

Geomorphology Update Fall 2008 South River Science Team Expert Panel Meeting

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Topics

- Reconstruction of Historic Hg Concentrations on Particles In Suspension, 1930-2005
- Modeling Hg Storage in Fine-Grained Channel Margin Deposits, 1930-2050
- Hg Concentrations in Eroding Banks
- Accelerating Rates of Bank Erosion, 1937-present
- Improved Sediment Budget, RRM 2.5-5.5
- Hg Concentrations in “Channel Margin Floodplain Deposits”
- Explanation for “The Hump”
- Revised Geomorphic Conceptual Models of the South River

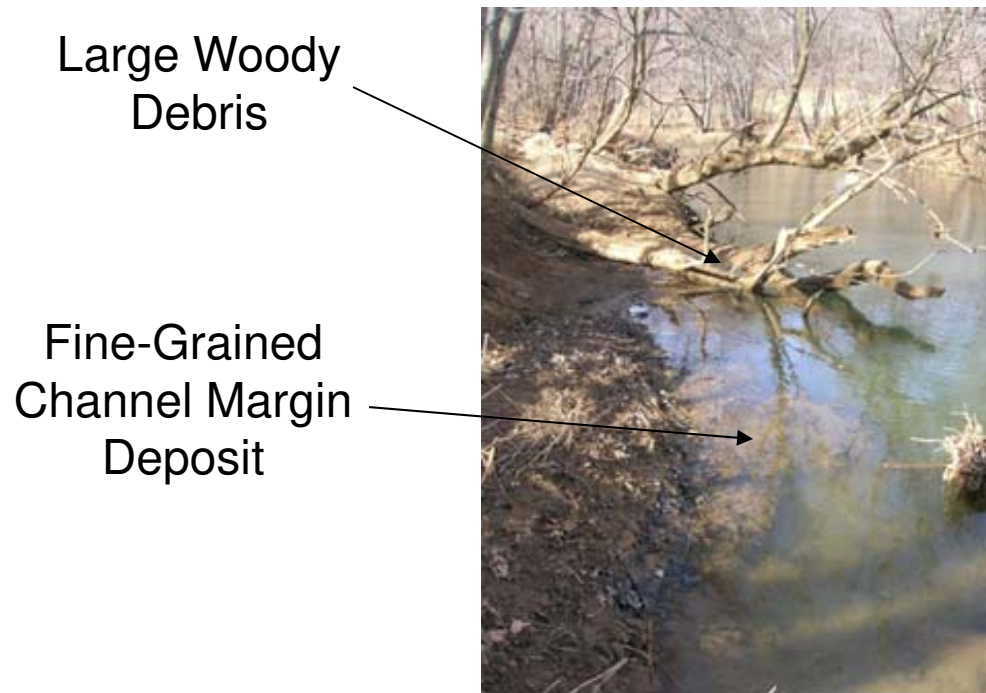
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“Fine-Grained Channel Margin” Mud Deposits

- Deposits of silt, clay, and sand on the channel margins, typically associated with large woody debris

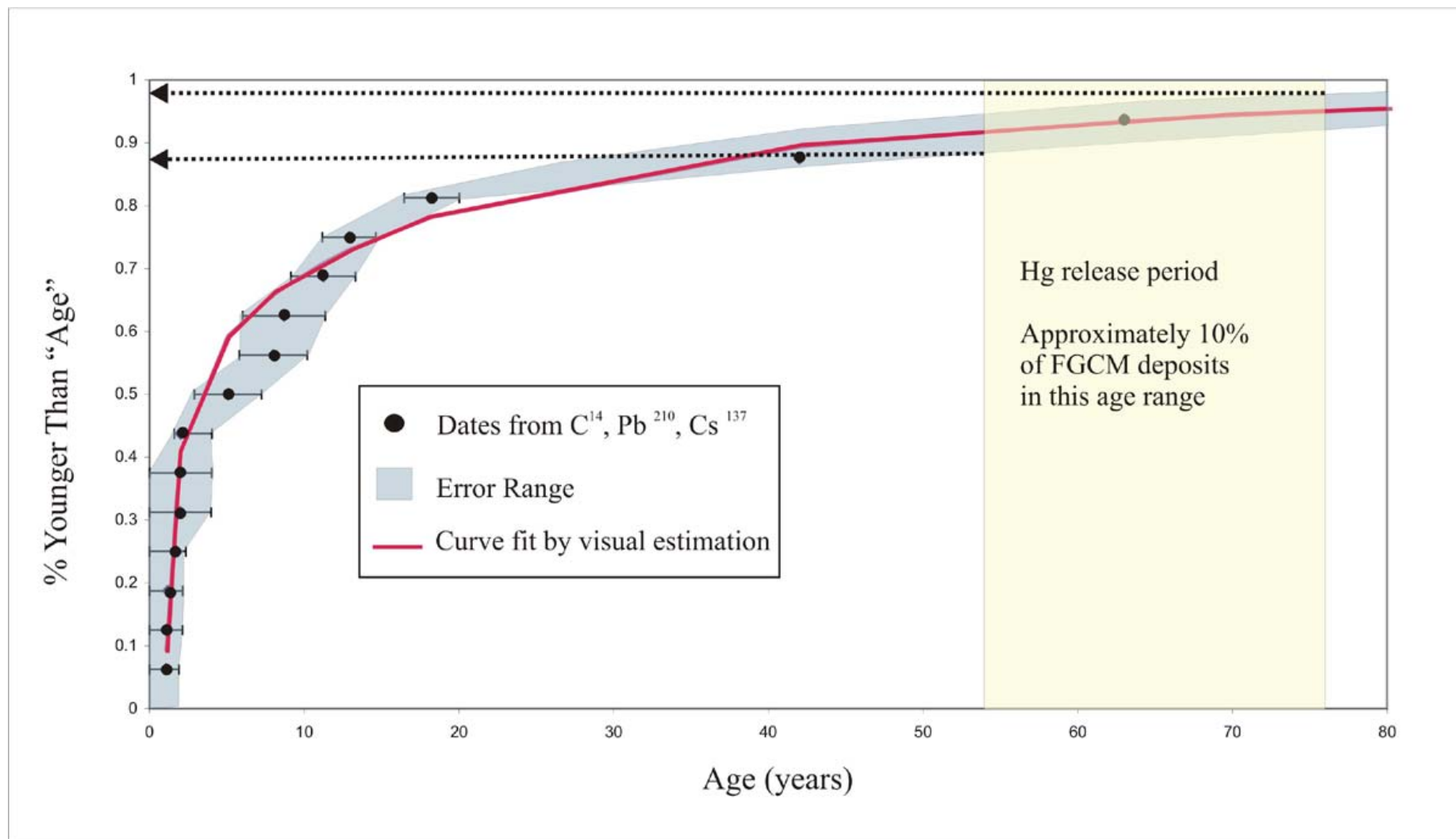
An Example..



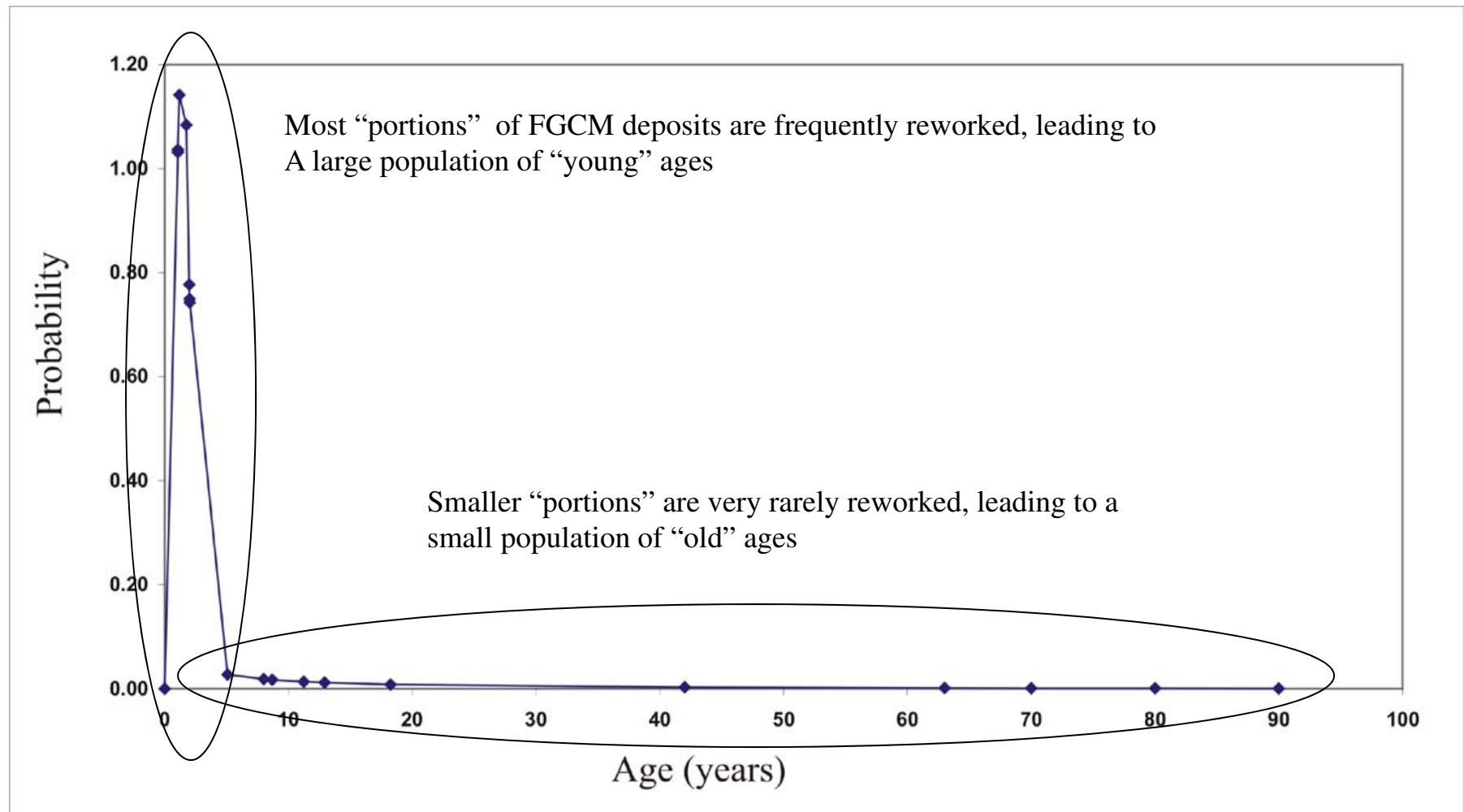
Radiometric Dating

- “Bomb radiocarbon”
- Pb210, CS137

Frequency Distribution of Ages from All FGCM Depsoits



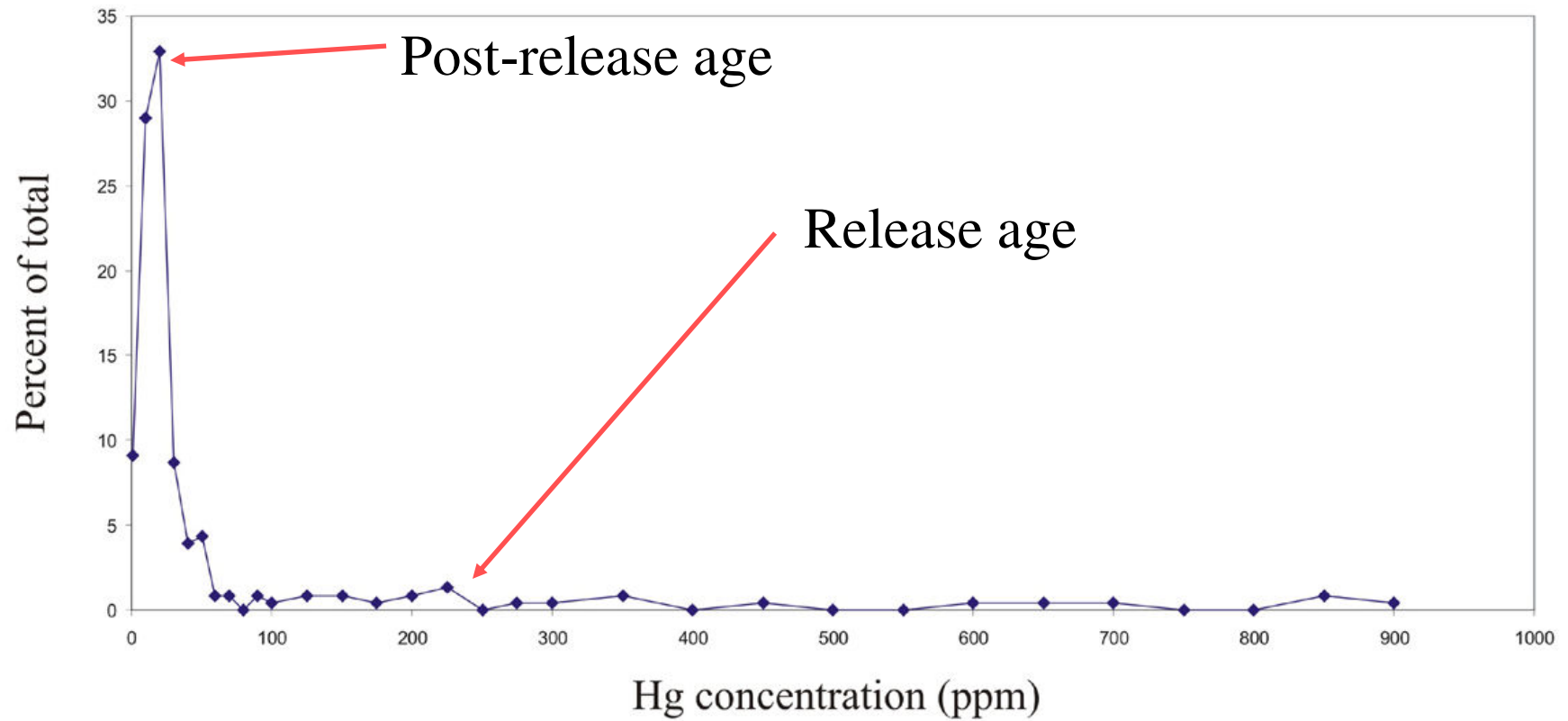
“Histogram” Derived From the Empirical Age Cumulative Frequency Curve – note apparent presence of two populations of ages



Age analysis using Hg concentrations in deposits

- Parallel age analysis using Hg concentration as a proxy for time.
 - Can release age Hg concentrations be determined from Hg distribution?

Hg concentration in FGCM deposits



Mass of Hg in FGCM deposits From Release Period Compared to Post Release Period

- Average release concentration: 370 ppm
 - (1930-1950)
- Average post-release concentration: 15 ppm
 - (1950-present)
- Volume in FGCM approximately 1820 m³
 - *70 kg of Hg from release period*
 - *25 kg of Hg post-release period*
- Release age material is about 74% of total mercury mass.

Modify the Conceptual Model!

- Most of the Hg in these deposits is NOT reworked from eroding riverbanks.
- Most of the Hg originated “directly” from the plant itself during the period of high Hg release.

Summary – Historic Hg Concentrations and Storage in FGCM Deposits

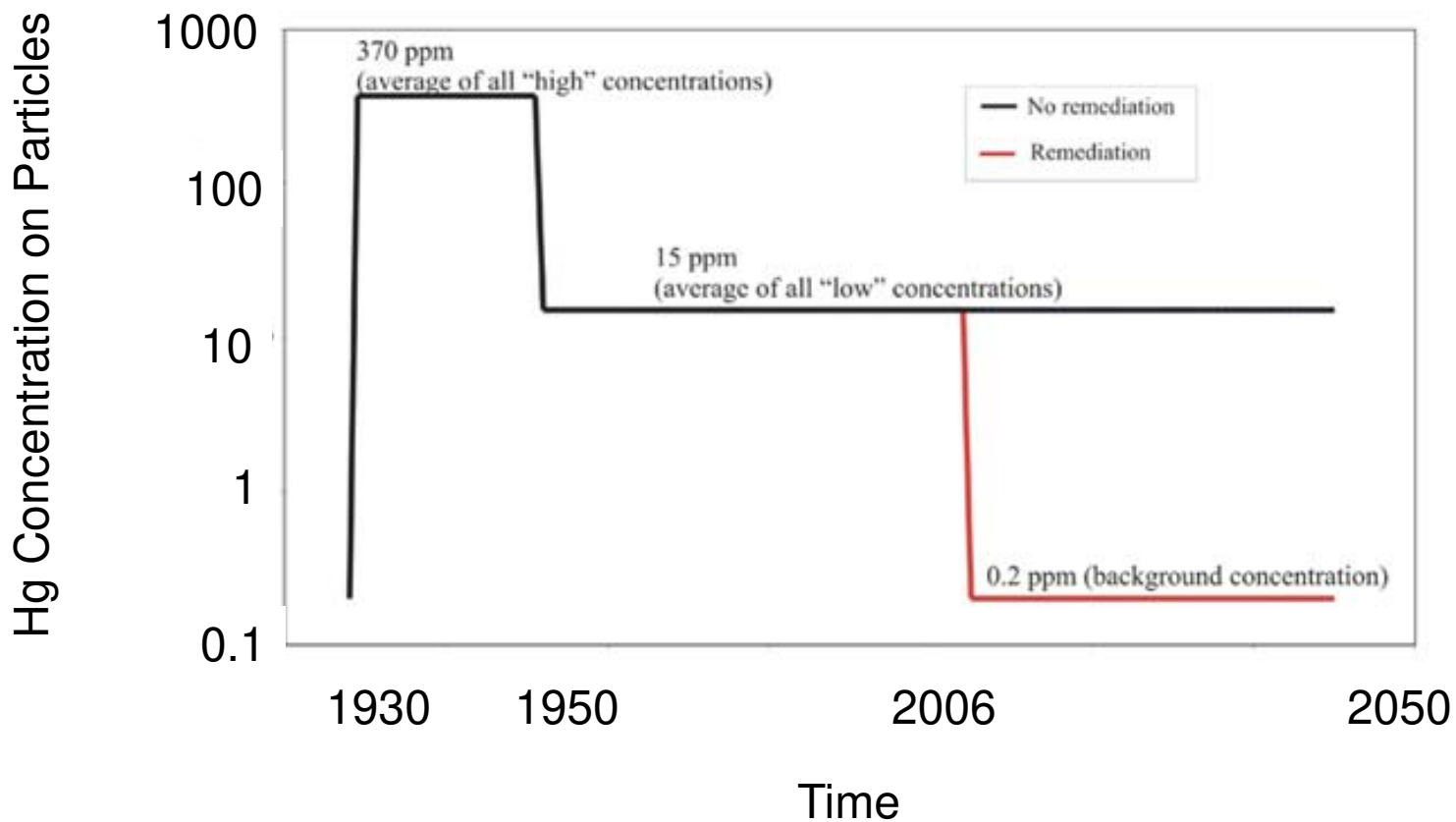
- Hg concentrations on particles during the release period (1930-1950):
 - ~100-900 ppm
 - Average ~ 370 ppm
- Hg concentration on particles AFTER the release period (1950-present):
 - ~15 ppm
- ~ 75% of the mass of Hg stored in these deposits dates from the release period (1930-1950)

Topics

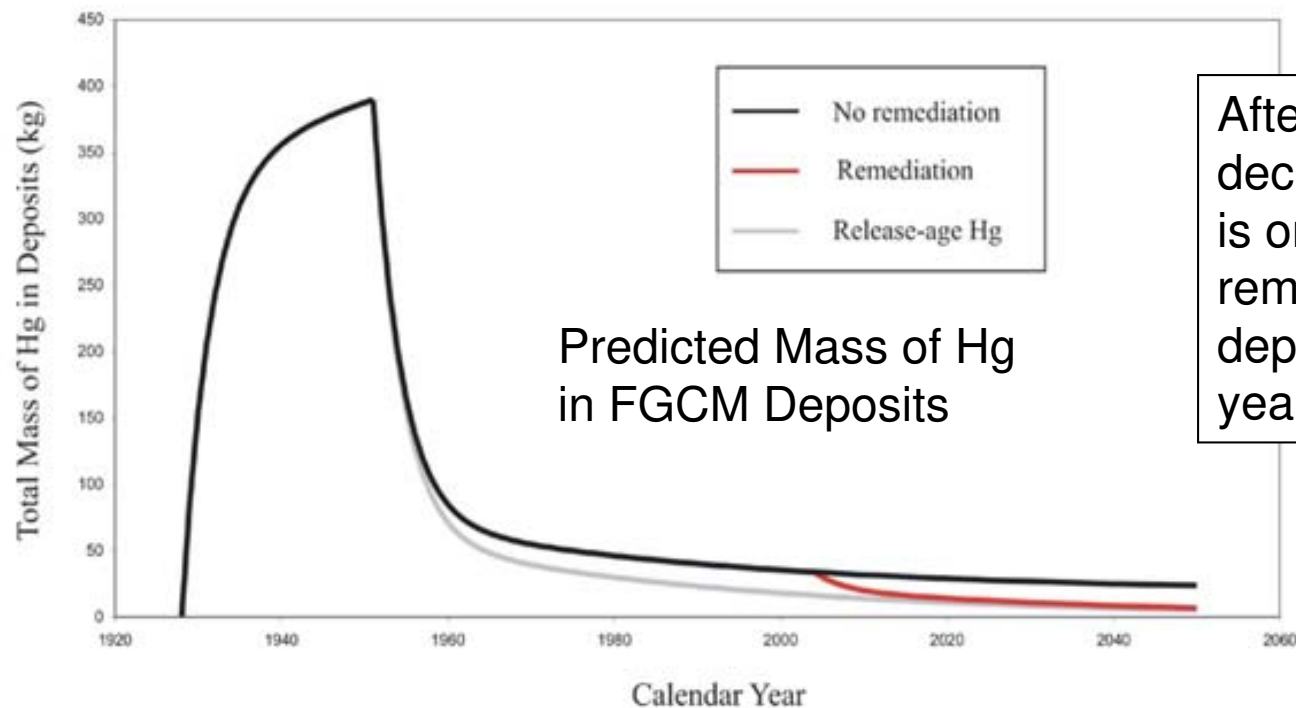
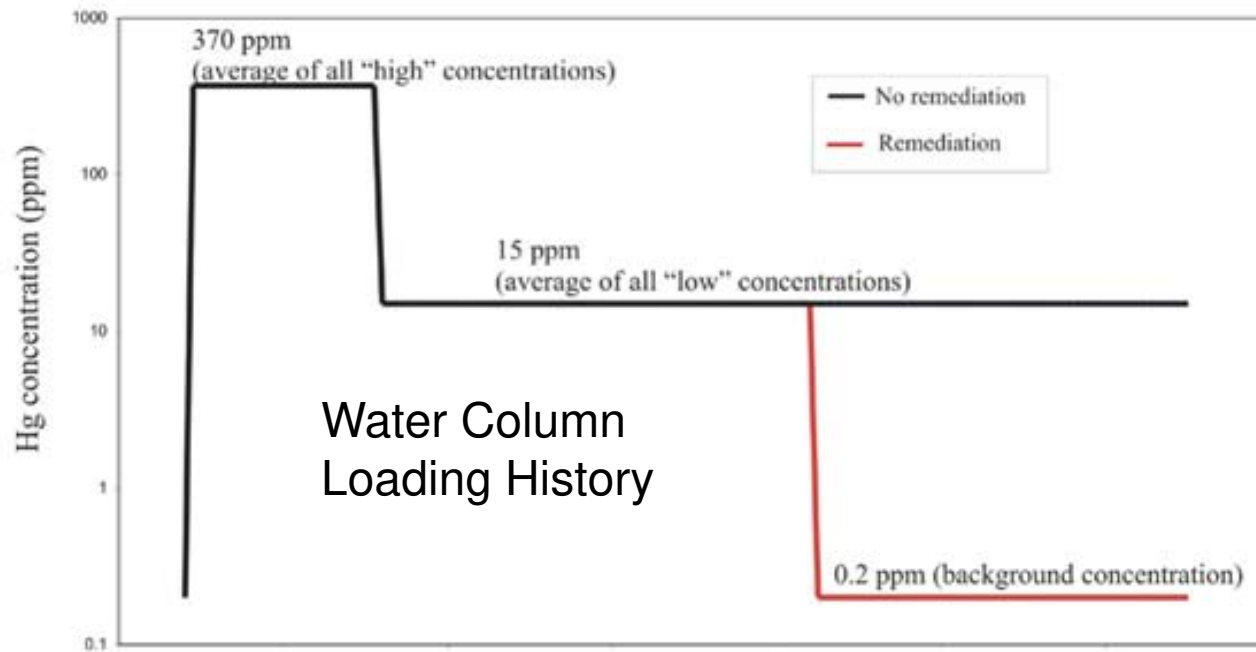
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- *Modeling Hg Storage in Fine-Grained Channel Margin Deposits, 1930-2050*
- Hg Concentrations in Eroding Banks
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Approach

- Specify concentration of Hg on particles in the water column through time;
- Make 2 assumptions:
 - *Mass of sediment in storage in FGCM deposits has remained constant through time*
 - (may not be true...)
 - *Distribution of ages remains constant through time though ongoing deposition and resuspension*
- Predict:
 - *Mass of Hg in the deposits through time*



Scenarios for Hg on Particles in the Water Column Through Time...



After 1950, mass of Hg decreases VERY slowly and is only weakly affected by remediation. Hg in these deposits will persist for ~ 100 years or more

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Motivation

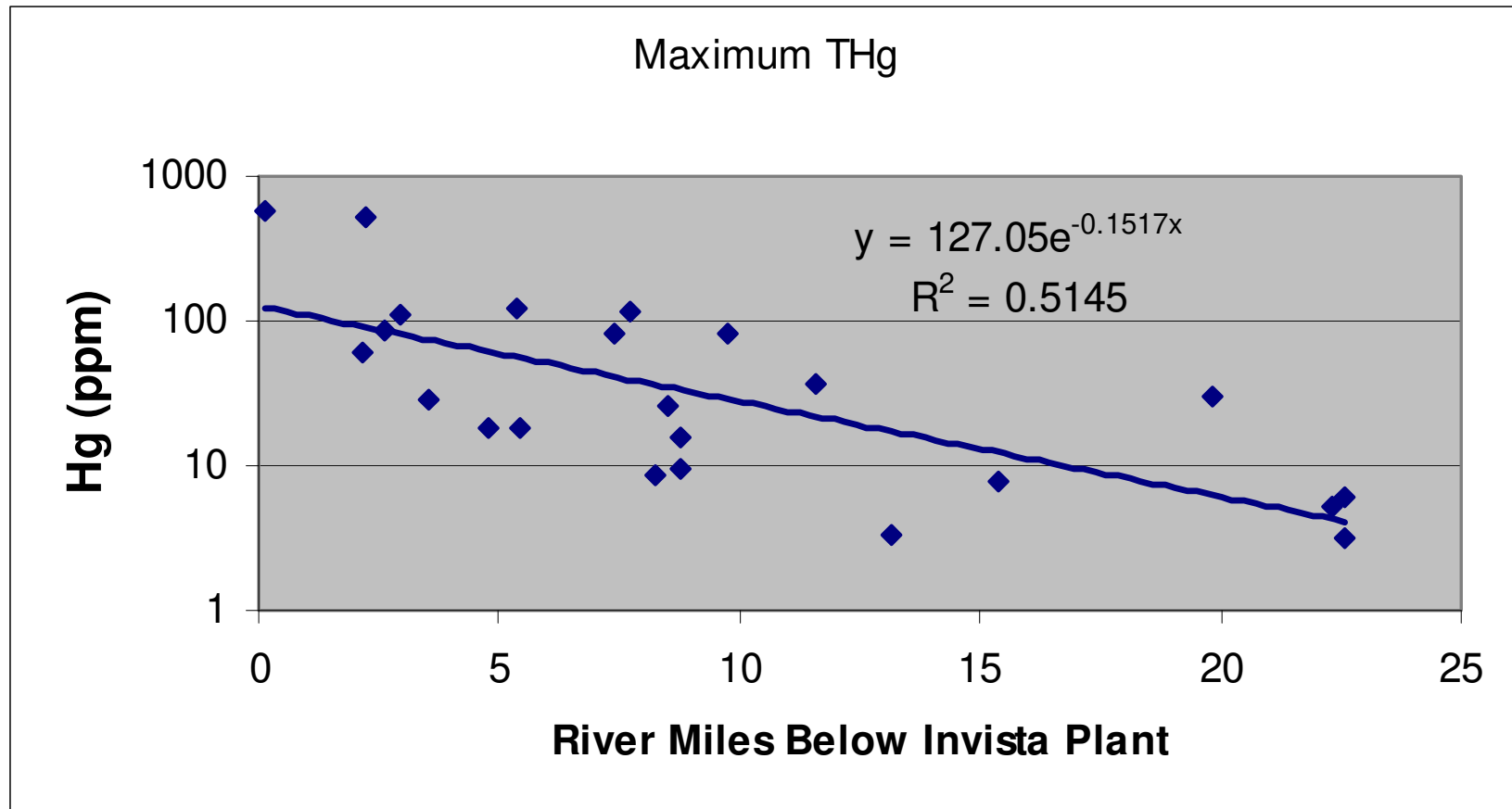
- Erosion of contaminated bank sediments represent an ongoing source of Hg to the river channel

Eroding Bank Data

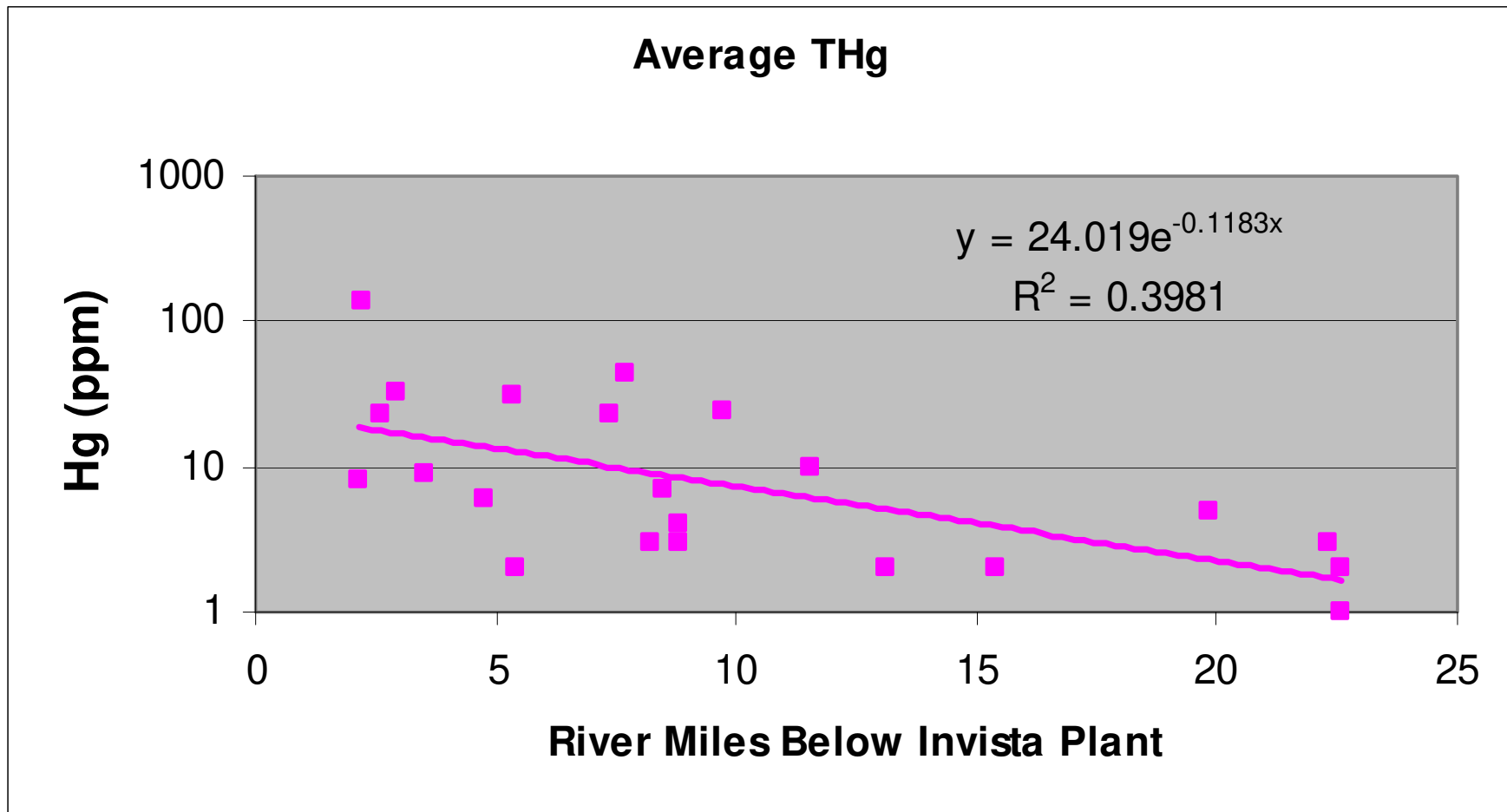
(Two sites from cut-off area not included here)

RRM	Max THg (ppm)	Average THg (ppm)
0.1	584	
2.18	61	8
2.2	515	140
2.6	87.7	23
2.96	110	32
3.54	28.5	9
4.75	18.4	6
5.36	120	31
5.4	17.8	2
7.4	83.4	23
7.7	117	43
8.25	8.42	3
8.5	25.9	7
8.78	9.41	4
8.8	15.7	3
9.75	80	24
11.58	37.4	10
13.13	3.4	2
15.4	7.8	2
19.84	30.4	5
22.3	5.12	3
22.58	3.23	2
22.61	6.06	1
23.1	12.6	4

Eroding Banks - Downstream Trends in Maximum THg

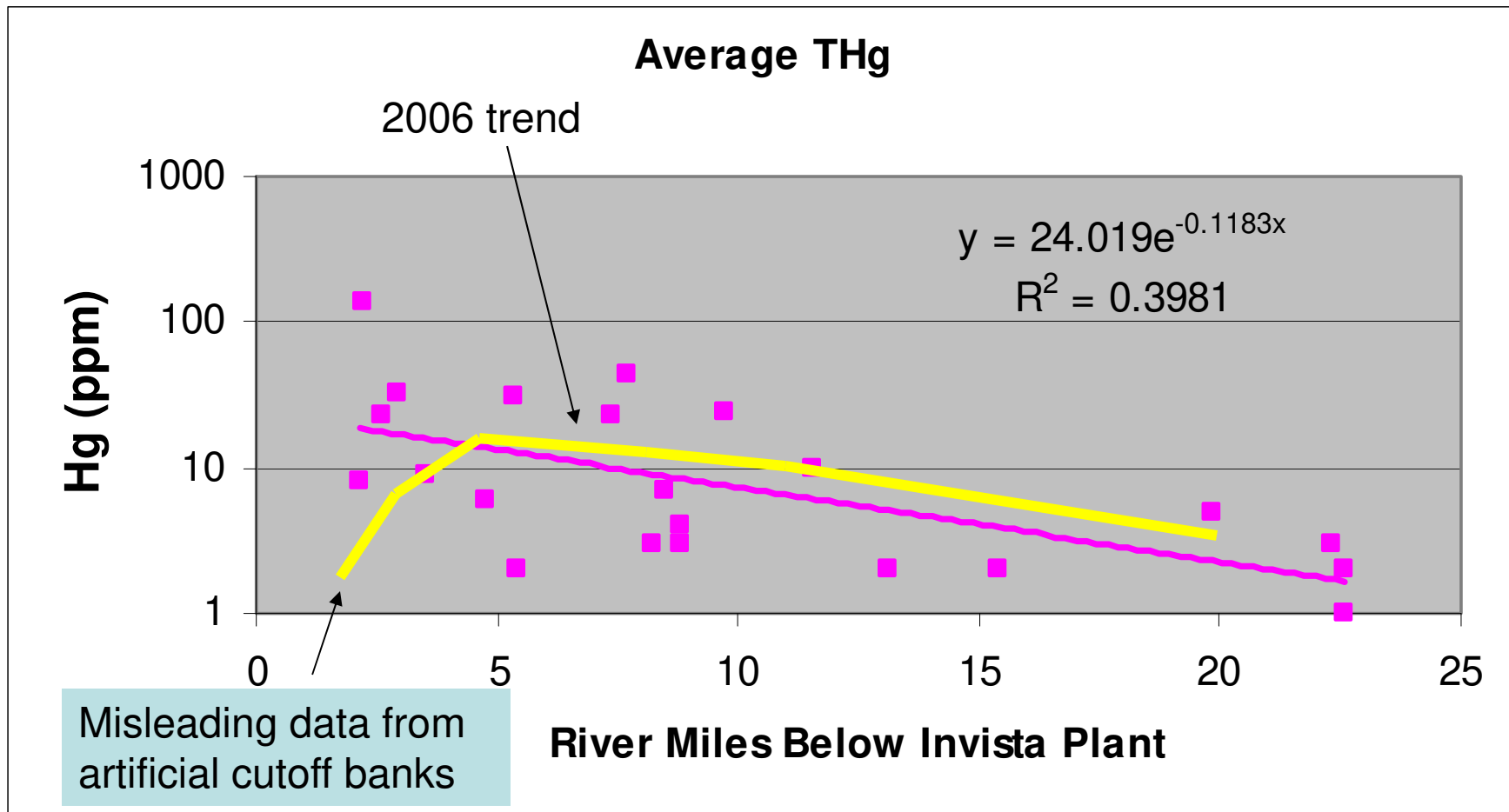


Eroding Banks - Downstream Trends in Vertically Averaged THg

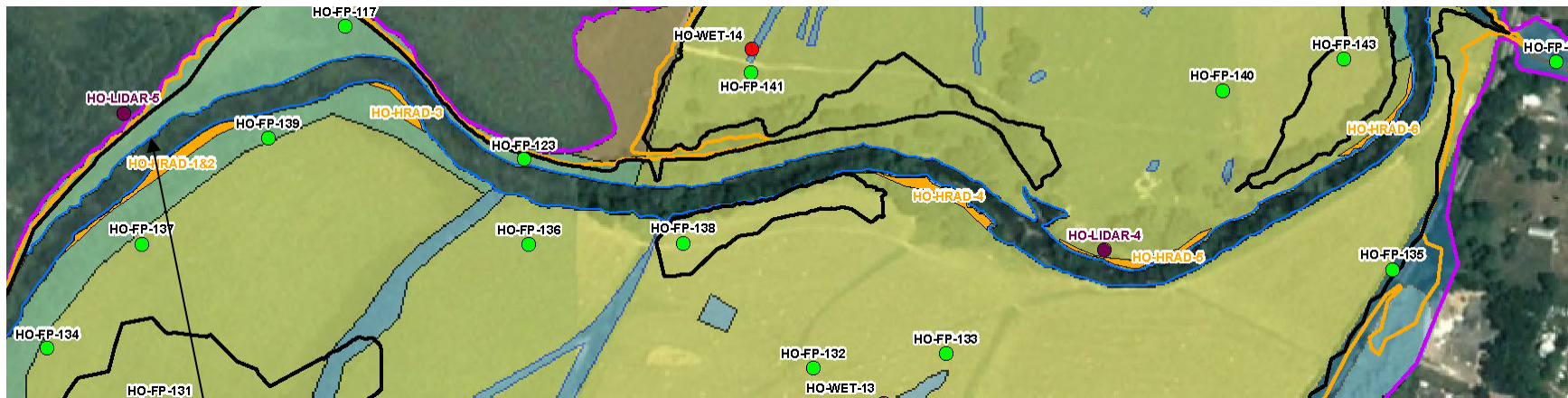


New Data vs 2006 Sampling

2006 data suggested a “hump” distribution due to misleading data from banks of the artificial cutoff RRM ~1.5-1.8

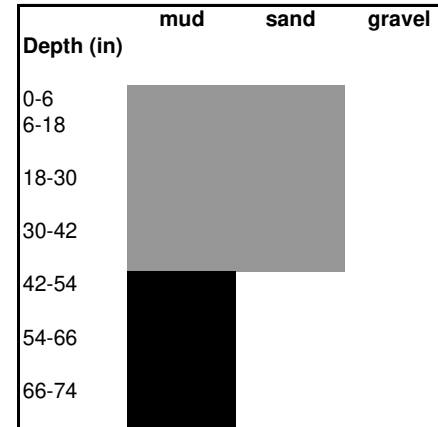
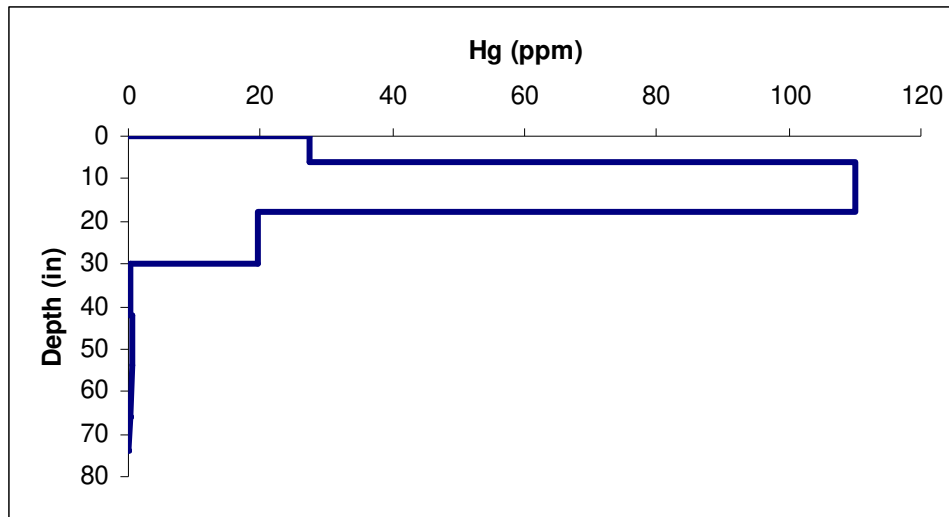


Some Examples



Lidar 5

LiDAR 5

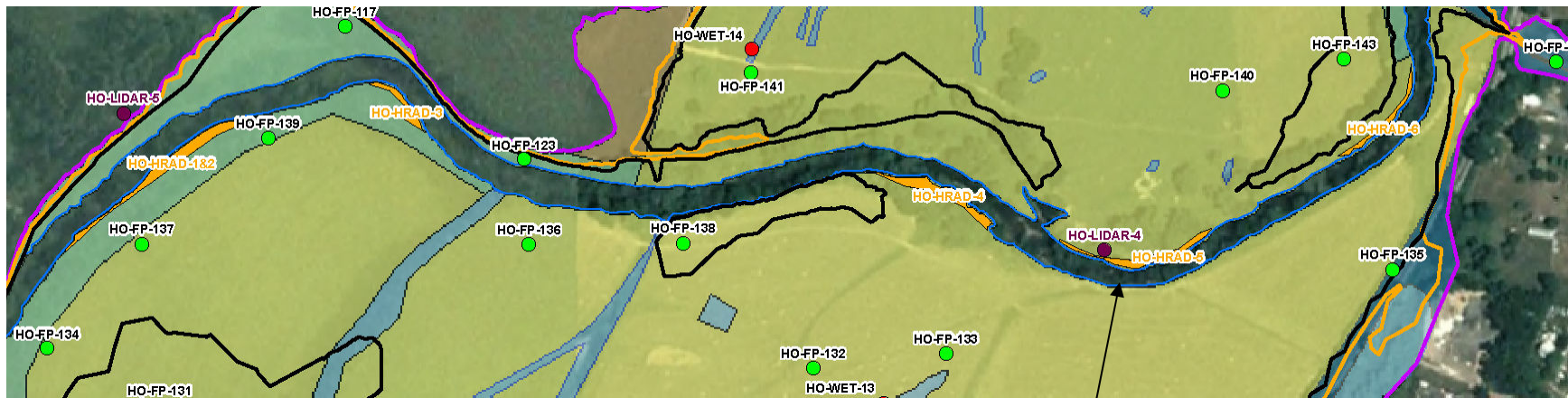


Depth (in)	Description	Hg (ppm)
0-6	Muddy medium sand, 20% mud	27.4
6-18	Muddy fine sand, 20% mud	110
18-30	Muddy fine sand, 10% mud	19.5
30-42	Muddy fine sand, 40% mud	0.445
42-54	Dark brown sandy mud, 40% sand	0.72
54-66	Dark brown sandy mud, 20% sand	0.195
66-74	Dark brown sandy mud, mottled, 20% sand	0.132

Vertically Averaged Hg concentration

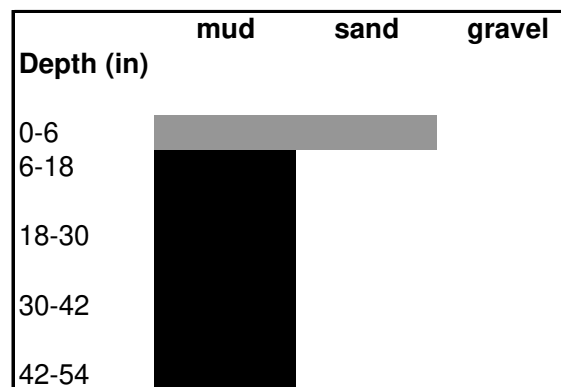
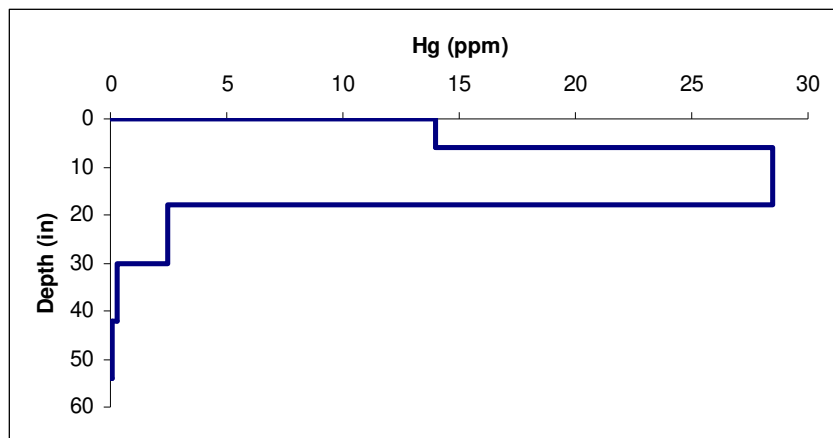
32

Some Examples



LiDAR 4

Lidar 4

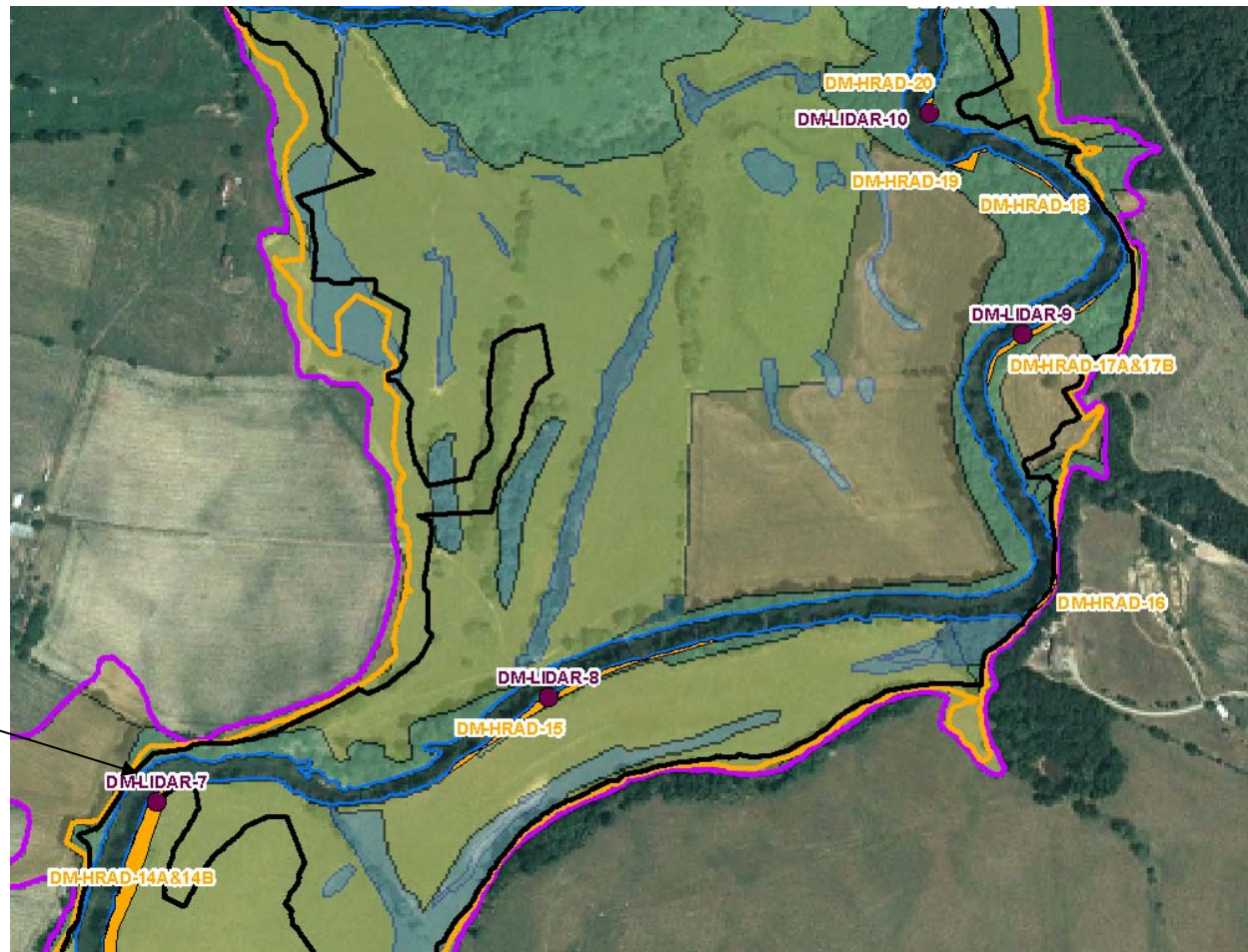


Depth (in)	Description	Hg (ppm)
0-6	Muddy fine sand, 30% mud	14
6-18	Same as below	28.5
18-30	Brown sandy mud, 20% sand	2.46
30-42	30"-37" yellowish brown sandy mud, 20% sand, 37"-42" same as below	0.269
42-54	Dense, intensely mottled orange gray sandy mud, 20% sand	0.0365

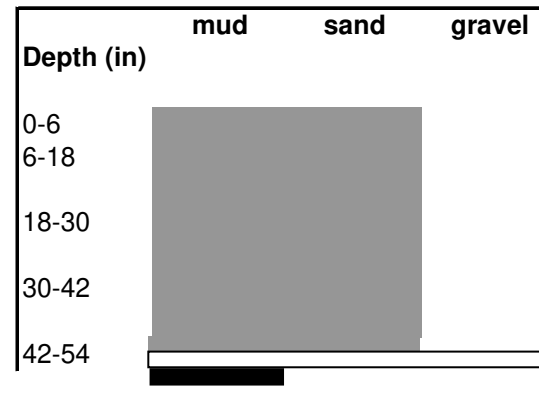
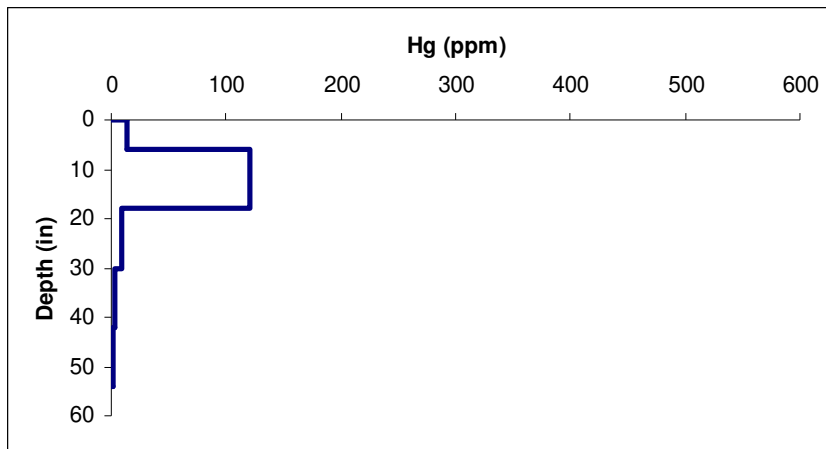
Vertically Averaged Hg concentration

HRAD 14A, B, LiDAR 7

LiDAR 7

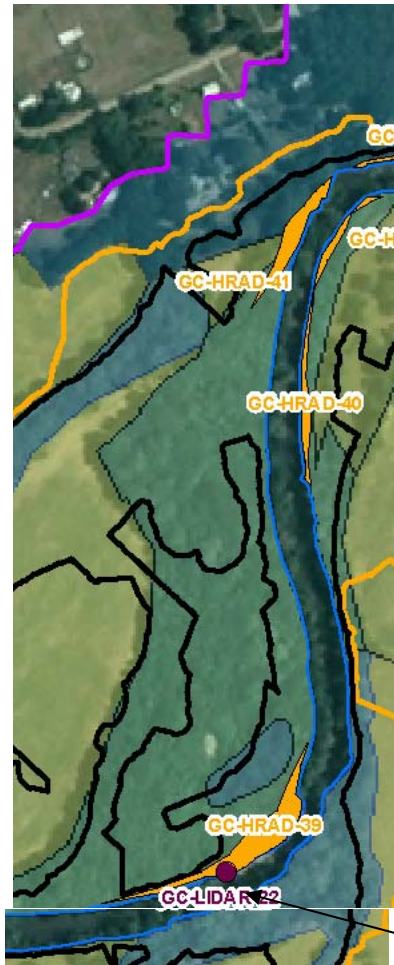


LiDAR 7



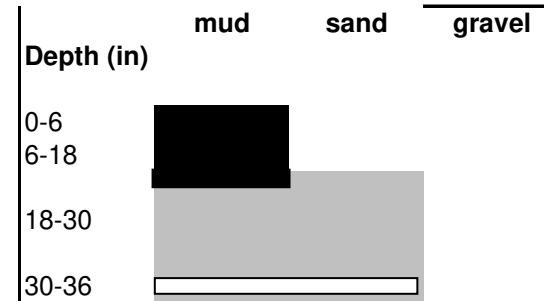
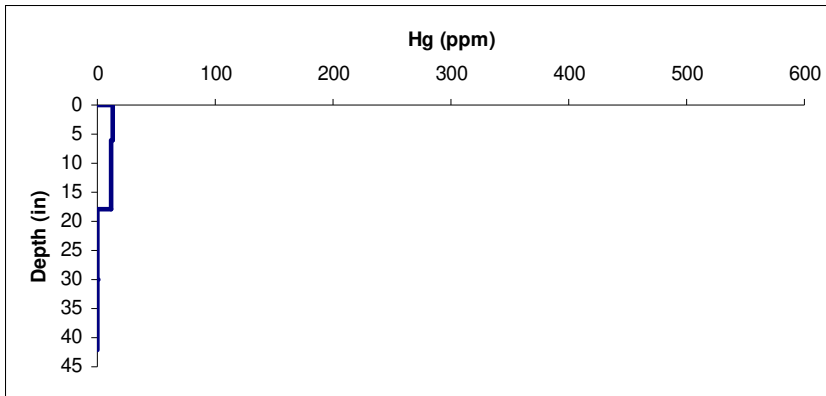
Depth (in)	Description	Hg (ppm)
0-6	muddy med. Sand (30% mud)	13.6
6-18	muddy med. Sand (30% mud)	120
18-30	muddy med. Sand (30% mud)	9.33
30-42	muddy med. Sand (10% mud)	3.69
42-54	muddy sand (40% mud) (42-47) sandy gravel (pebbles) 5% mud (47-50) sandy mud - 30% sand (54-50)	1.08
Vertically Averaged Hg concentration		31

LiDAR 22



LiDAR 22

LiDAR 22



Depth (in)	Description	Hg (ppm)
0-6	Same as below	12.6
6-18	6-14" sandy mud, 30% sand, soil structure 14-18" same as below	11.2
18-30	18-20" muddy coarse sand (20% mud), 20-25" coarse sand, trace mud, 25-30" same as below, but with a few muddy sand layers a few cm thick	0.244
30-36	stratified layers of gravel (pebbles), sand, and muddy sand 1 or 2 ~1/2" layer of sand with 20% mud	0.0934

Vertically Averaged Hg concentration

4

Summary of Eroding Bank Hg Concentrations

- Exponential decrease with distance downstream consistent with:
 - Hg deposition originating from the plant during the release period
 - Downstream dilution from “clean sediment” and other processes

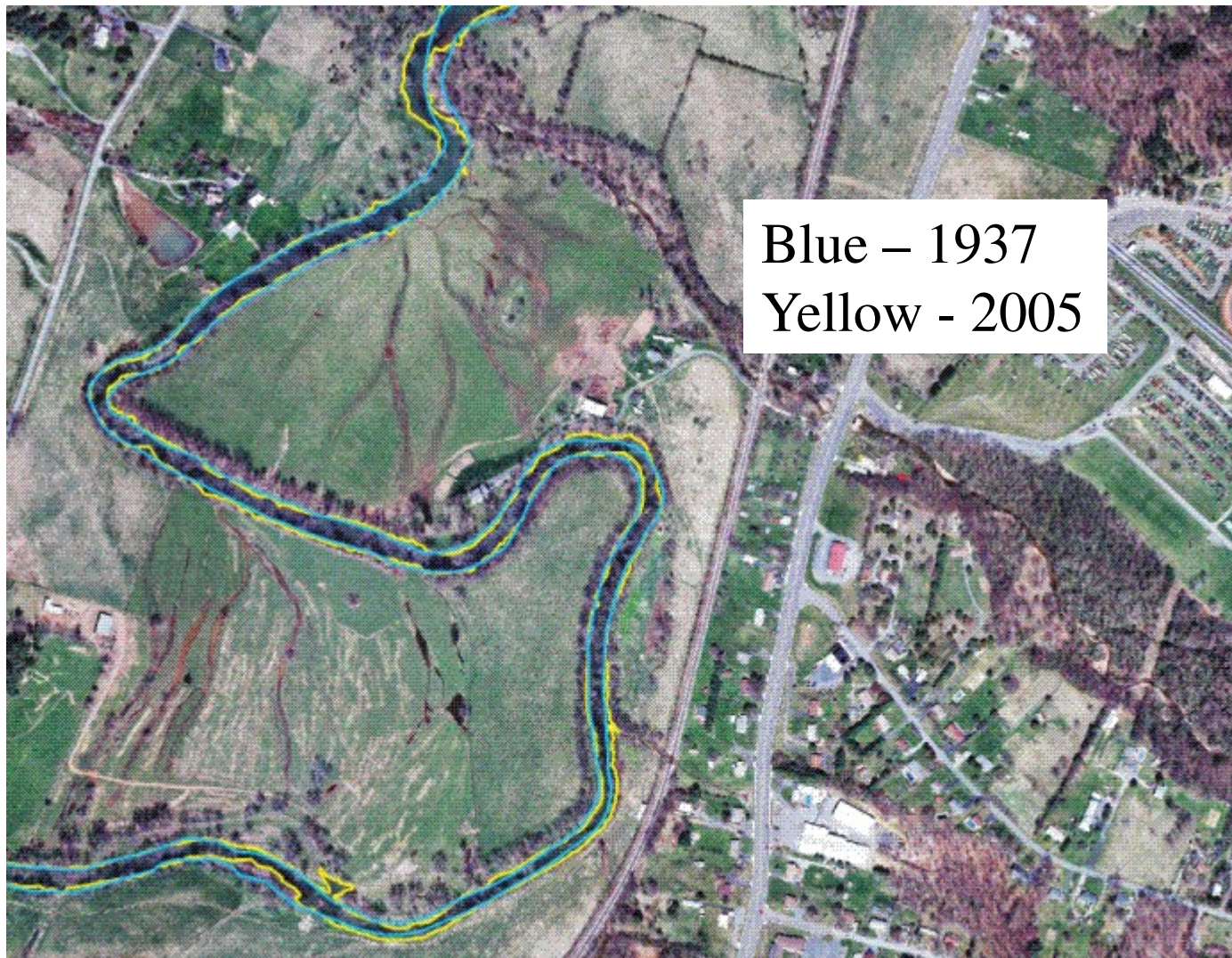
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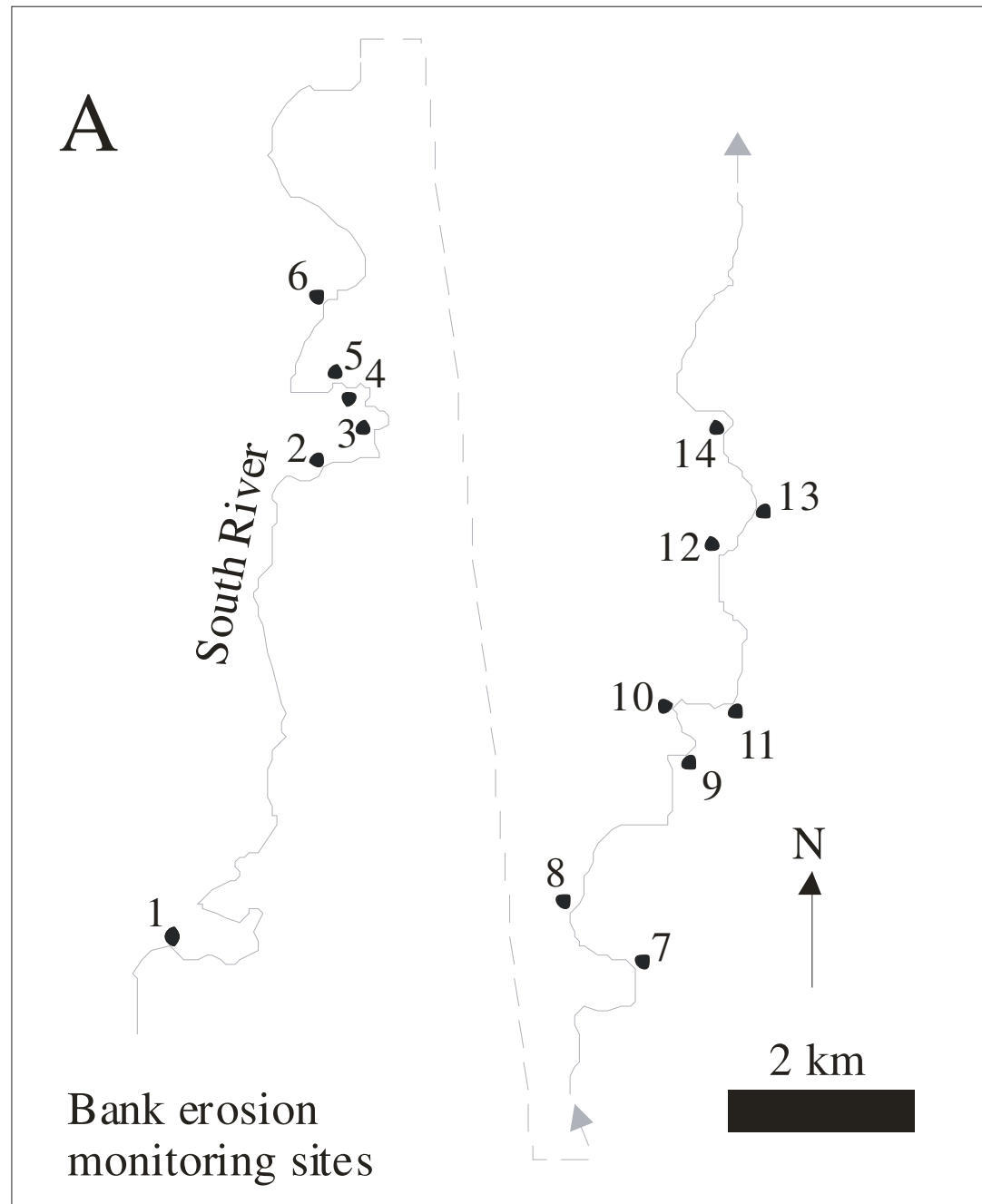
Bank Erosion Rate Measurements

- Aerial Photographs
 - 1937-2005
 - These cover the entire river
 - Rhoades et al., in press, Applied Geography
 - 1937-1957, 1957-1974, 1974-2005
 - 14 sites where *relatively* rapid erosion allows measurement of decadal changes in erosion rates
 - Pizzuto and O'Neal, in press, Geology
- Tripod mounted lidar
 - Annual and seasonal timescales

Rates of Bank Erosion Averaged From 1937-2005
Along South River are VERY LOW (a few cm/yr)



Decadal Erosion Rates at These 14 Sites

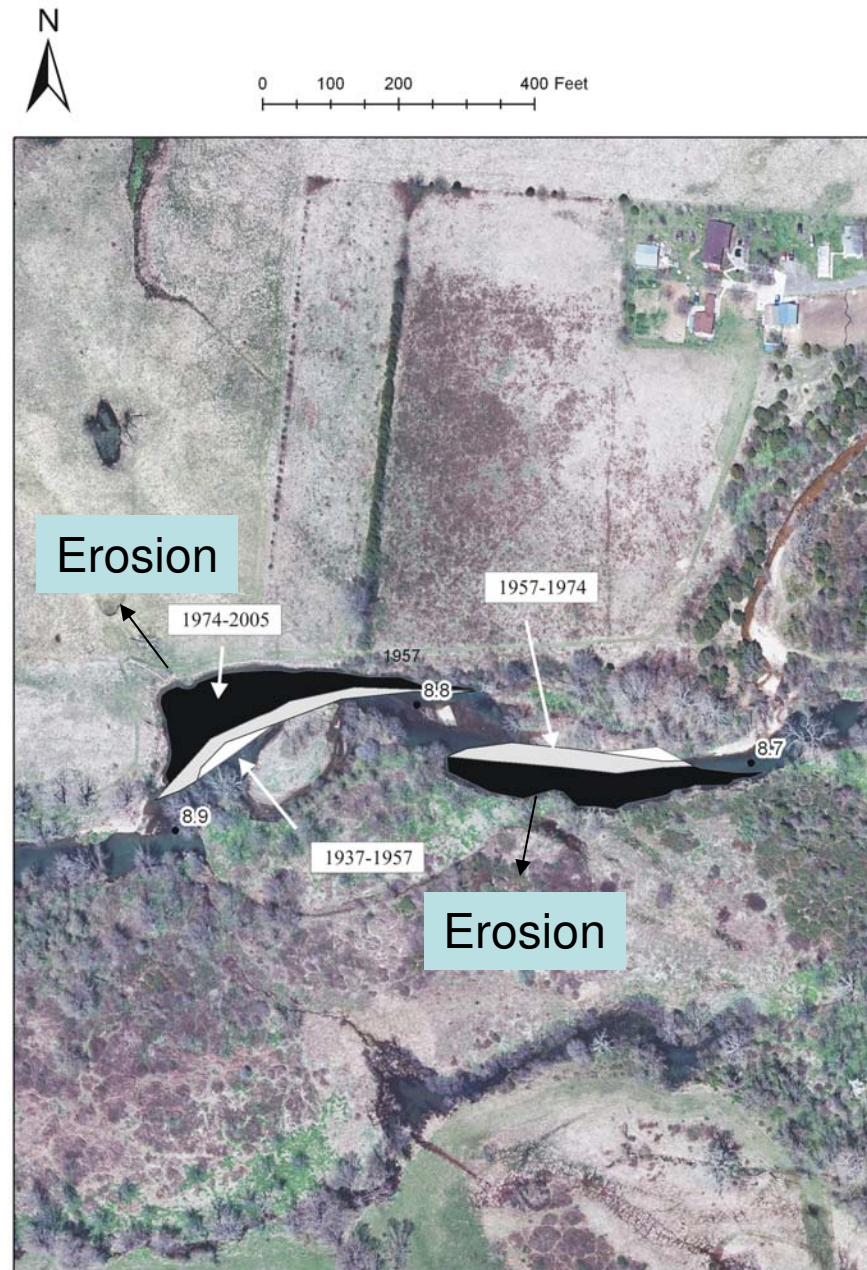


Polygons show
extent of lateral
migration of a
single bank
from:

1937-1957

1957-1974

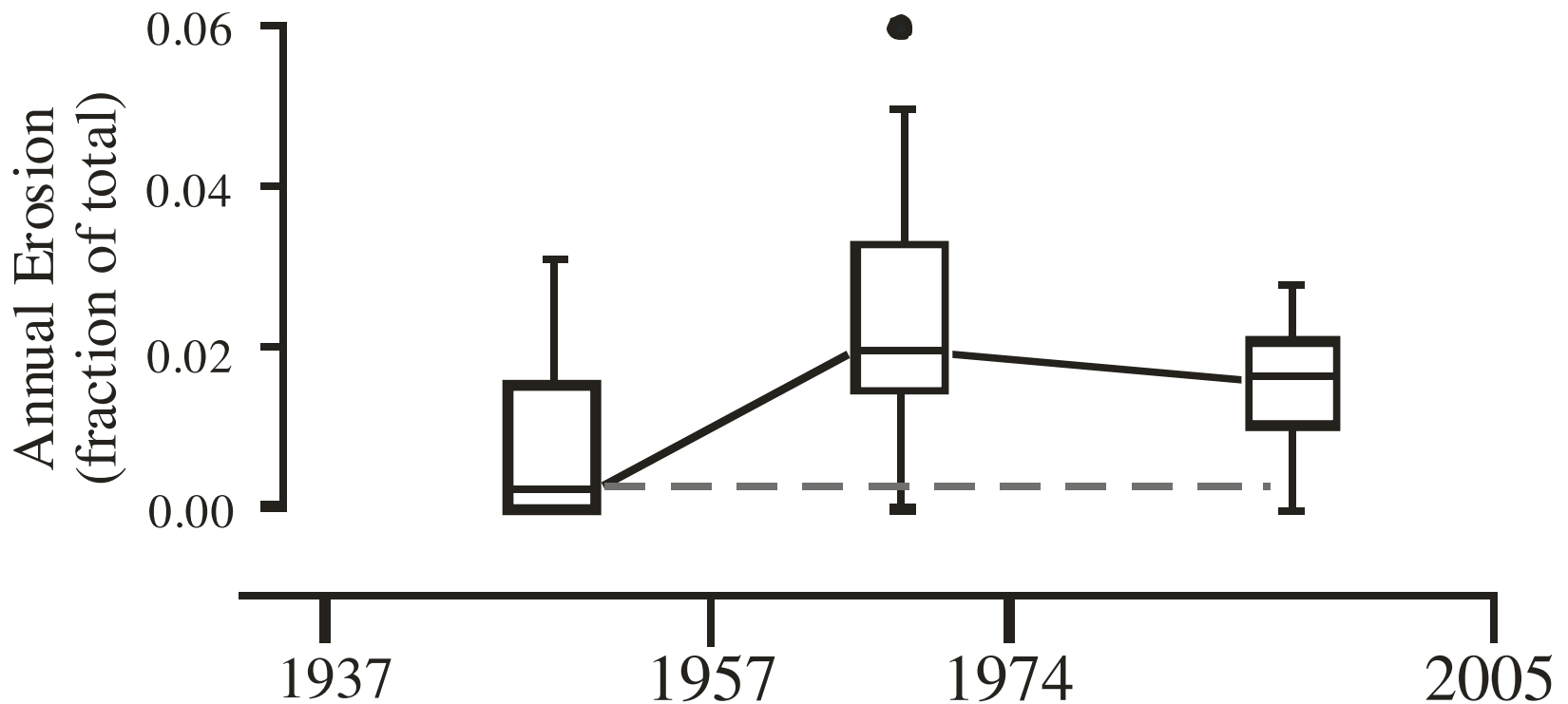
1974-2005



Normalize Results to Remove Spatial Variability *(so temporal variability can be assessed)*

- Normalize areal erosion rates at each site by:
 - Number of years between photos
 - Total area eroded at each site from 1937-2005
- Resulting values represent:
 - Fraction of total erosion at a given site per year

Bank Erosion Rates Increased by ~3x after 1957!



Possible Explanations – Changes in.....

- Frequency of high discharges
- Riparian vegetation
- Climate (freeze-thaw)
- Sediment supply
- Mill dams

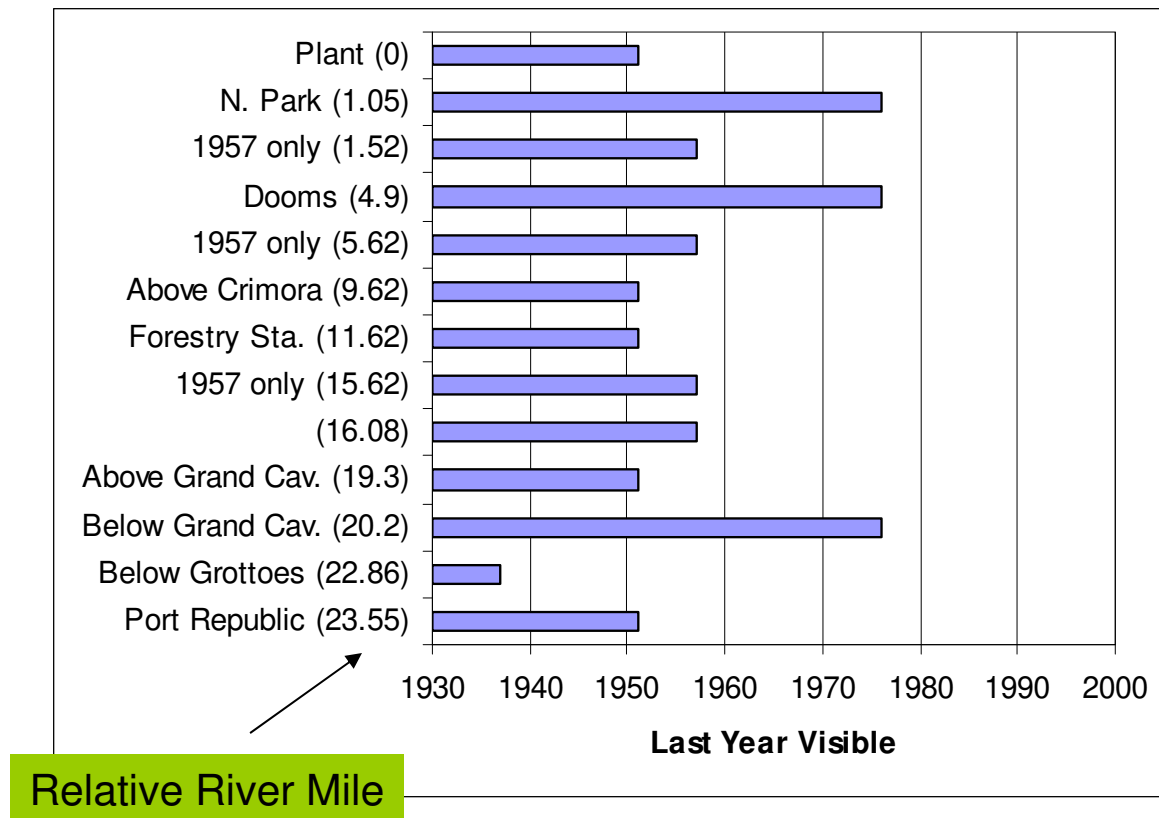
Trends in the first 4 are inconsistent with observations, leaving the MILL DAM hypothesis as the best explanation of the acceleration in bank erosion rates!!

Former Colonial Mill Dams

- Located using...
 - Historical documents
 - Aerial photographs
 - Field observations
 - Often not very useful....

Historic Mill Dams and Impoundments

In 1937 ~ 1 Impoundment every 2 mi



All mill dams are gone or breached today!
Most gone.....after 1957, when bank erosion rates increased!



Geological
Sciences

South River: a series of mill ponds ~1900

“E. Folger Taylor, long-time DuPont water control specialist, often characterized the South River in the early part of the Century as a series of mill ponds. Dams from Sherando to Port Republic were strategically located, often at 2 to 3 mile intervals”.

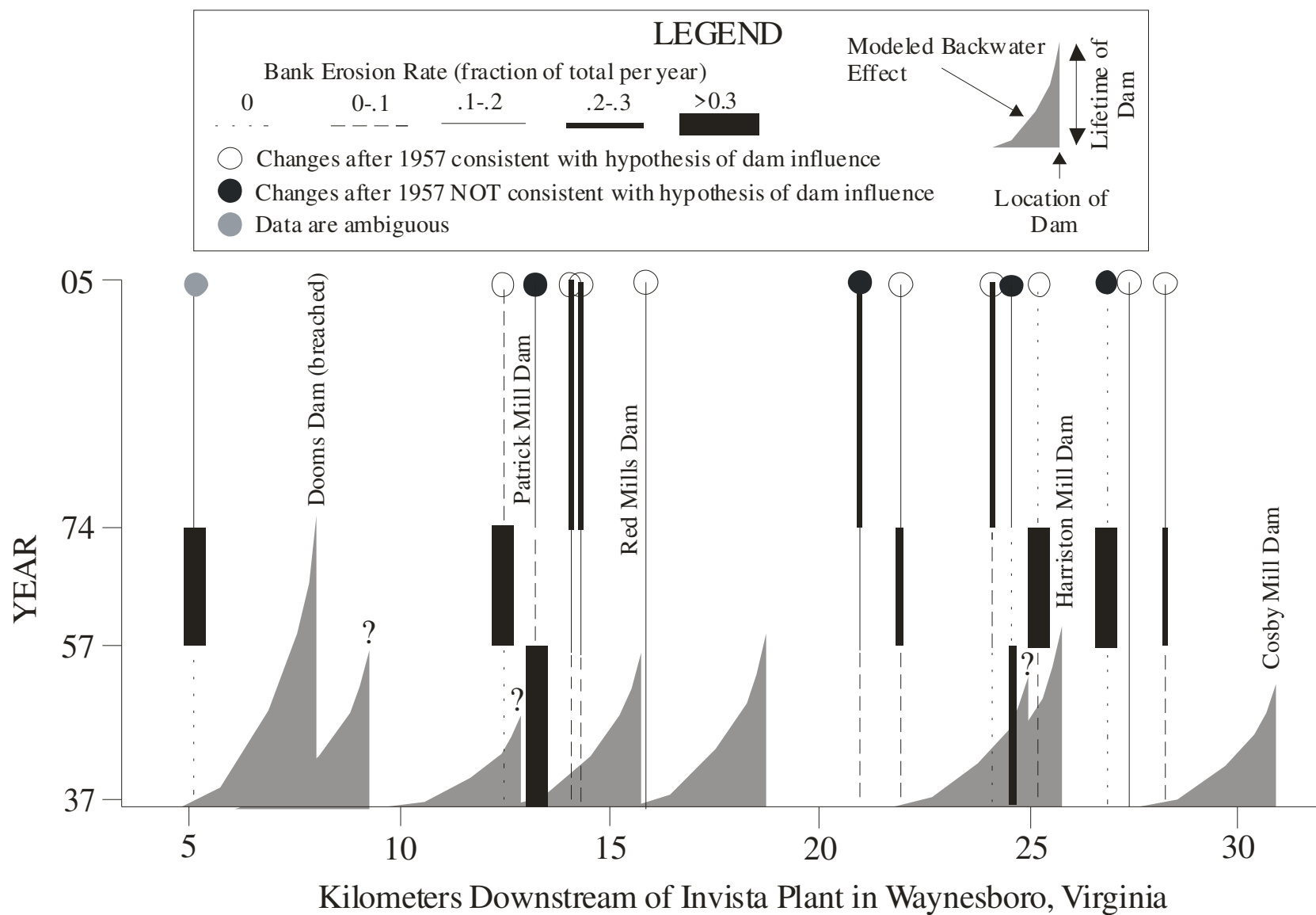
Downs et al., 2006, Mills of Augusta County

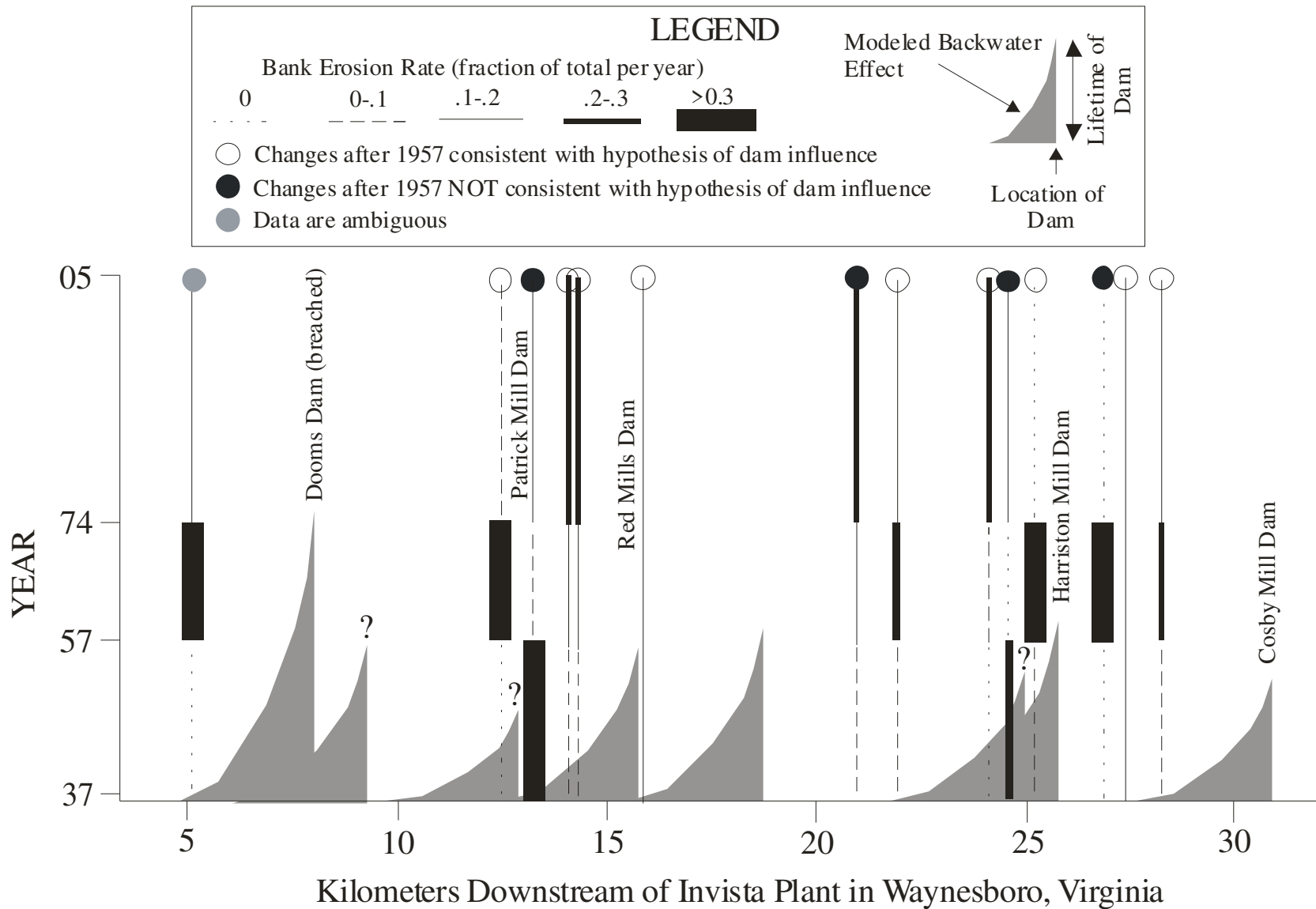
Hypothetical Mechanisms Relating the Loss of Mill Dams to Bank Erosion....

- After mill dams are breached:
 - Velocity increases upstream
 - Potential lowering of the bed
- Both could result in increased bank erosion

Backwater Computations To Assess Extent of Reach Effected By Mill Dams

- Based on 5-year return period discharge
- Computed with and without sediment fill behind dam





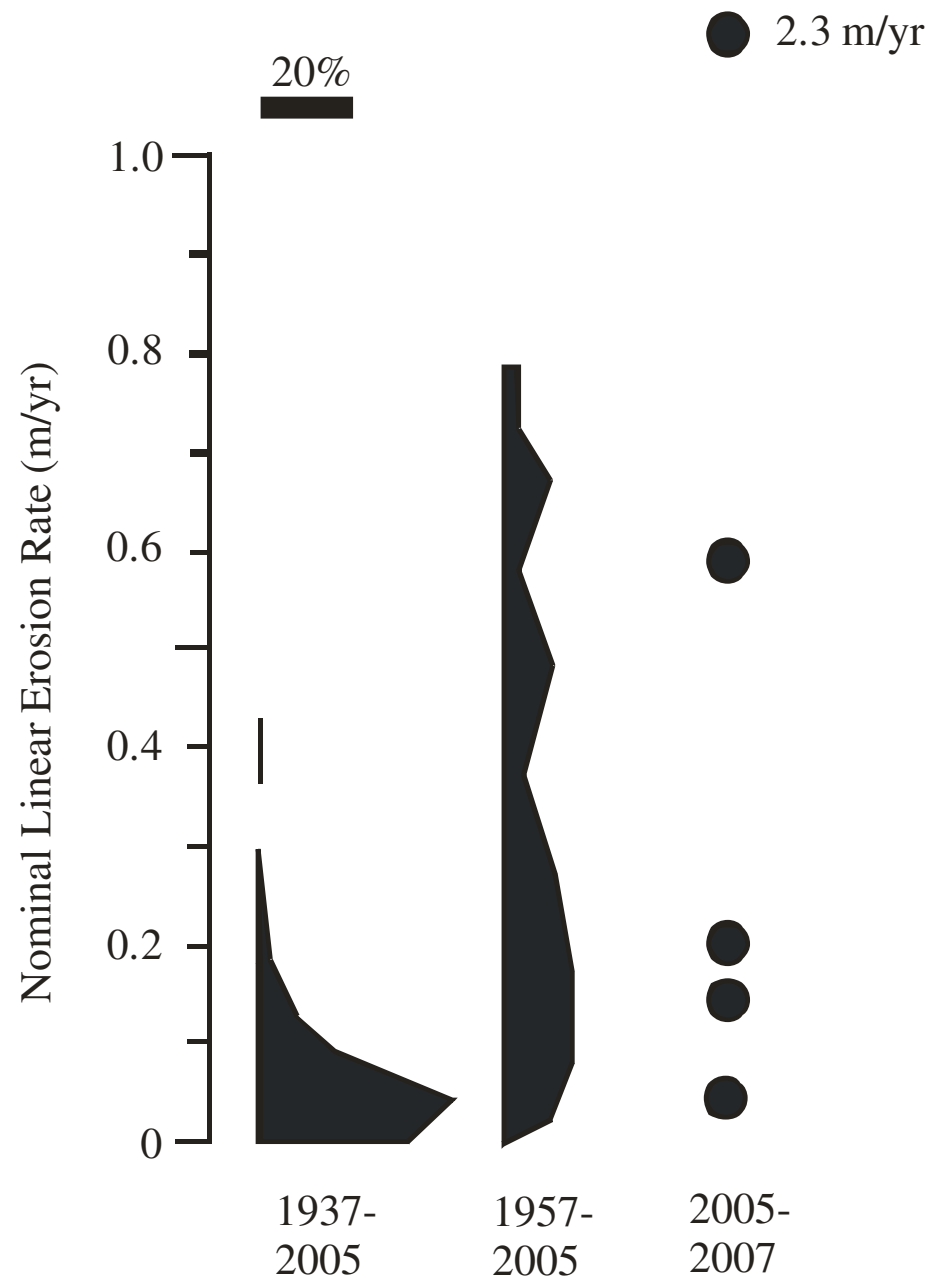
Loss of mill dams “explains” observed erosion rates at 9-10 of 14 sites!

Conclusions

- Bank erosion rates increased after 1957 along the South River by $\sim 3x$
- The observed increase cannot be explained by....the usual geomorphic suspects (storms, sediment supply, riparian vegetation)
- The loss of mill dams is the best explanation....

Contemporary Annual Erosion Rates??

Contemporary annual erosion rates are similar to those from 1957-2005



Some Implications

- Rates of contemporary bank erosion are higher (3x?) than originally documented by 1937-2005 aerial photo analysis
- Hg concentrations in eroding banks follow an exponential distribution downstream
 - Not a “humped” distribution
- ***Hg loading estimates from bank erosion must be revised upwards!!***

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Why a Sediment Budget?

- Better understand pathways of Hg transport, deposition, and storage associated with fine-grained sediment

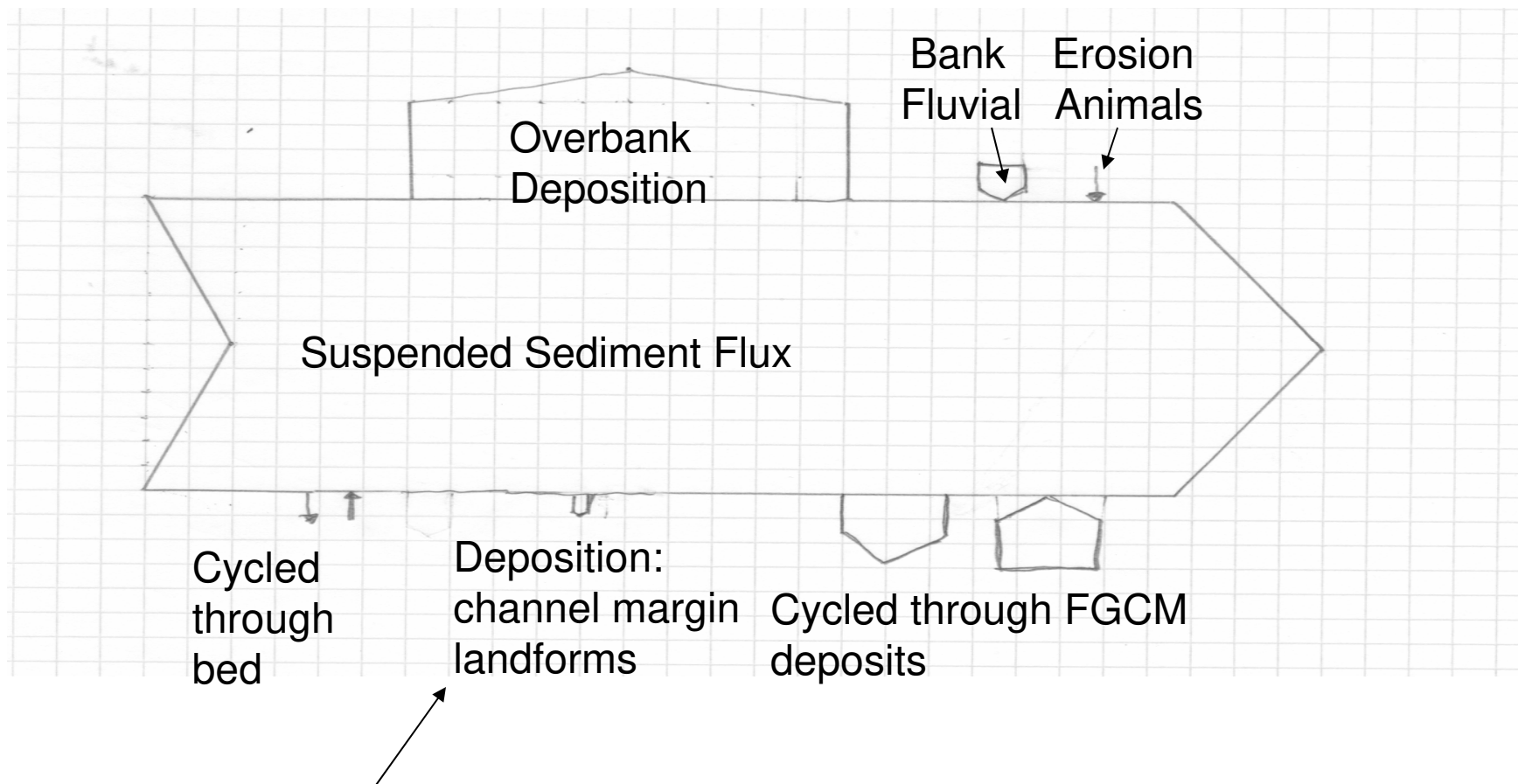
Time and Spatial Scale

- RRM 2.5 to 5.43
 - Just below Hopeman Parkway to just below the bridge at Holsinger Farms downstream of Dooms
 - Why here: best data available for the floodplain
- 1937-2005
 - Comprehensive aerial photo analysis of channel migration

Units

- Compute the TOTAL mass of sediment transported, deposited, or eroded by different processes
 - 1937-2005
 - RRM 2.5-5.43

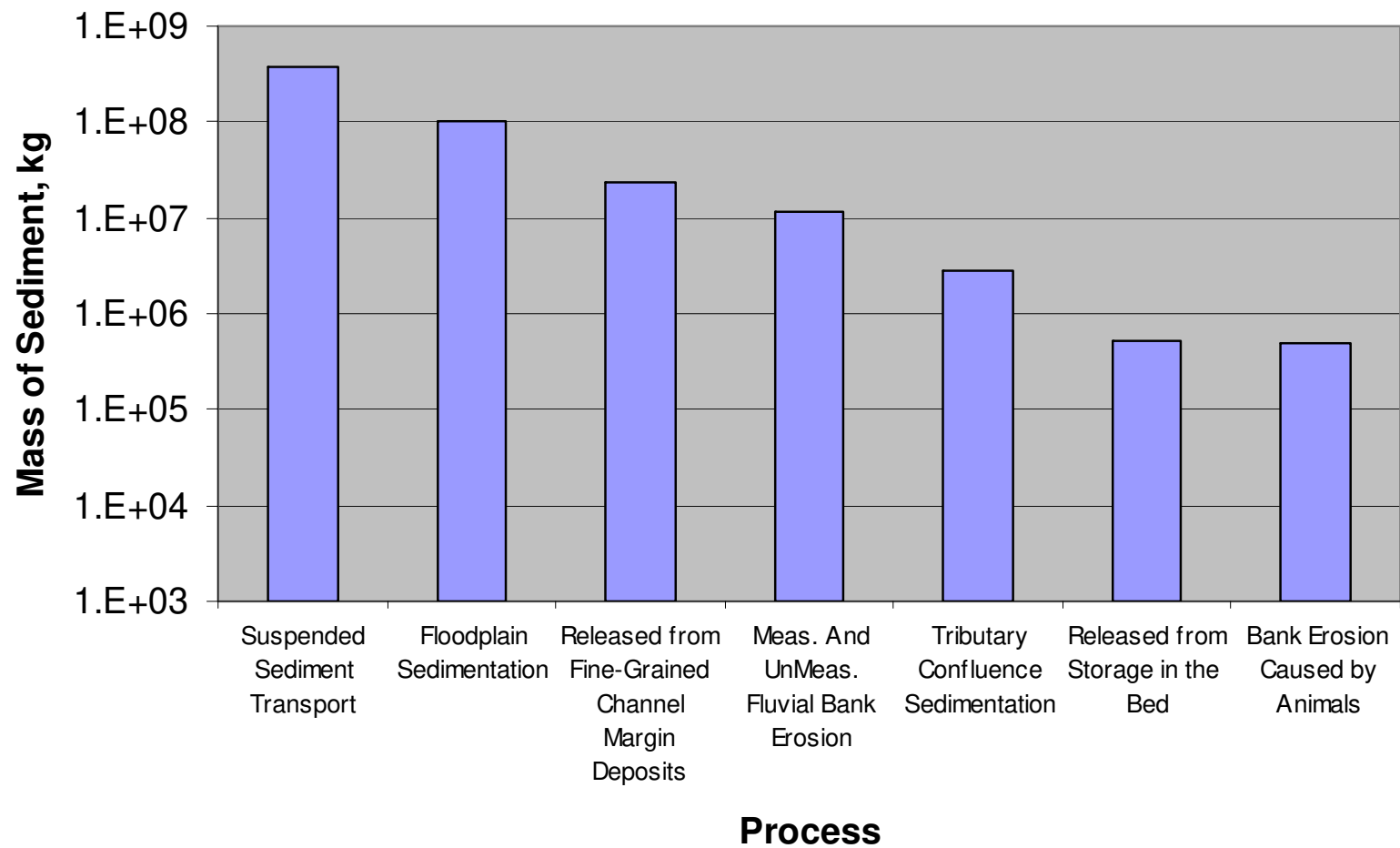
Discussion – Relative Magnitude of Sediment Transport Processes – Graphical Representation??



Point bars and “benches” adjacent to the channel

Summary of Sedimentation Processes

Relative Magnitude of Sedimentation Processes, South River, VA, 1930-2005 (RRM 2.5-5.43)



The Numbers....

Process	Mass of Sediment (kg)
Suspended Sediment Transport	3.75E+08
Floodplain Sedimentation	1.01E+08
Released from Fine-Grained Channel Margin Deposits	2.40E+07
Meas. And UnMeas. Fluvial Bank Erosion	1.15E+07
Tributary Confluence Sedimentation	2.80E+06
Released from Storage in the Bed	5.30E+05
Bank Erosion Caused by Animals	5.00E+05

New Results for Floodplain Sedimentation – Where do they Come From?

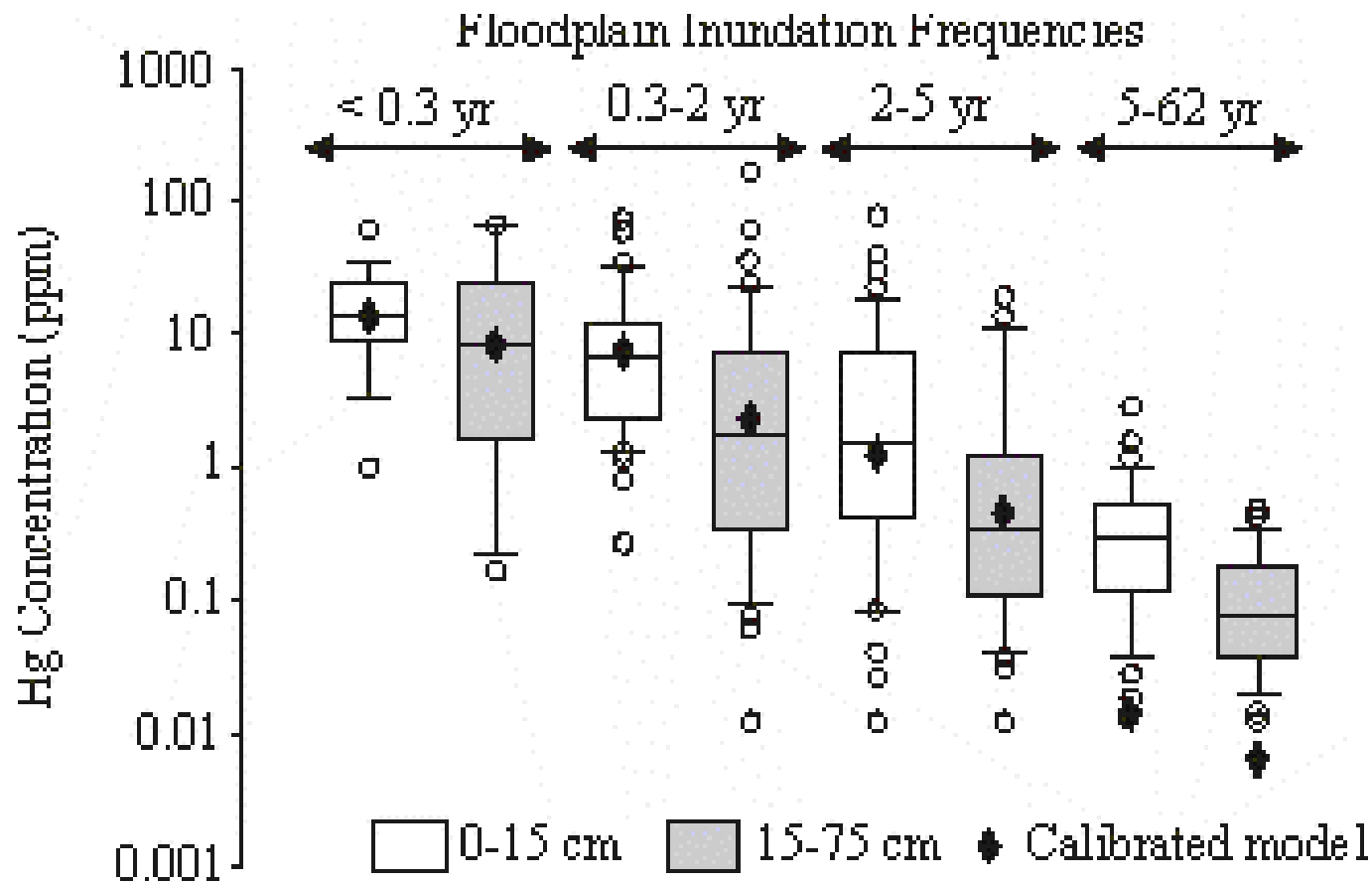
- Hg analyses from floodplain sampling for Hg
- Hypothesize that the distribution of Hg explained by:
 - Frequency of flooding 1930-present on different parts of the floodplain
 - Hg concentration on particles during release and post-release periods
 - Vertical mixing of Hg downward into soil after deposition
- Use Hg analyses to calibrate a simple model of overbank deposition and soil mixing through time

Parameters Determined Through Model Calibration

- Thickness deposited per flood: *0.05 cm*
- Thickness of mixing depth: *39 cm*
- Contemporary Hg concentration on particles during over bank flows: *14 ppm*
- Hg concentration during release period: *180 ppm*

Implications: ~82% of the Hg on the
Floodplain Dates from the Release Period

Calibrated Model Computations of Hg Concentrations in Overbank Deposits – Comparison with Data



Thickness of Sediment Deposited in 75 Years On Different Floodplain Surfaces

Inundation Frequency (yr)	# of Floods	Thickness Deposited (cm)	Thickness Deposited (ft)	Hg (ppm) Surf./Subsurf.
≤ 0.3	250	12.5	0.41	14/8
0.3-2	143	7.2	0.24	8.9/4.3
2-5	26	1.3	0.043	1.5/0.61
5-62	1	0.05	0.002	0.018/0.007

Though important for budgets of sediment and mercury, these deposits are too thin to modify the form of the floodplain !!

Implications of The New Sediment Budget

- Important components of the new sediment budget:
 - Floodplain sedimentation
 - The new estimate is too high....
 - Bank erosion
 - Cycling through fine-grained channel margin deposits
- Less important components:
 - Storage on point bars and benches
 - Animals
 - Cycling through channel gravels ??

A related Hg budget is in progress

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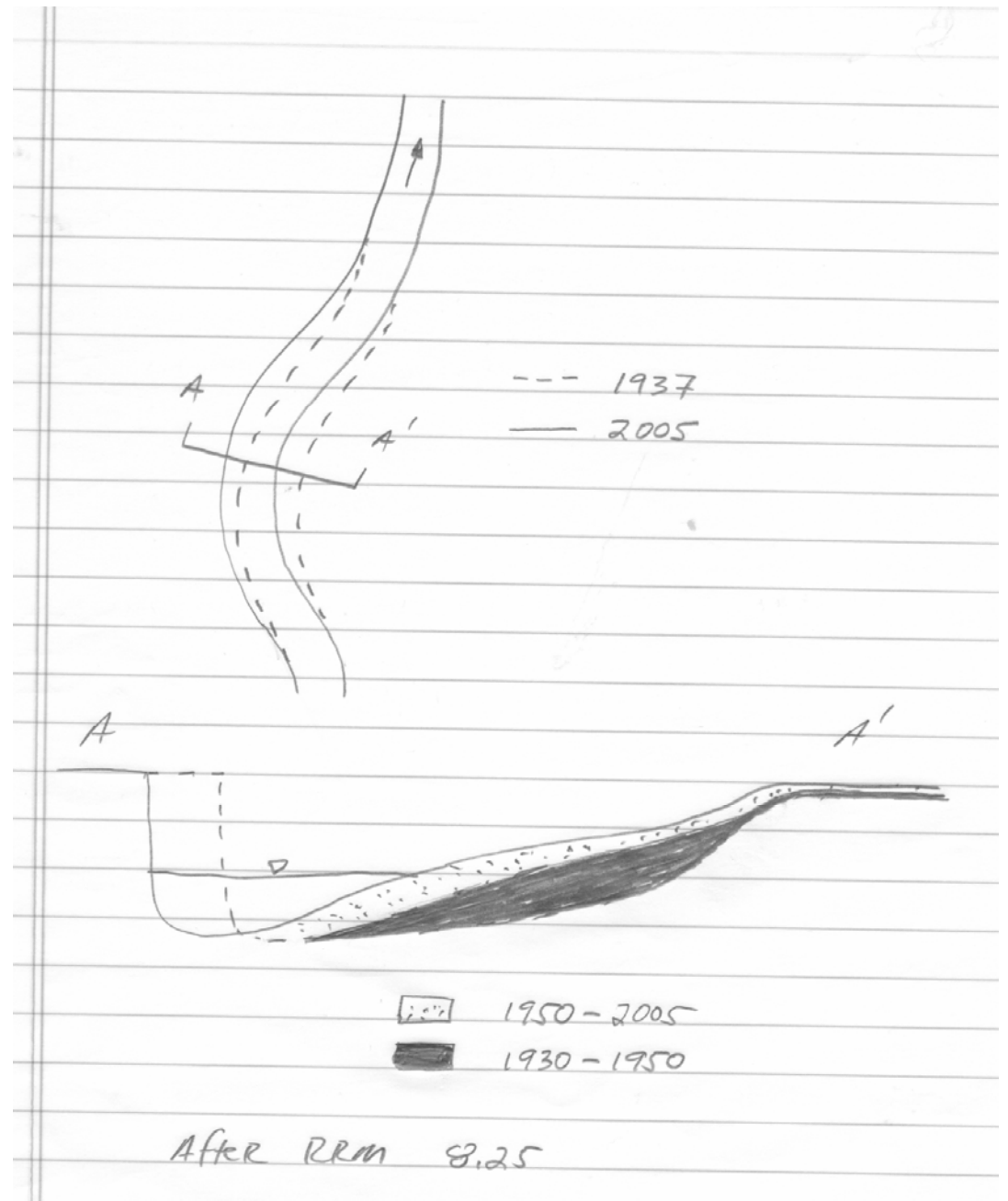
Channel Margin Floodplain Deposits

- Deposits initially identified by shoreline mapping from aerial photographs
 - 1937-2005
- Hypothesis:
 - Deposits dating from the period of mercury release could have very high Hg concentrations
- Denoted as HRADs:
 - Hg Release Age Deposits

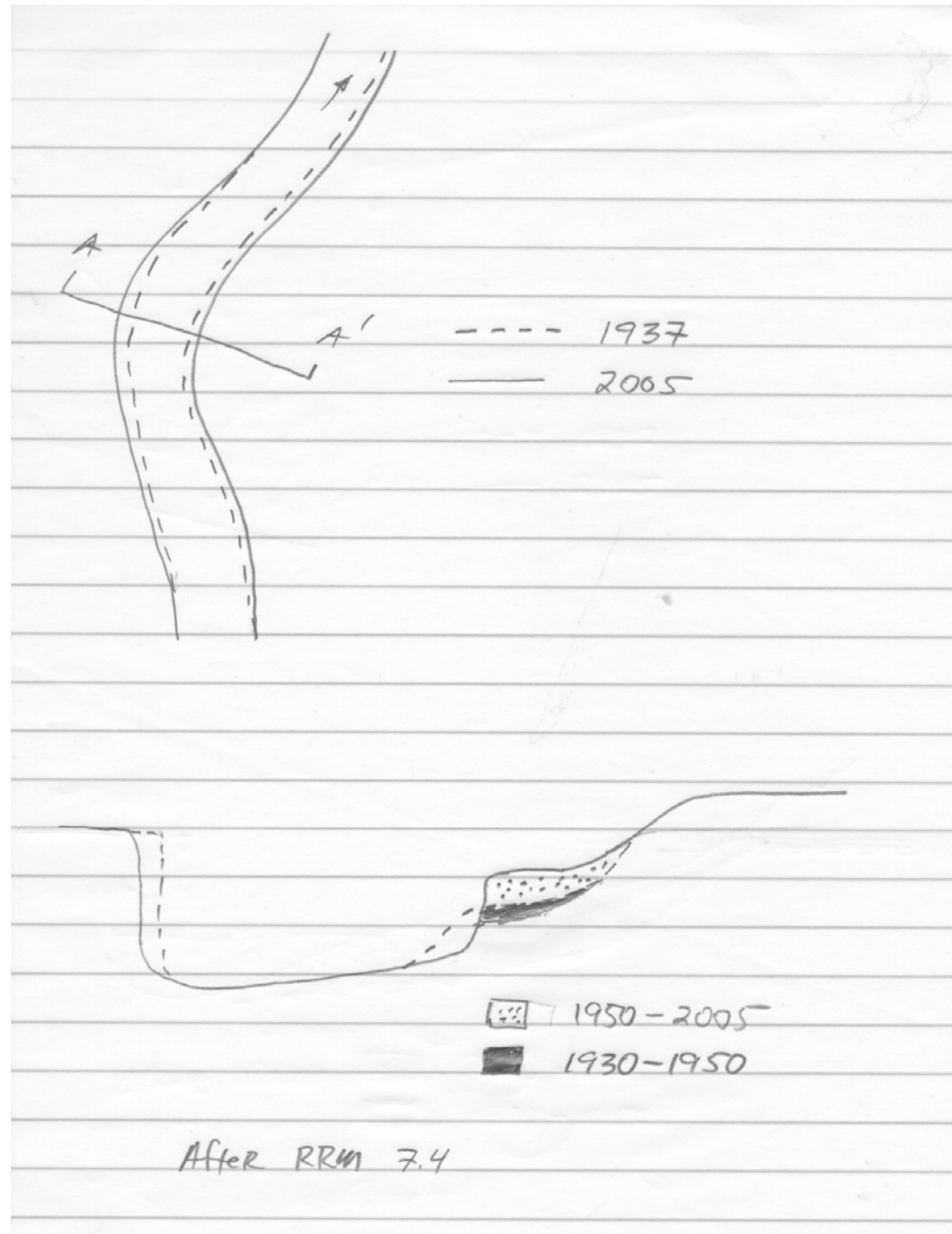
Classification

- Point bars
- Benches
- Tributary Confluence Deposits
- “Floodplain” Deposits

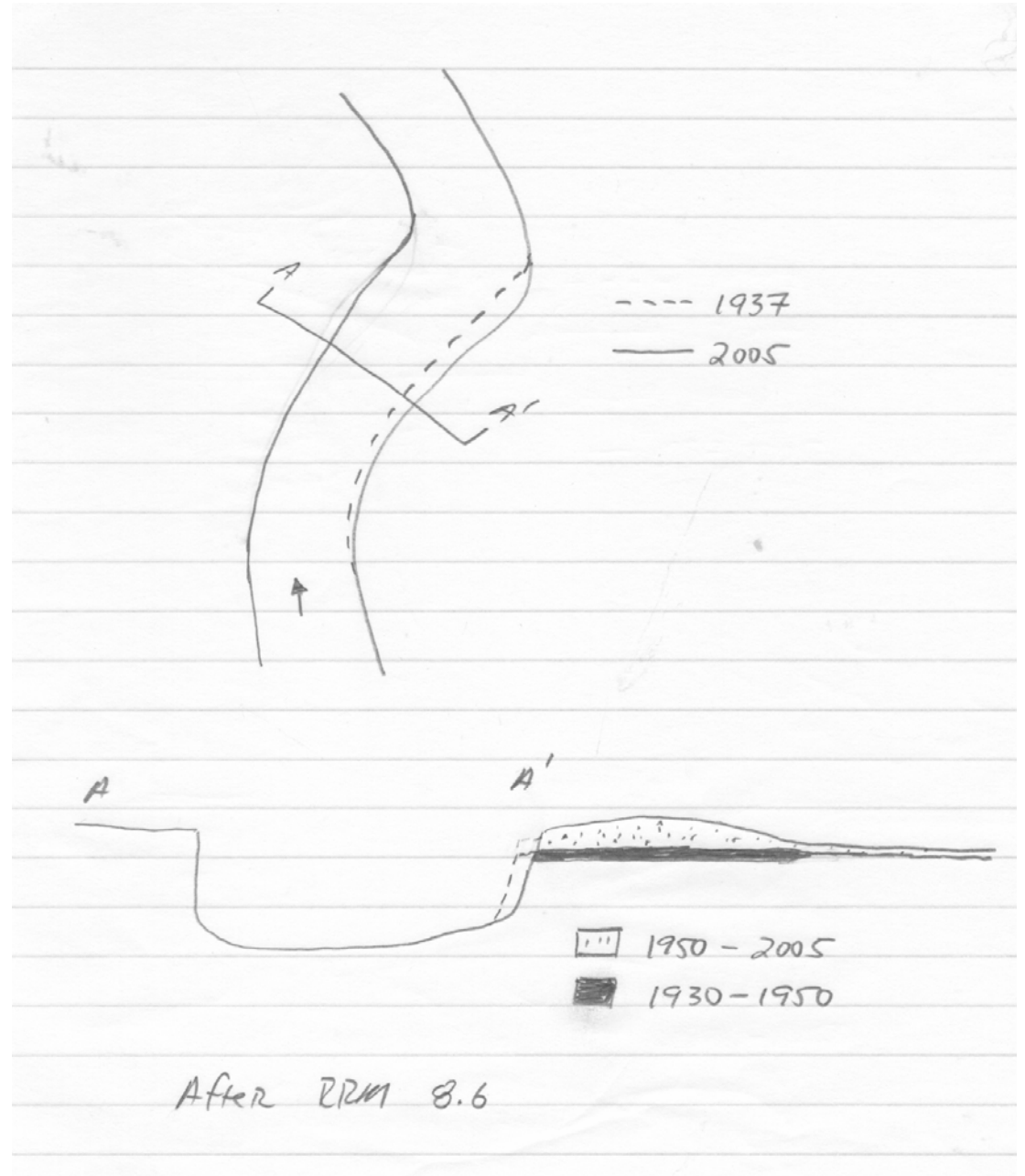
Point Bar HRAD



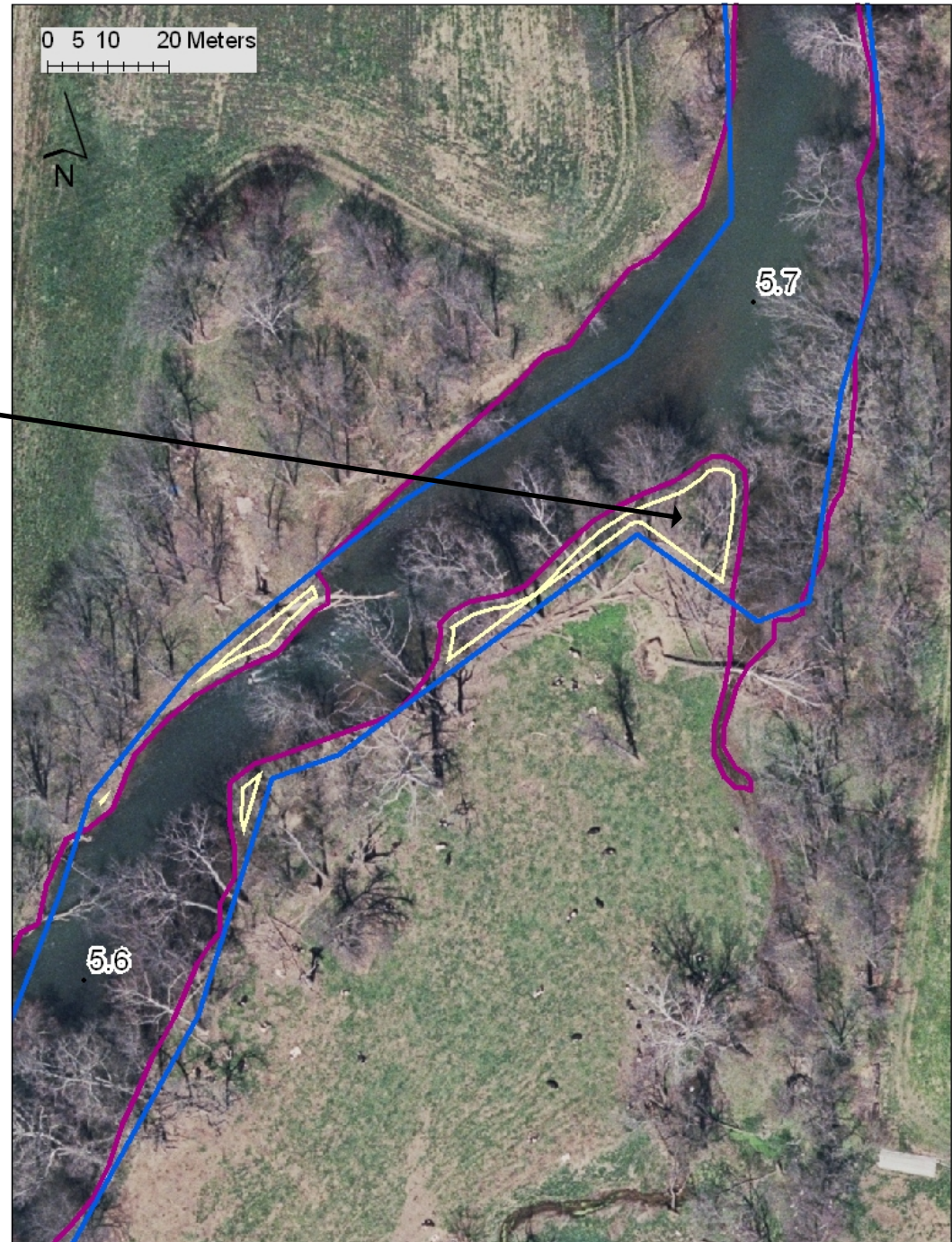
“Bench” HRAD



“Floodplain” HRAD



Tributary Confluence



The Data



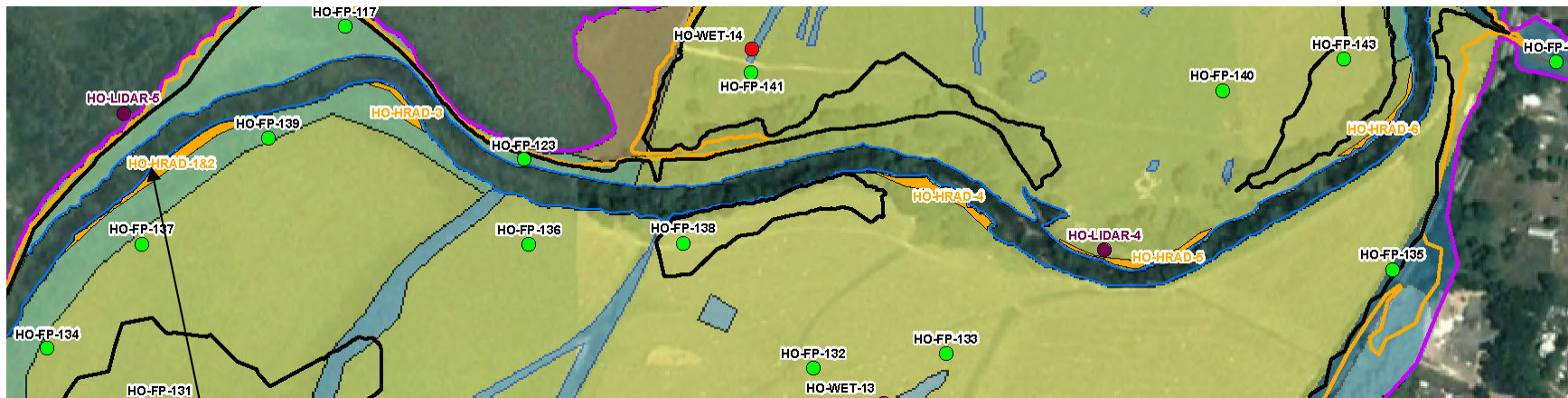
HRADs with release age Hg deposits

Eroding HRADs with release age Hg deposits

HRAD	RRM	Bank	HRAD Type	Max Hg (ppm)	Ave. Hg (ppm)	Comments
1	2.95	right	bench	432	102	near artificial levee
3	3.09	right	bench	18.4	13	
4	3.39	right	point bar	75	31	near side channel
5	3.53	left	point bar	204	49	buried FGCM deposit
6	3.68	left	point bar	839	247	buried FGCM deposit
7A	3.9	left	bench	10.5	7	near river
7B	3.9	left	bench	78	11	near floodplain
8	4.11	right	point bar	14.7	8	sandy point bar
9	4.76	right	tributary	1	1	sand/gravel confluence point bar
10A	4.85	right	floodplain	26.6	5	dooms dam, just upstream
10B	4.85	left	floodplain	29.9	11	near upstream end of pool behind dam
11	5.14	left	point bar	11.9	4	
12	5.69	right	tributary	27.8	19	muddy confluence deposit
14A	7.4	right	bench	96.6	47	overlies mill dam deposits
14B	7.4	right	floodplain	2.6	0	on high terrace
15	7.8	right	bench	26.2	17	
16	8.05	right	floodplain	270	65	outside of bend, upstream of terrace
17A	8.25	right	point bar	17.5	15	
17B	8.25	right	floodplain	196	49	adjacent to point bar
18	8.8	left	point bar	144	54	just above FGCM deposit
19	8.49	left	floodplain	52.9	30	low swale - side channel
20	8.5	right	point bar	26.6	12	
21	8.6	right	floodplain	163	77	outside of bend, upstream of terrace
22	8.65	left	point bar	8.1	6	
23	8.78	right	tributary	5.3	5	sand/gravel confluence point bar
24 (100)	9.2	right	floodplain	62.3	10	at far end of gravel point bar
24(101)	9.27	right	floodplain	15.3	10	near side channel terminus; mill dam accum
26A	9.42	right	bench	129	58	bench (mill dam deposit)
26B	9.54	right	floodplain	25	10	floodplain (along mill dam impoundment)
28	13.72	right	floodplain	30.7	14	
29	15.3	right	point bar	4.3	4	sand/gravel point bar
39	23.13	left	point bar	1.5	0	sand/gravel point bar
40A	23.44	right	point bar	0.3	0	sand/gravel point bar
41	23.44	left	floodplain	15.7	12	

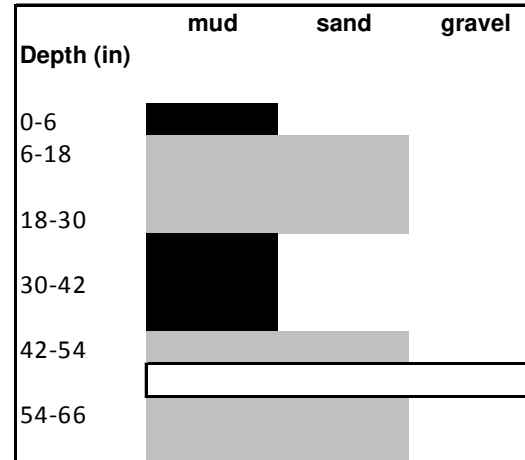
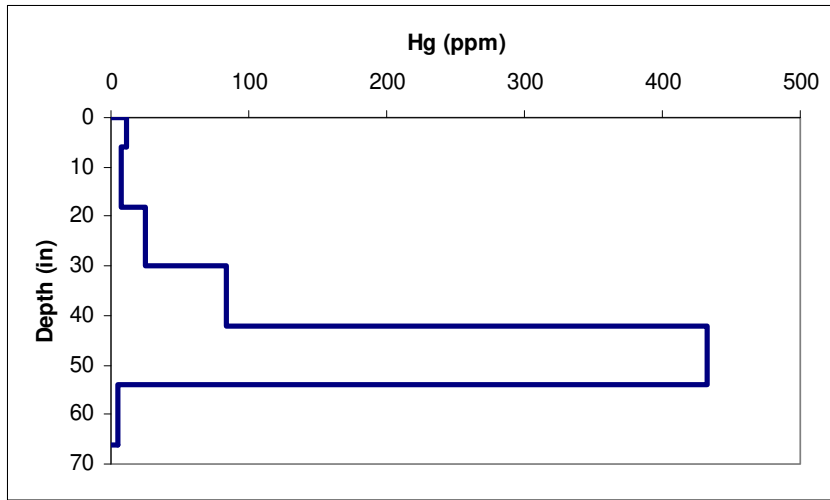
Some Examples

Some Examples



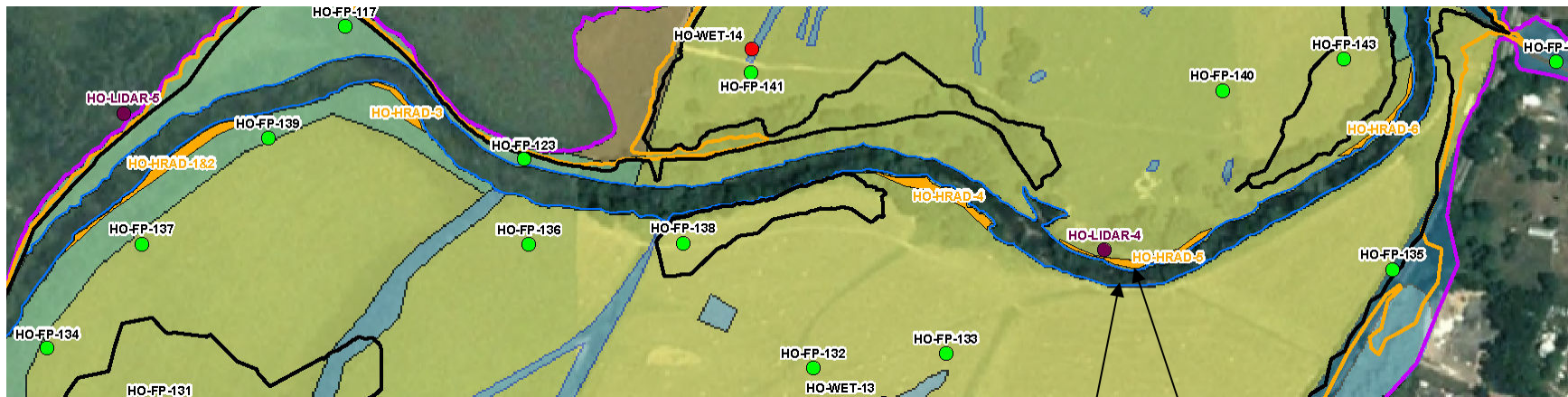
HRAD 1 ("bench")

HRAD 1



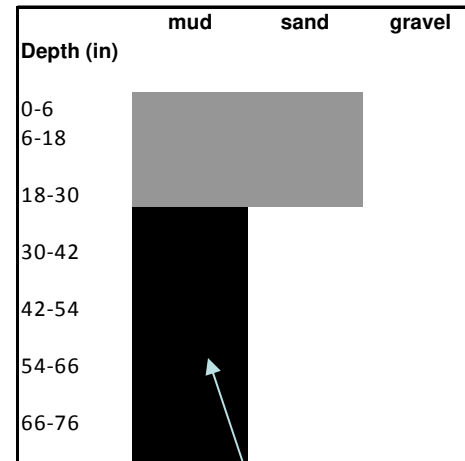
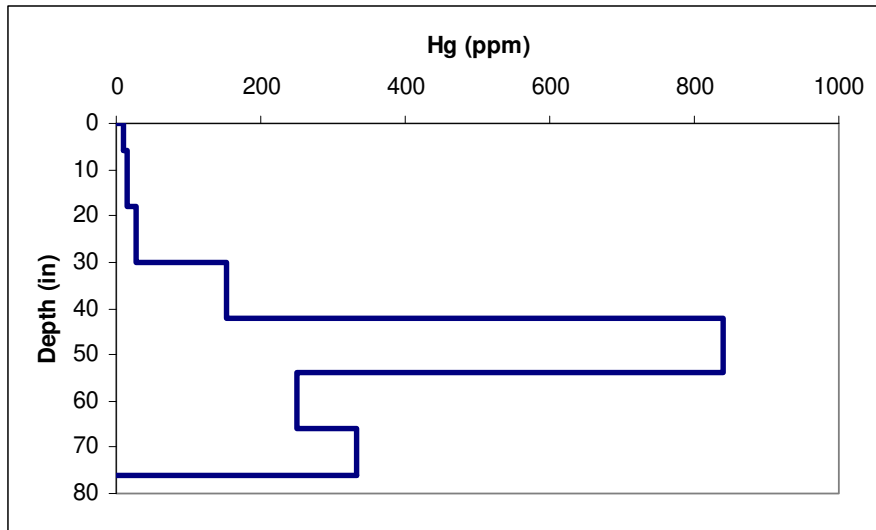
Type	bench	
Depth (inches)	Description	Hg (ppm)
0-6	Dark brown sandy mud (30% sand)	11.7
6-18	Muddy medium sand (30% sand)	7.92
18-30	Muddy sand to sandy mud at base ~50% each	25.1
30-42	Sandy mud 40% sand	84.1
42-54	Top- muddy med-coarse sand 40% mud, bottom- sandy gravel (pebbles, granules), trace mud	432
54-66	Coarse-very coarse sand, scattered pebbles	5.41
Vertically averaged Hg concentration (ppm)		101.8873

Some Examples



HRAD 6 (Point Bar)

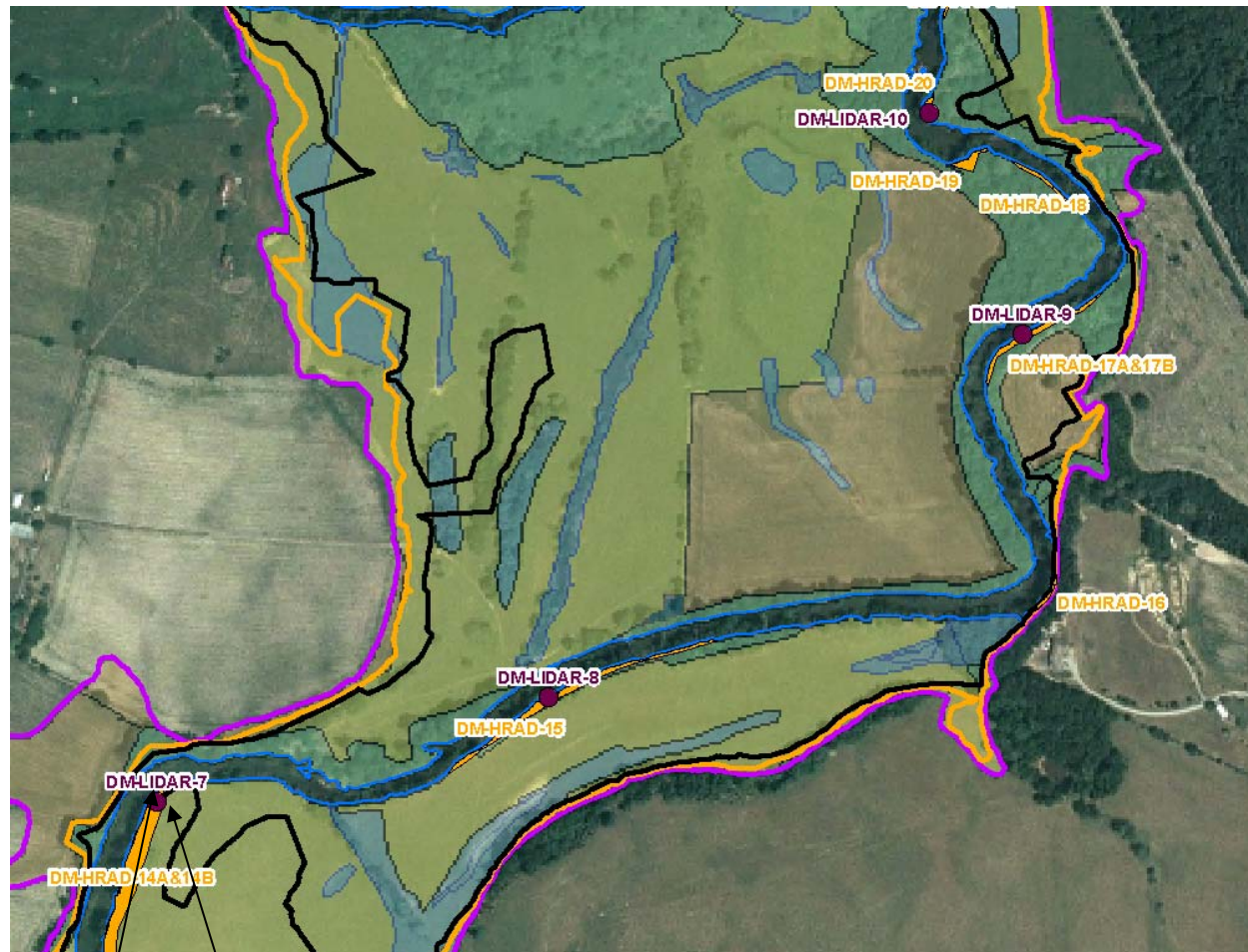
HRAD 6



Type	point bar	
Depth (inches)	Description	Hg (ppm)
0-6	Muddy medium sand (30% mud)	9.6
6-18	Muddy medium sand (15% mud)	13.8
18-30	Sandy mud/muddy sand	28.6
30-42	Sandy mud (25% sand)	153
42-54	Dark gray organic-rich (twigs, stems, leaves), sandy mud (20% sand)	839
54-66	Dark gray sandy mud (10% sand), organics	251
66-76	Same as above	332
Vertically averaged Hg concentration (ppm)		247

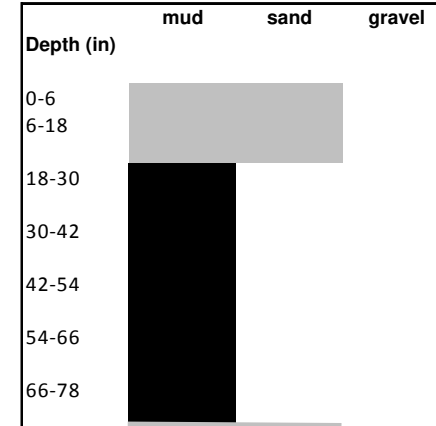
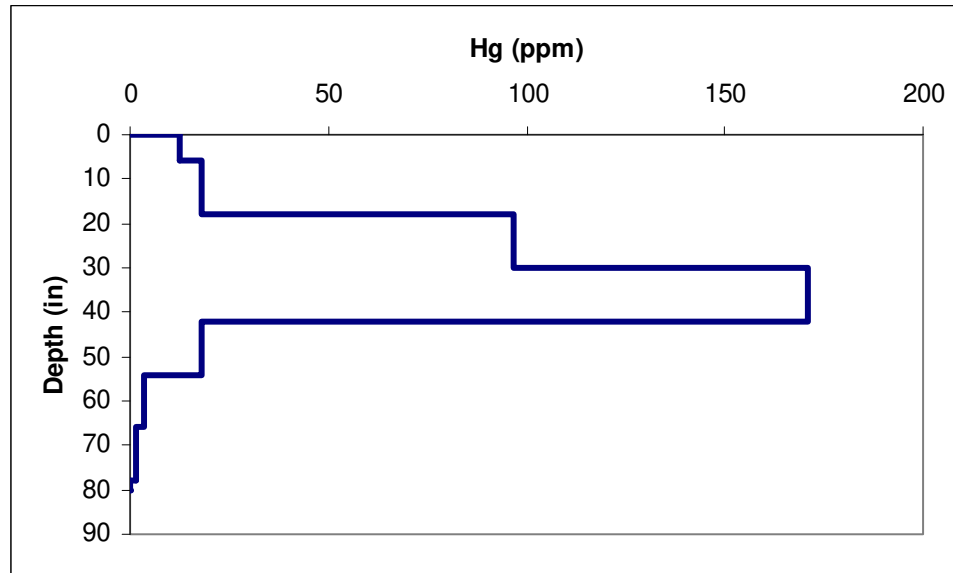
A buried Fine-Grained Channel Margin Deposit!!!

HRAD 14A, B, LiDAR 7



HRAD 14A, 14B (B on terrace)(bench)

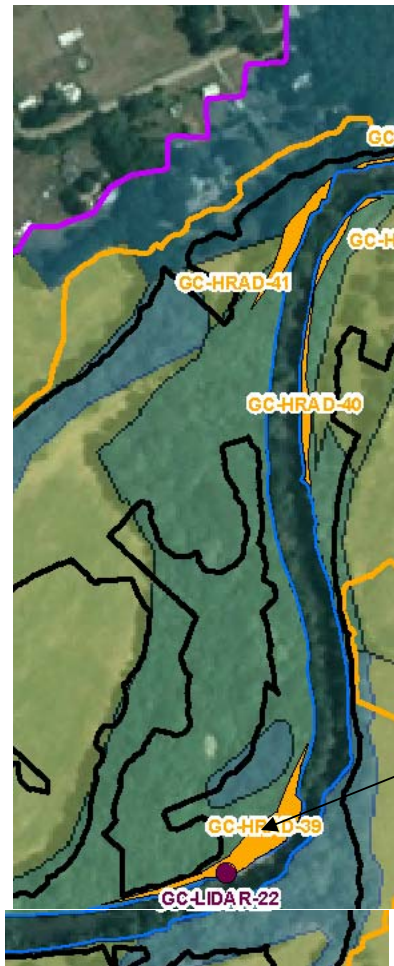
HRAD 14A



Type	bench	
Depth (inches)	Description	Hg (ppm)
0-6	muddy sand, 20-30 mud, bottom few inches more sand	12.4
6-18	muddy sand, 30-40% mud	18.2
18-30	sandy mud, with layers of sand, a few cm thick, 20% sand	96.6
30-42	mud, 10% sand, with some laterals of sand at ~35 inches, color change, really fine banded mud	171
42-54	sandy mud, 10-15% sand, maybe less sand	18.1
54-66	sandy mud, 15-20%, at 58 layer of muddy sand, 59-66 dark muddy organic layer	3.35
66-78	66-74 mud with abundant organic, 74-76 not recovered, 76-78 muddy sand with abundant organic	1.38
78-80	muddy sand, with abundant organic and layers of mud	0.234
Vertically averaged Hg concentration (ppm)		47

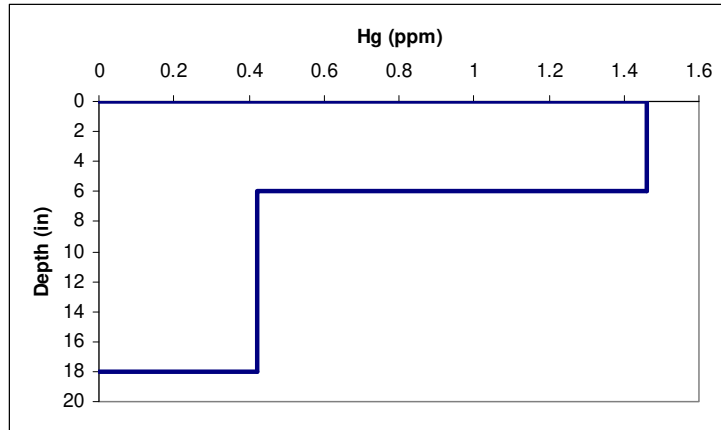
Other cores show clear evidence of “buried” mill dam deposits

HRAD 39



HRAD 39 (on big gravelly point bar)

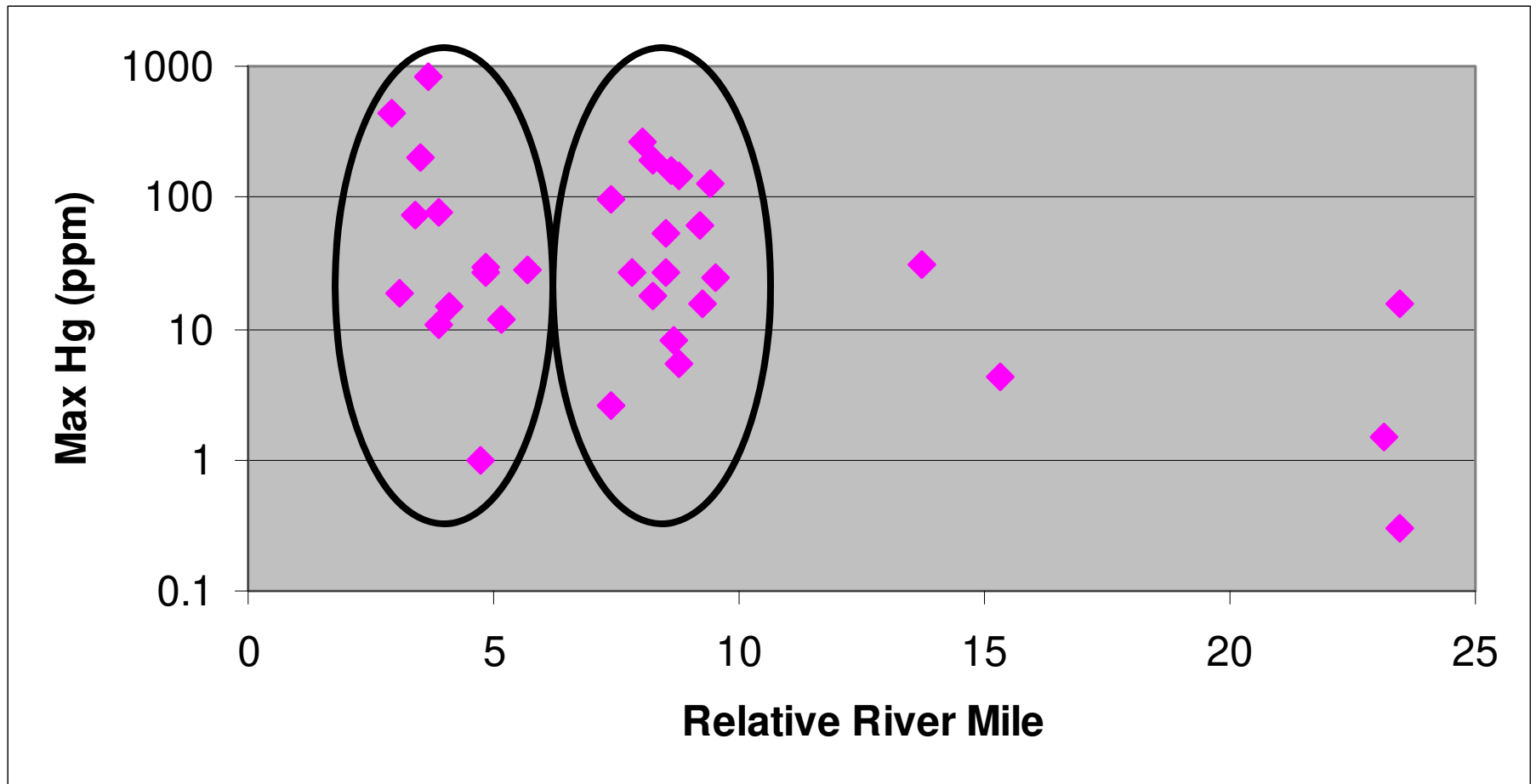
HRAD 39



	mud	sand	gravel
Depth (in)			
0-6			
6-18			

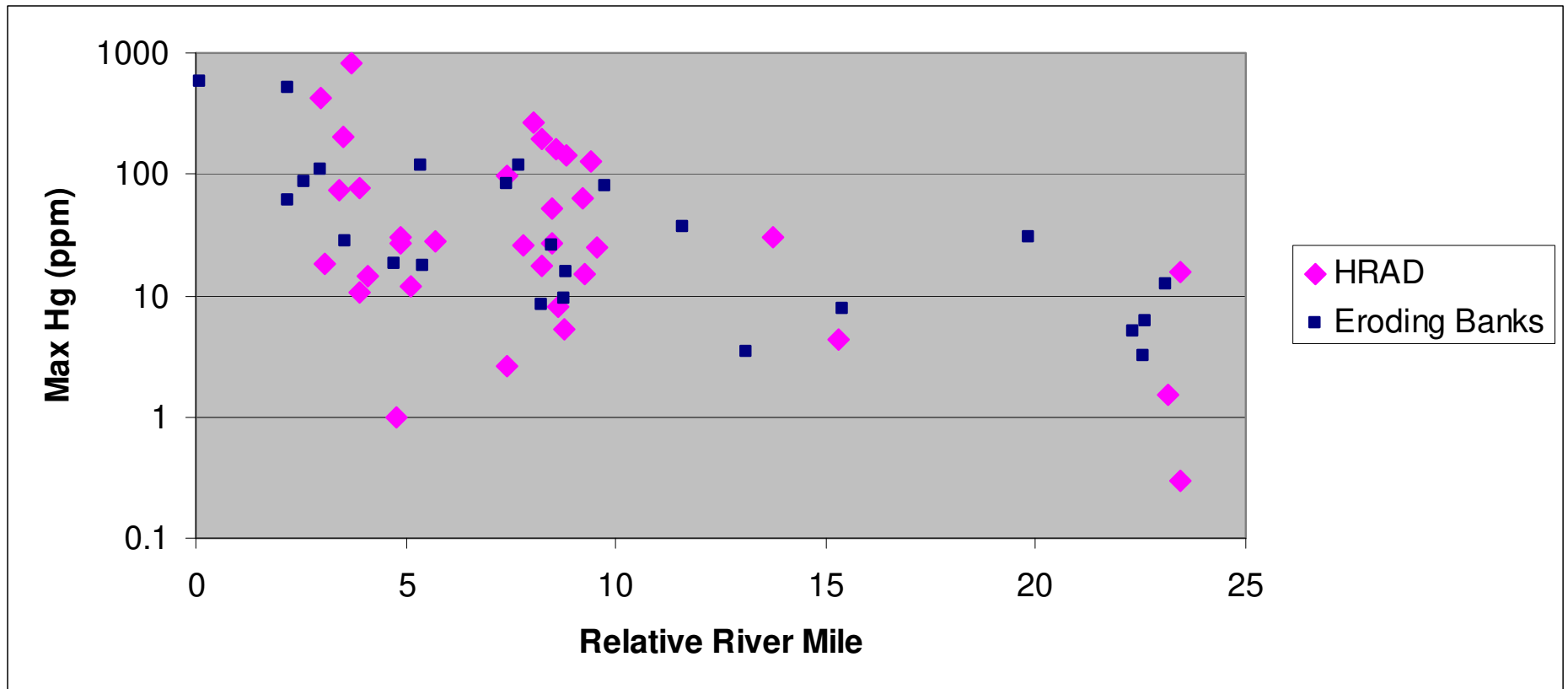
Type	point bar (sand and gravel)	
Depth (inches)	Description	Hg (ppm)
0-6	m-c sand, scattered pebbles, trace mud and organic matter	1.46
6-18	same as above gravel below could not penetrate	0.423
Vertically averaged Hg concentration (ppm)		0.282

Downstream Trends: HRAD Max Hg concentrations



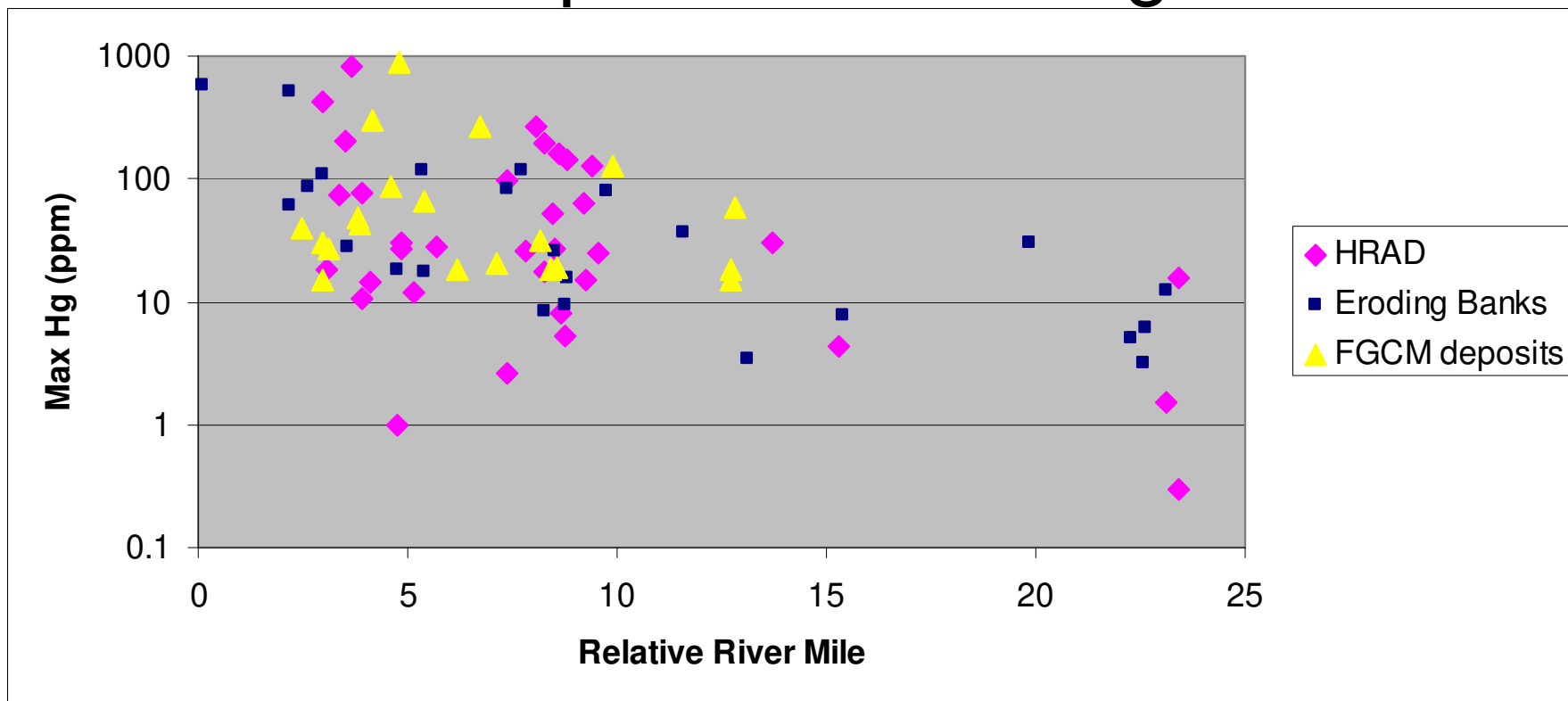
Note: most deposits located at RRM 3-5.5 and RRM 7-9.5

HRADS and Eroding Banks – Max Hg



Historical Deposition on Different Types of Floodplains (some now eroding) Follow Similar Spatial Patterns (Hg on HRADs and eroding banks have been controlled by broadly similar processes)

HRADS, Eroding Banks, FGCM Deposits – Max Hg



Exponential decrease downstream in all these deposits suggests primary control of Hg distribution from original plant release!!

Channel Margin Floodplain Deposits - Summary

- Some of these deposits have very high concentrations of mercury
 - A few of these are actively eroding into the river
- Maximum Hg concentrations are very high upstream and decrease exponentially downstream:
 - Suggesting initial deposition from a point source at the plant during the release period (1930-1950) with progressive dilution during transport
- Other floodplain deposits follow similar patterns

Topics

- Reconstruction of Historic Hg Concentrations on Particles In Suspension, 1930-2005
- Modeling Hg Storage in Fine-Grained Channel Margin Deposits, 1930-2050
- Hg Concentrations in Eroding Banks
- Accelerating Rates of Bank Erosion, 1937-present
- Improved Sediment Budget, RRM 2.5-5.5
- Hg Concentrations in “Channel Margin Floodplain Deposits”
- *Explanation for “The Hump”*
- Revised Geomorphic Conceptual Models of the South River

Our Hypothesis in 2006

- Hg concentration in the banks appeared to follow a “hump” distribution with distance downstream
 - Seemed to be similar to Hg concentrations sampled in the bed sediment.
 - Eco study gravel pore sampling
- We proposed that supply from the bank occurred at relatively small discharges
 - Decoupled from general flux of suspended sediment at higher flows
 - Higher flows with “clean” sediment can dilute contaminated supply from the banks, and the data from that time did not seem to support extensive dilution

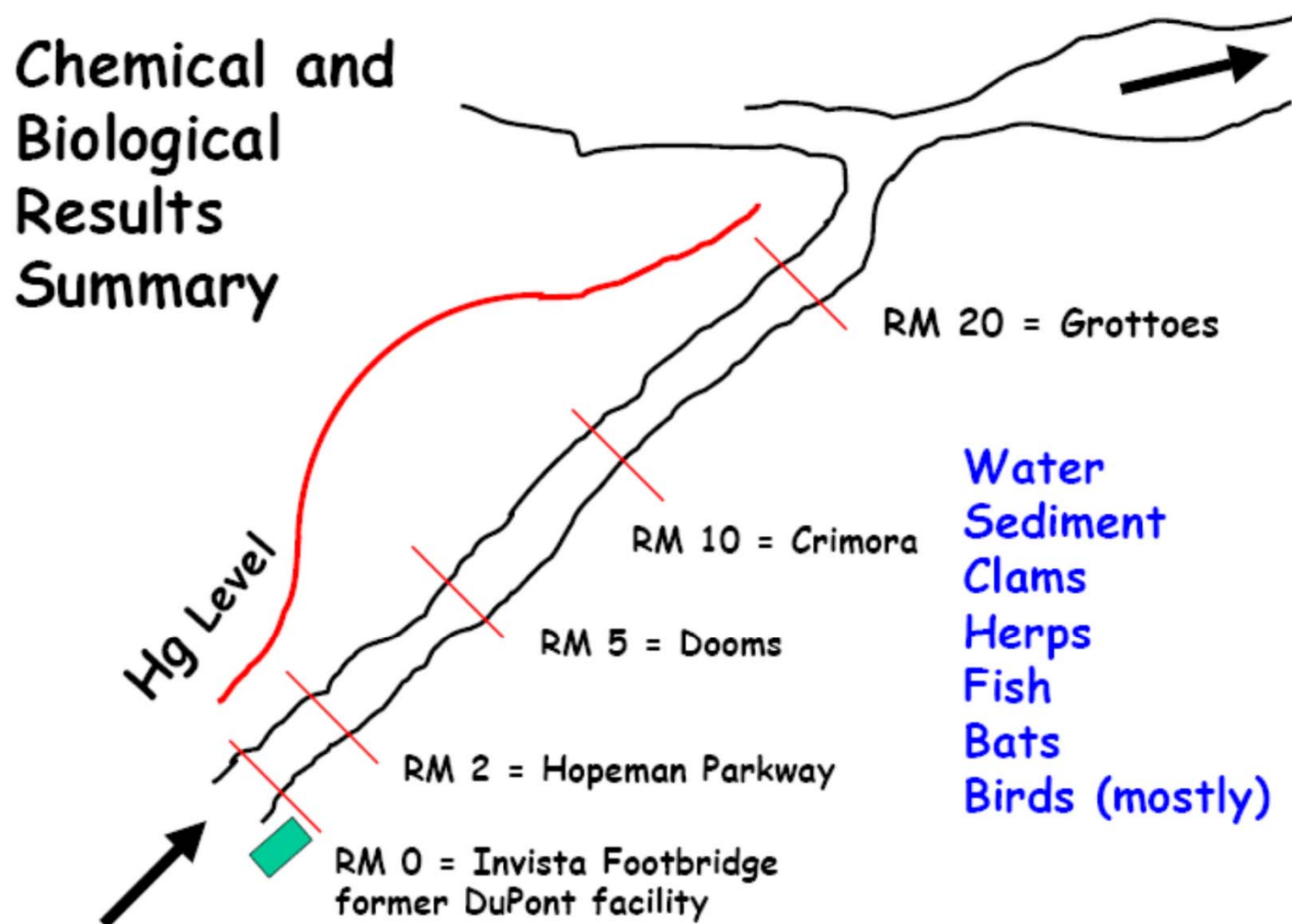
In 2008

- Exponentially decreasing concentration from the banks
 - Very high concentrations upstream
- Our 2006 hypothesis is likely unnecessary
 - The “hump” in Hg concentration can be explained by:
 - Ongoing supply from eroding banks
 - Dilution from upstream and other watershed sources
 - May be other mechanisms as well

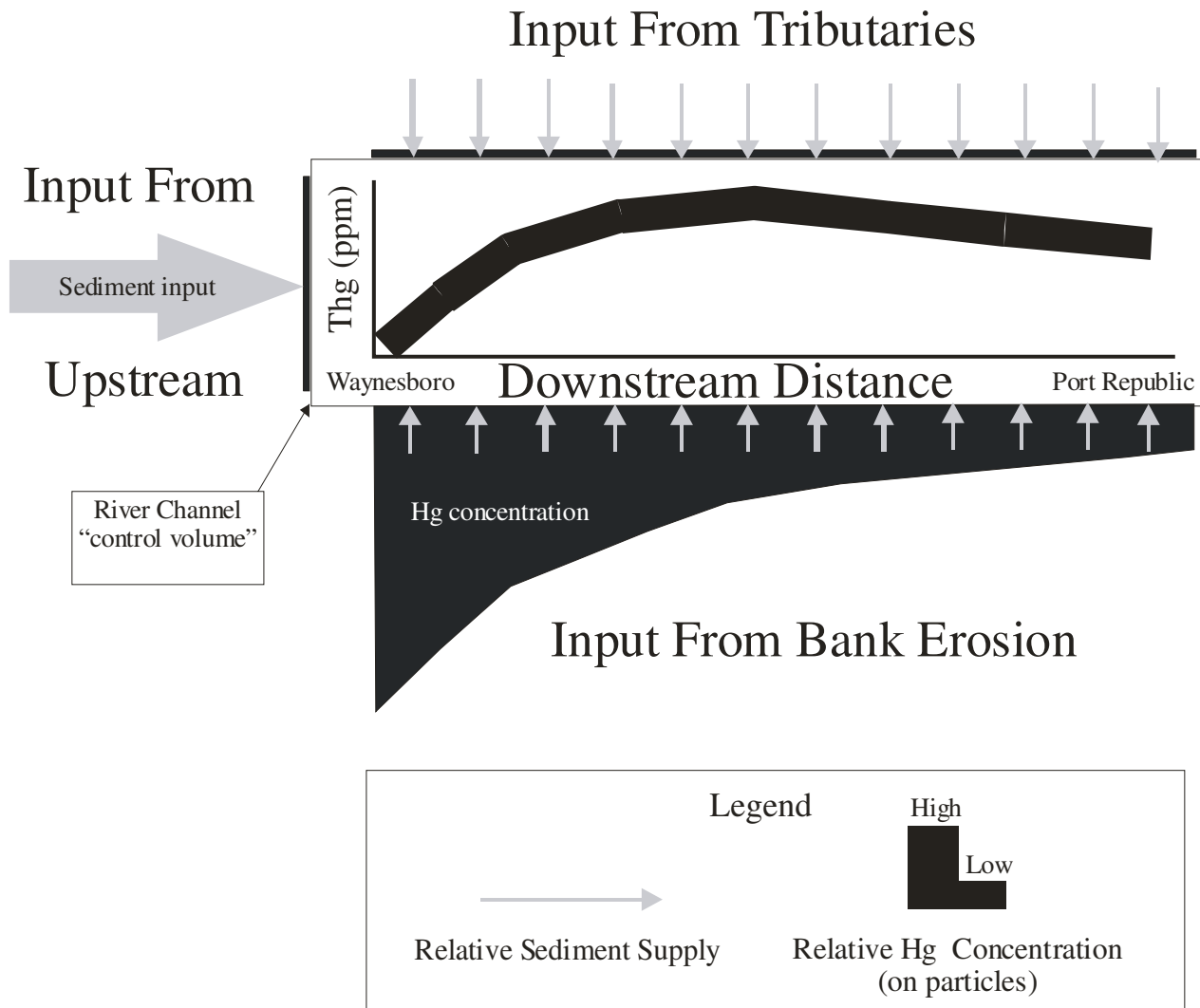
Conceptual Model of Ongoing Mercury Contamination

- The plant provided the original source from 1929-1950
 - The river transported this material downstream, where it has been:
 - Deposited on the floodplain
 - Deposited on fine-grained channel margin deposits
 - Transported out of the study area
- Since 1950
 - Bank erosion provides a continuing source

Are these ideas consistent with THE HUMP?

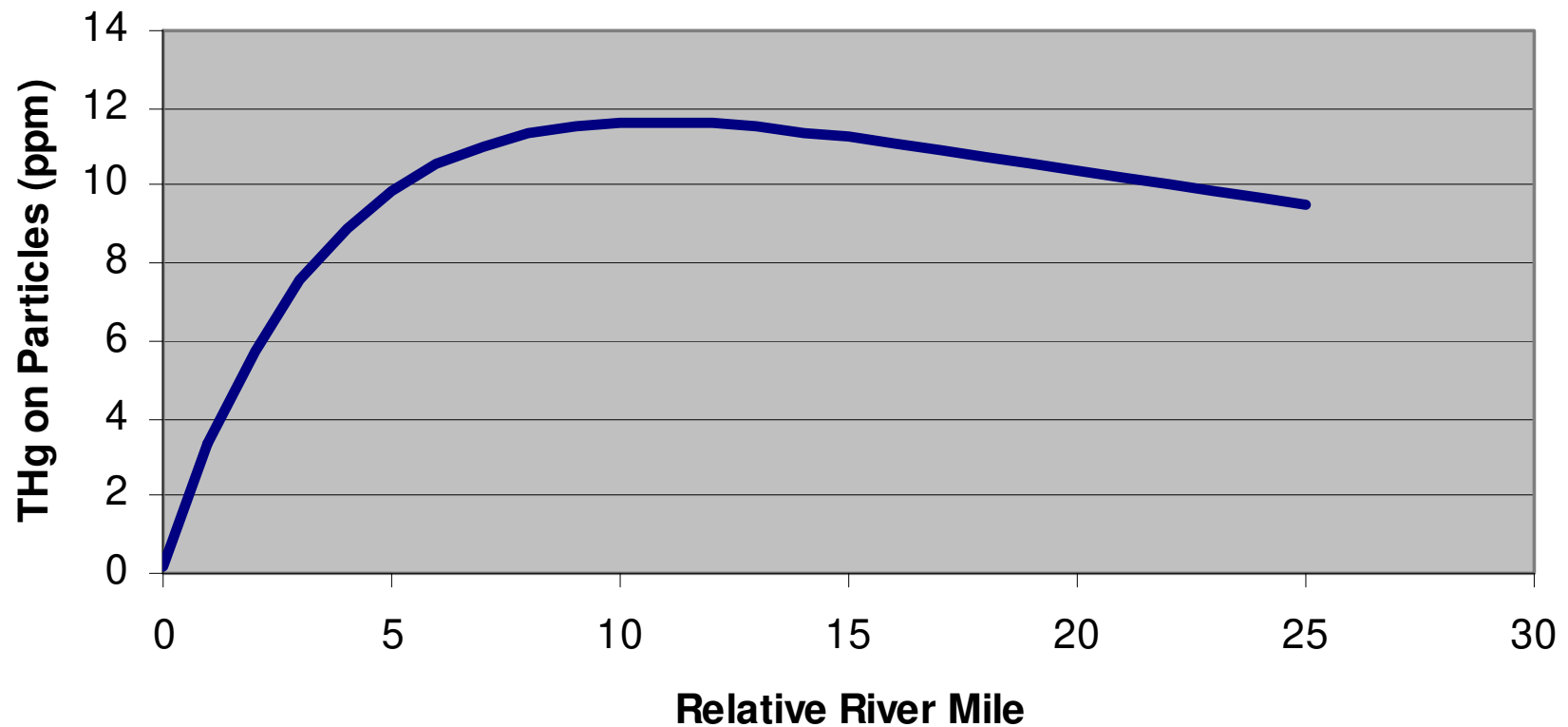


Explanation for the HUMP



A “Real” Computation

(based on the sediment budget, background and bank Hg concentrations)



Summary

- Simple budget of Hg and sediment provides 1st-order explanation for the observed “hump” distribution of Hg concentration downstream
- Requires:
 - erosion of contaminated banks with exponentially decreasing concentration downstream
 - supply of uncontaminated sediment from the watershed

Topics

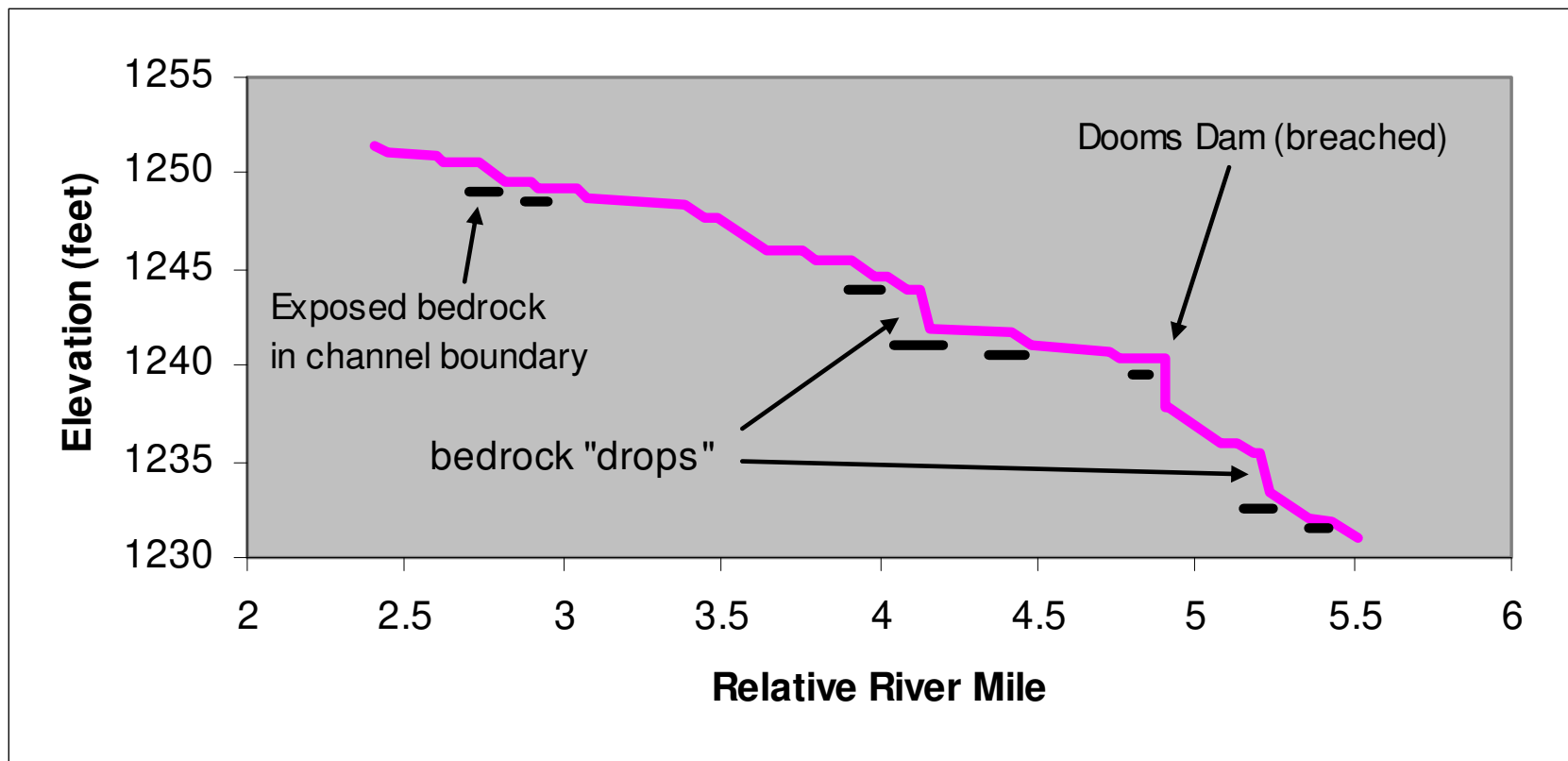
- Reconstruction of Historic Hg Concentrations on Particles In Suspension, 1930-2005
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- Improved Sediment Budget, RRM 2.5-5.5
- Hg Concentrations in “Channel Margin Floodplain Deposits”
- Explanation for “The Hump”
- *Revised Geomorphic Conceptual Models of the South River*

New Concepts Arise From

- Better appreciation of:
 - Role of bedrock
 - Historical influence of mill dams
- Improved mapping and dating of deposits along the river

A New Longitudinal Water Surface Profile

Pools and Riffles, Bedrock Drops, and a Breached Dam



38% of the vertical drop of the river in this reach occurs where the river flows over bedrock

Geomorphic Classifications of South River

Variable	Classification
Bed material	Gravel-bed
Plan Form	Sinuuous (not meandering)
Type of load	Mixed load

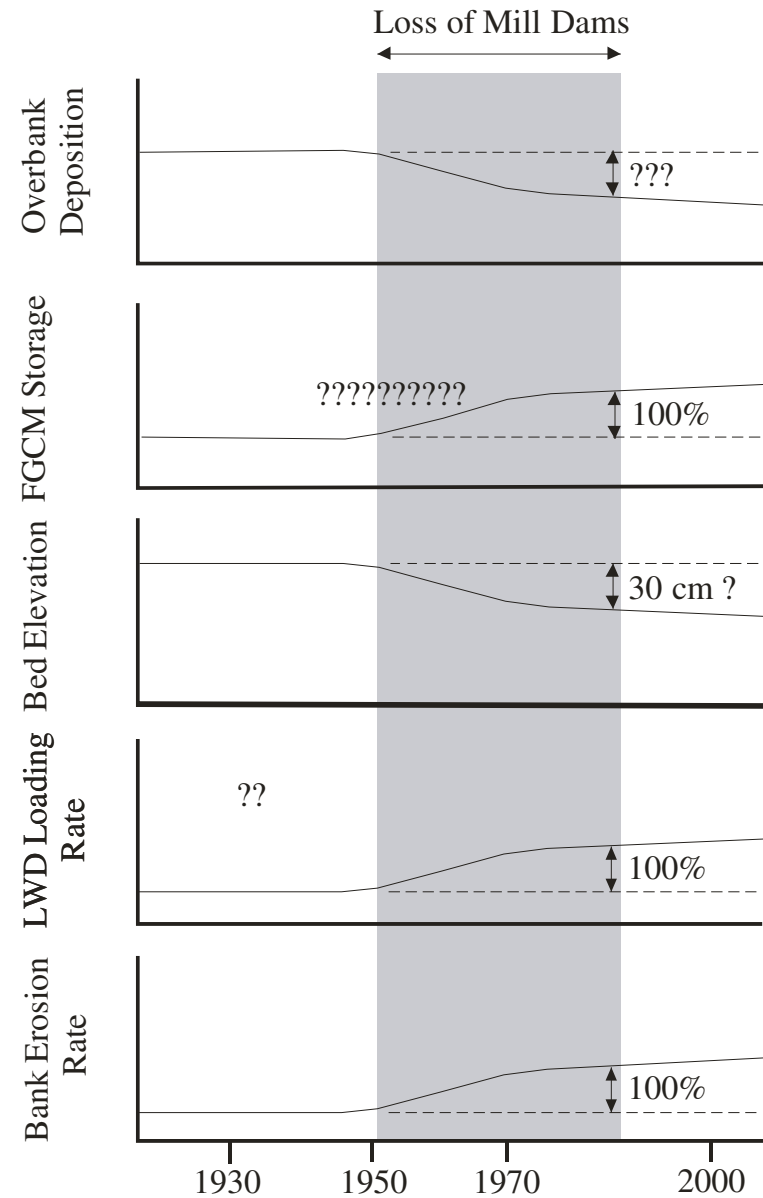
The Best Summary Classification For South River

- South River is:
 - a *bedrock channel*
 - with a gravel bed...
 - And an well-developed floodplain
 - “A bedrock channel cannot substantially widen, lower, or shift its bed without eroding bedrock”
 - Turowski et al., 2007

Historical Influence Of Mill Dams On the South River

- Early in the 20th Century, the river was in an ***IMPOUNDED STATE***
 - ~ 50-80% of the river was a series of mill ponds
 - Not a freely flowing stream as observed today
- Currently:
 - The river is in an ***ERODING STATE***
 - SLOWLY reworking many older deposits

Hypothetical Implied Temporal Trends in Some Fluvial Processes



Timescales of Geomorphic Change

- Little has changed in the last 10^2 years..
- Significant geomorphic changes require.... 10^3 years
 - along the South River.
 - Except where tributaries supply coarse bed material to the channel, where changes happen more quickly

Periodic Catastrophic Debris Flows

- Occur in this part of Virginia
- VERY destructive to human life and engineering structures
- ~50 have occurred in Virginia since the mid-20th Century
- At any one place, recurrence interval ~1000 years

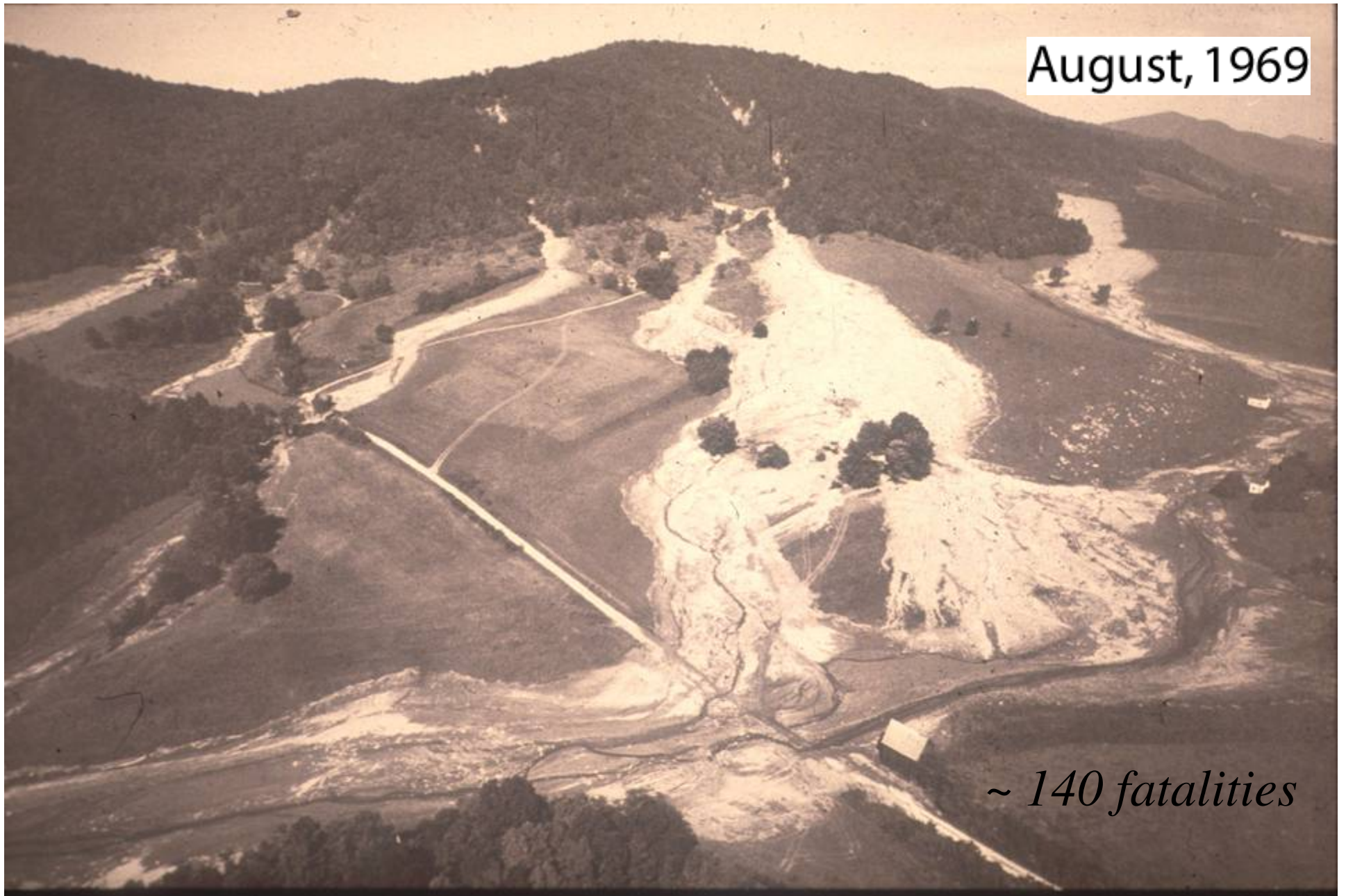
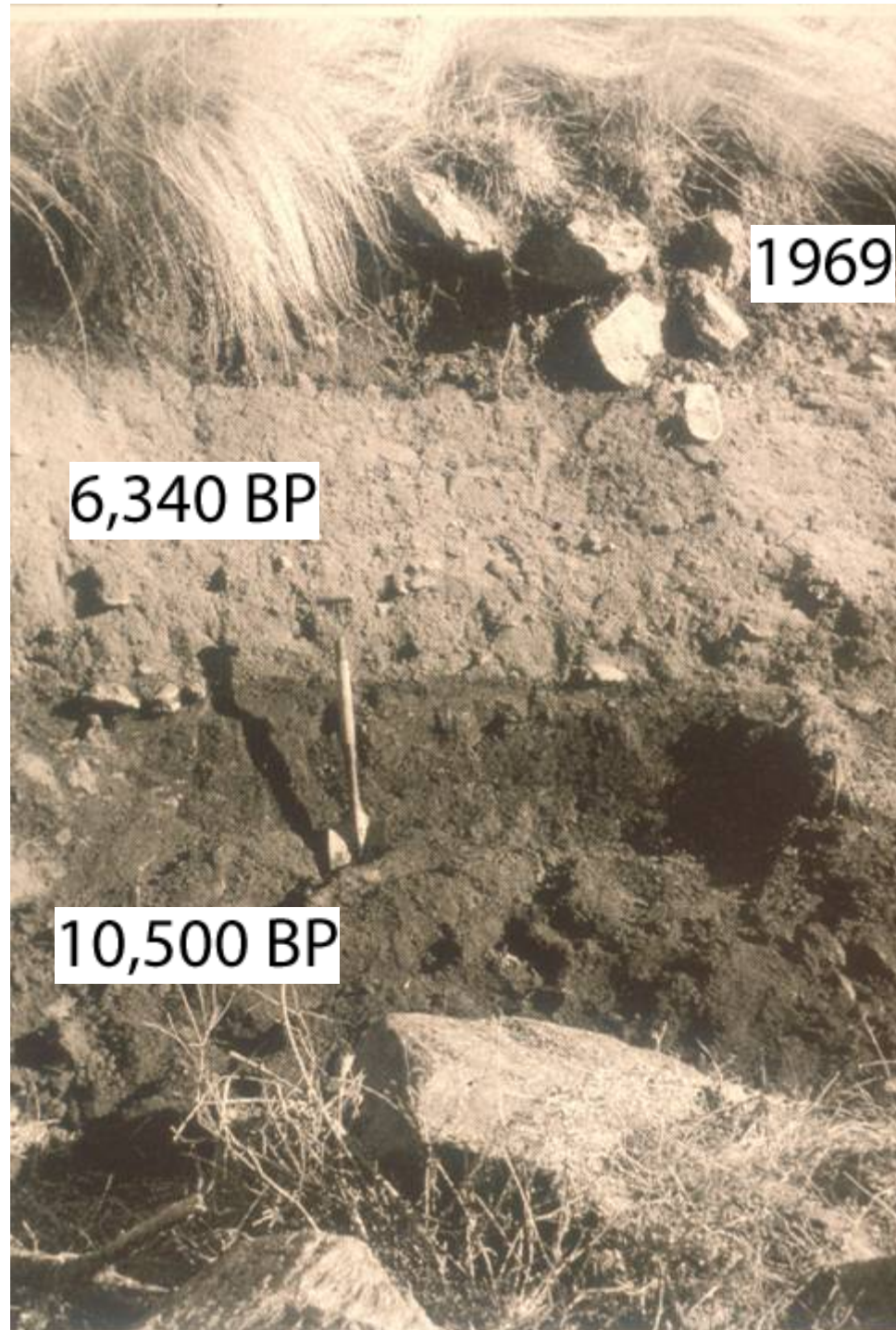
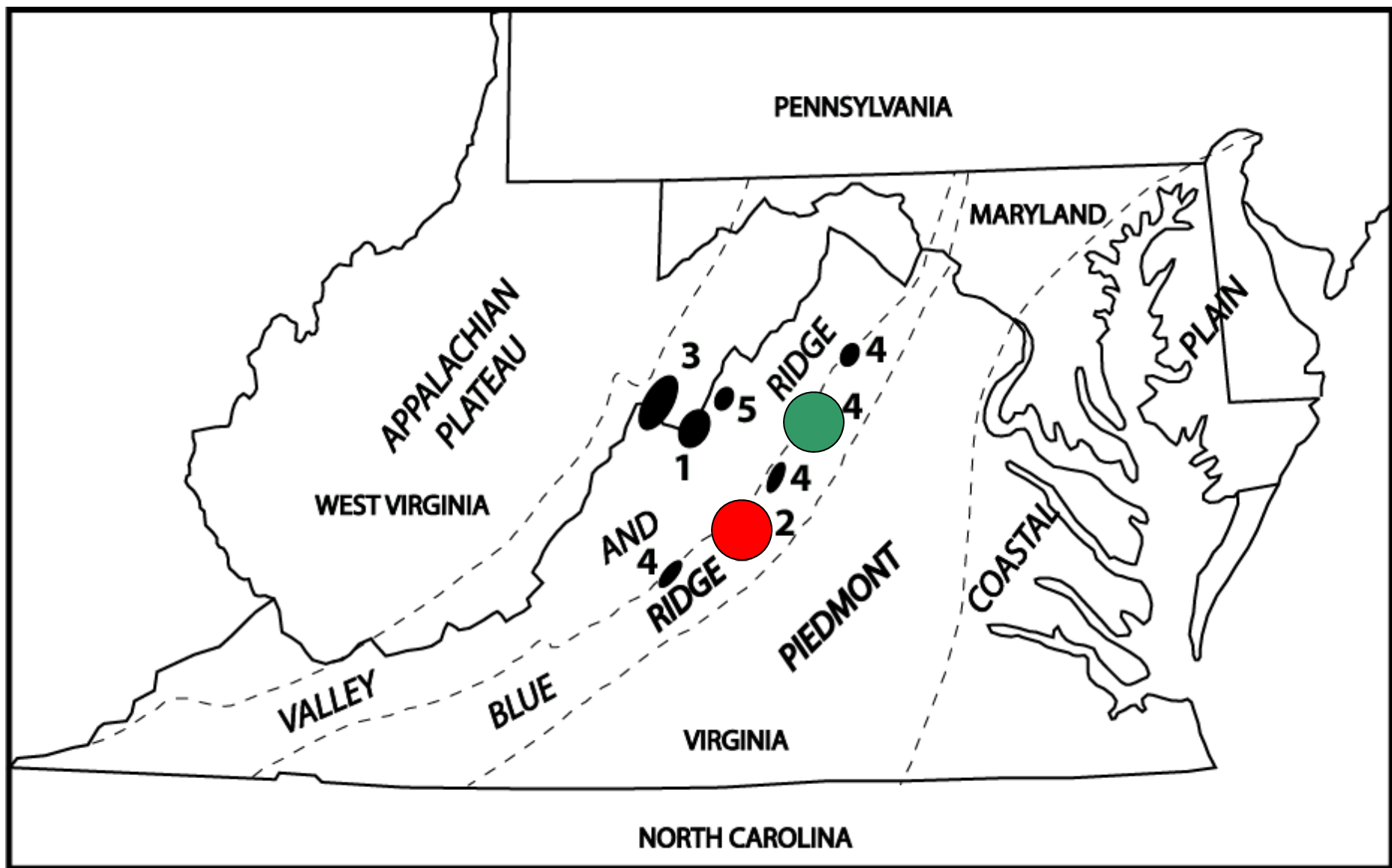


Photo: Virginia Geological Survey, 1969



From Kochel, 1987





**Rapidan Storm,
June, 1995**

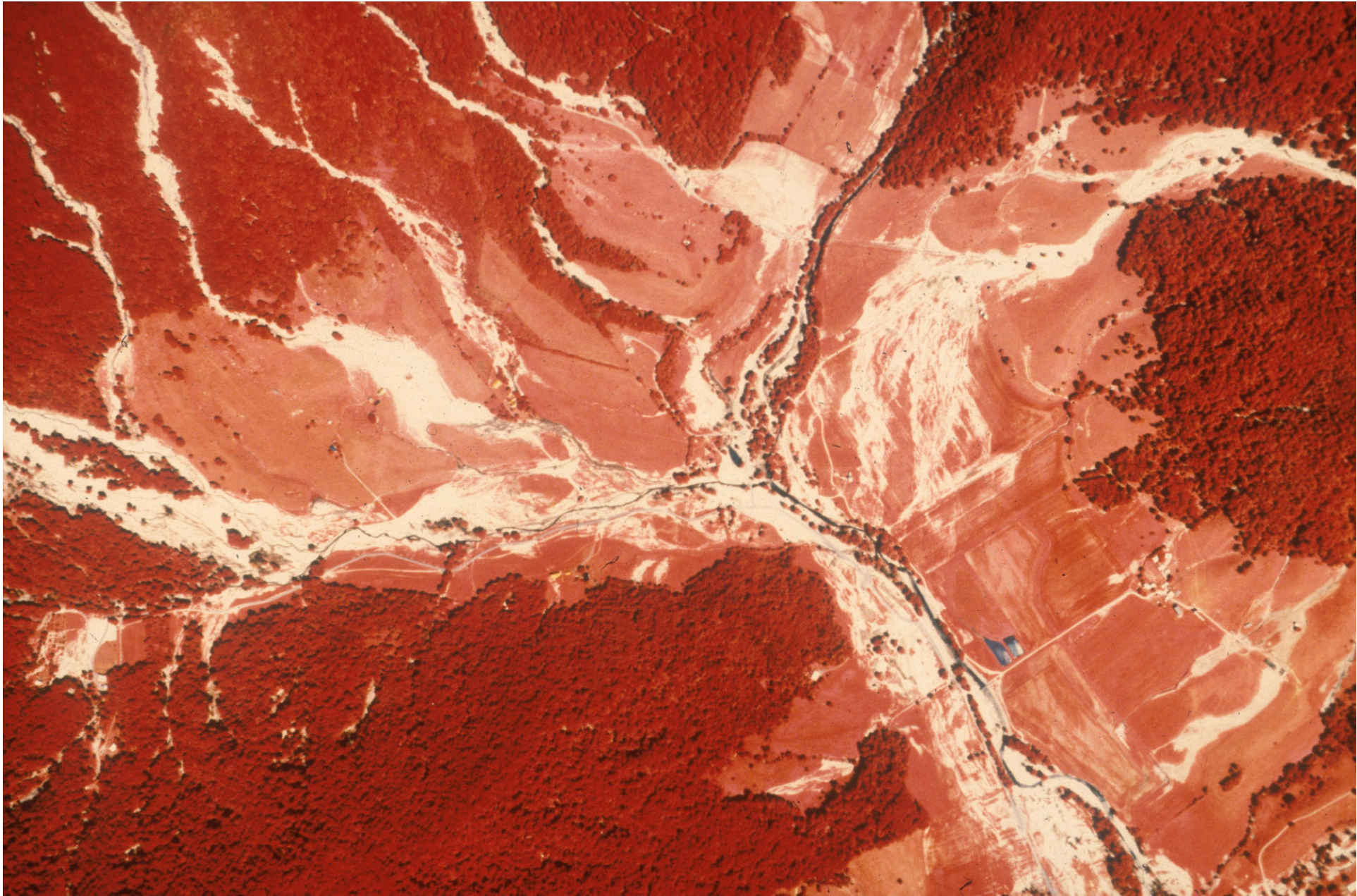
Madison County, Virginia











Take Home Points

- Most of the Hg in floodplain and FGCM deposits along the river originated from the period of direct Hg release from the plant
 - Timescales for removing this Hg are 10^2 - 10^3 years
- Contaminated sediments supplied to the river through erosion decrease in concentration exponentially downstream.
 - Contaminated sediment is progressively “diluted” with clean sediment from the watershed
 - These two factors are sufficient to explain the “humped” distribution of Hg observed in many samples along the river.
- Fluvial processes during the last 100 years have been strongly influence by the loss of mill dams in the middle of the 20th century
 - The river was in an “**impounded state**” before ~1950
 - After ~1950 and continuing to the present, it entered an “**eroding state**”
- The best geomorphic classification of the South River:
 - a **bedrock river** with a gravel bed and well developed floodplain.
 - Timescales for significant geomorphic changes: $\sim 10^3$ years
 - Except where tributaries supply coarse bed material to the channel, where changes happen more quickly