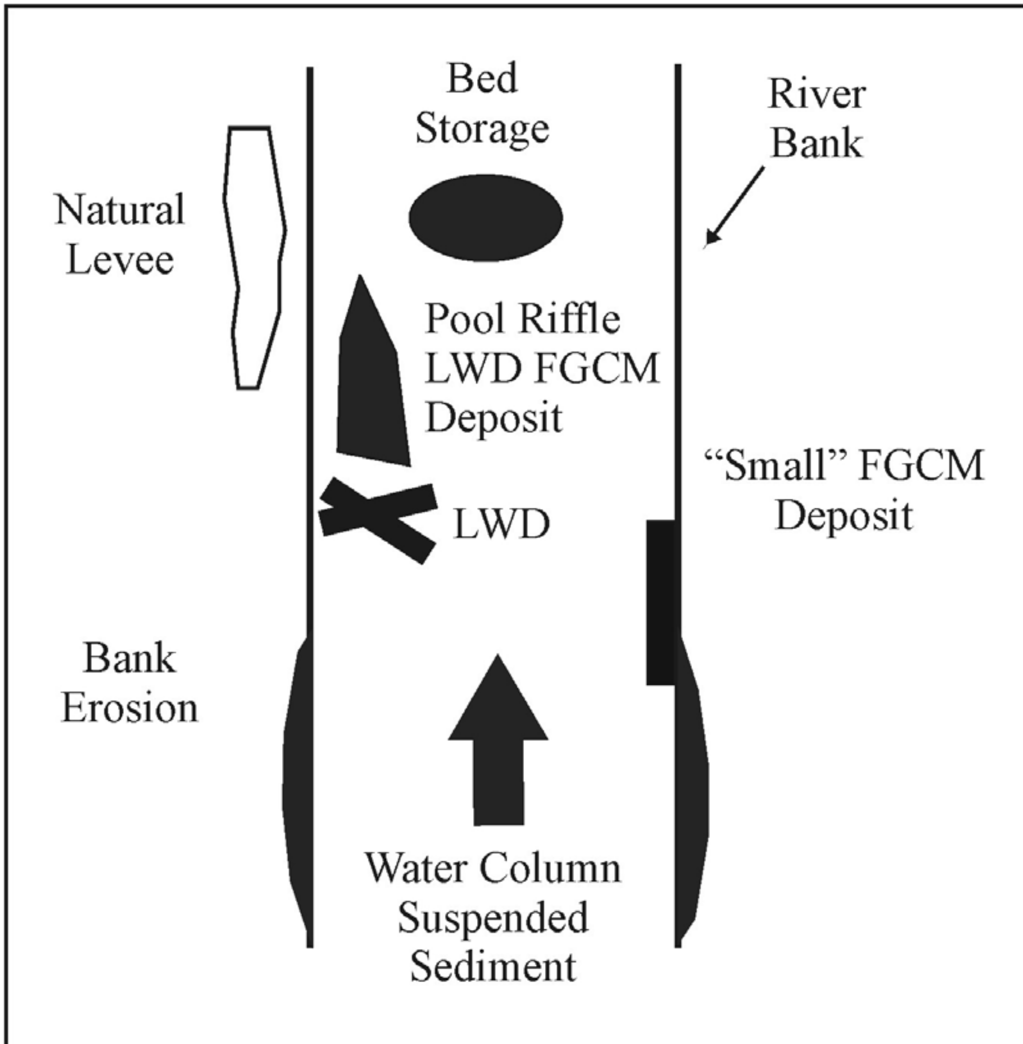


During a 1/3 Bankfull Flow

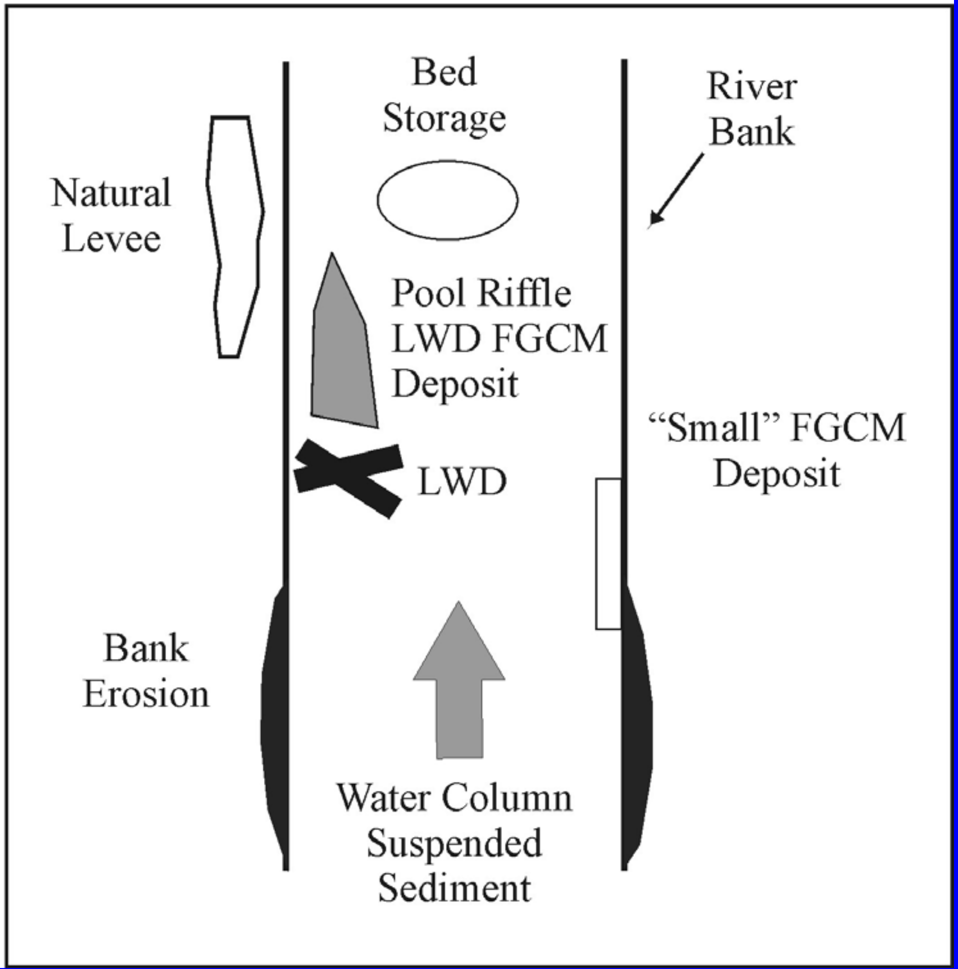
Legend

Hg Sediment Concentration In Active Areas





During a 3/4 Bankfull Flow

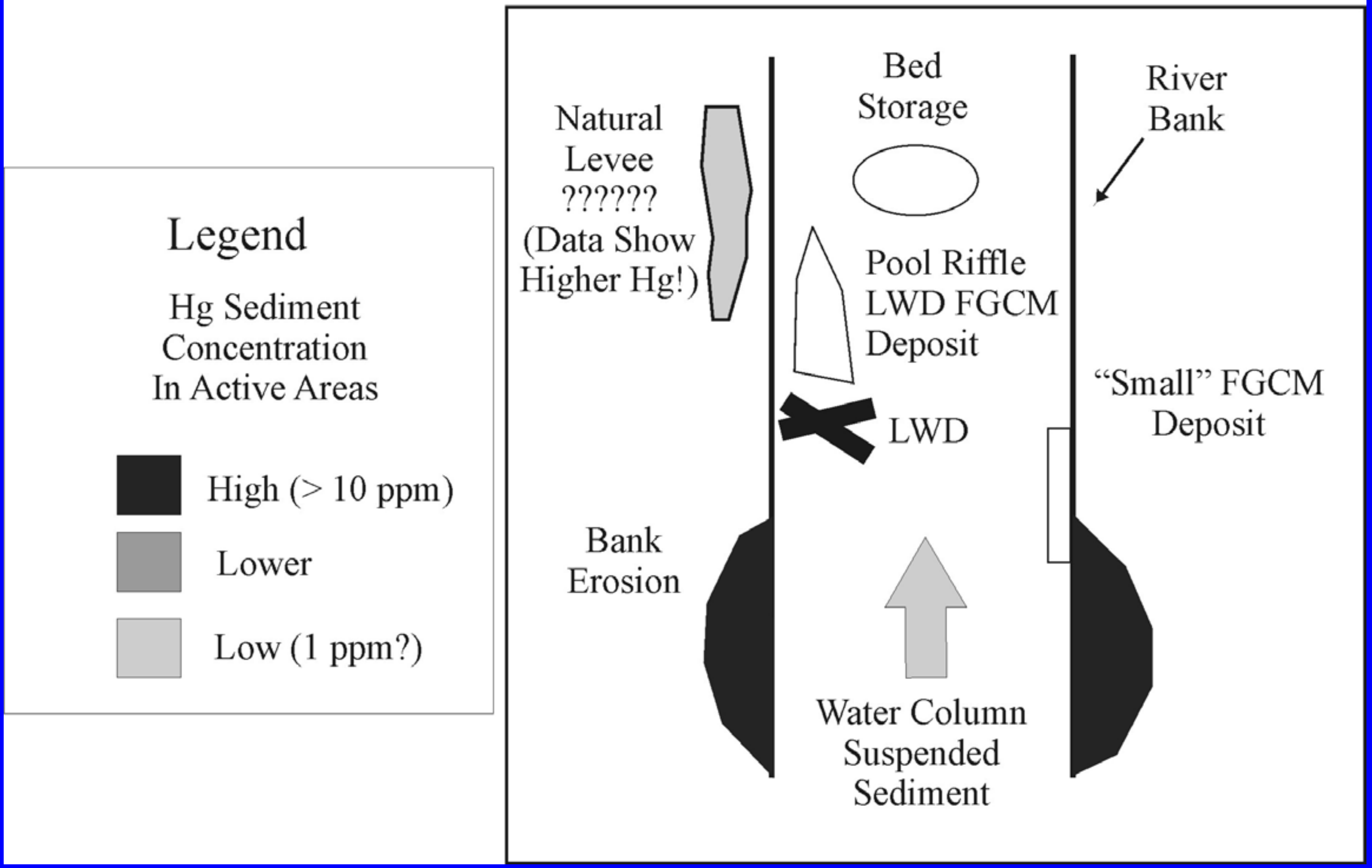


Legend

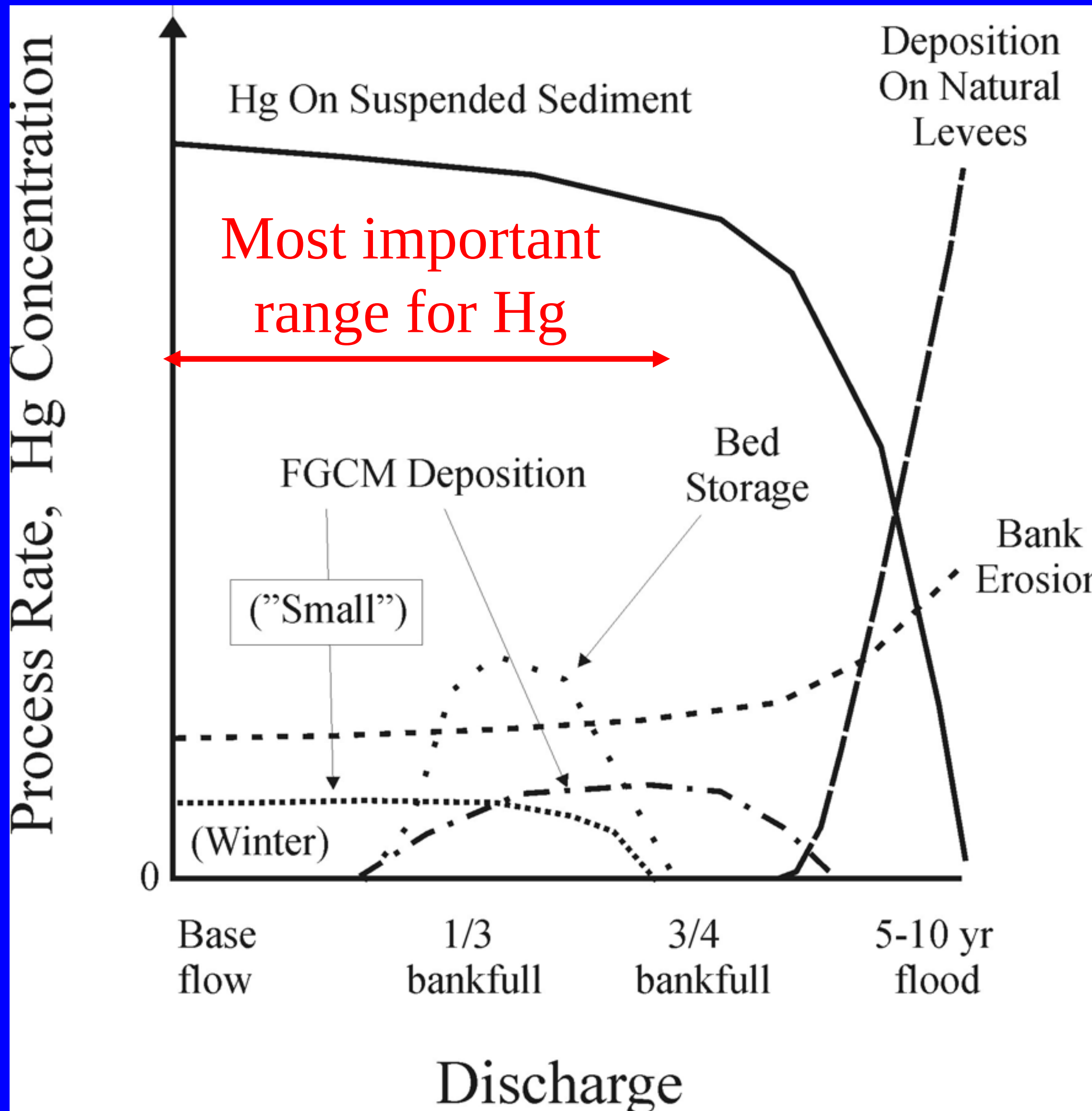
Hg Sediment Concentration In Active Areas

- High (> 10 ppm)
- Lower
- Low (1 ppm?)

During a 5-10 Yr Flow



Summary – Responses of Sediment Budget Components vs Discharge



Conclusions: Sediment Budget

- Sediment budget components:
  - Suspended sediment input, output, and supply from tributaries
    - All of these are “large”
  - Bank erosion
    - 10% of annual suspended sediment transport
  - Natural levee sedimentation
    - 2% of annual suspended sediment flux
- Storage in the channel:
  - FGCM deposits (behind LWD)
    - 4% of annual load
  - Gravel pores
    - 0.2%

Conclusions: Hg cycling

- Stored sediment in the channel provides a potential pathway (if other processes are conducive..) for Hg to move into the food chain
- Hg contaminated sediments likely are carried directly from the banks into storage by relatively small, frequent discharges
- Higher discharges have lower Hg concentrations on suspended material
  - Little storage likely occurs during high storm flows

A Take-Away Point

- ***Computing total loading by bank erosion is likely irrelevant***
- Most of the sediment and Hg eroded and transported by high flows leaves the study area immediately
- Sediment and Hg eroded by small flows is likely to be stored and to enter the food chain
- Small, frequent, VERY SLOW bank erosion processes are the most important to understand

This Year's Program

- Baseline lidar surveys of eroding banks
- Resurveys of selected eroding banks
  - Determine rates of erosion
  - Better understand timing and nature of erosional processes
- Analysis of aerial photographs at decadal intervals to determine if bank erosion is episodic or steady