Modeling Bank Erosion, Mercury Methylation/Demethylation, and Subsequent Receiving Water Impacts

Mercury Workshop

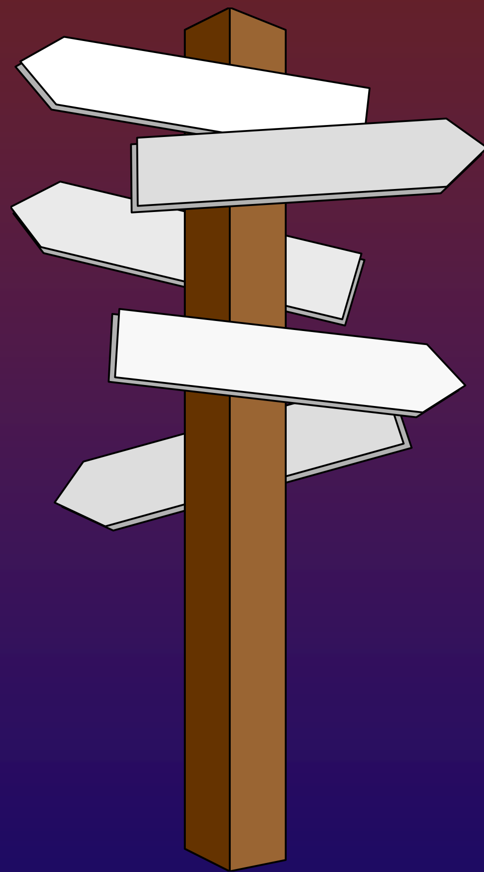
Sponsored by DuPont

At the University of Delaware
January 4-5, 2005

J.J. Warwick & R.W.H. Carroll
Desert Research Institute, Division of Hydrologic Sciences Reno, NV

Overview

- Site Description
- Modeling Tools
  - RIVMOD
  - WASP5
  - MERC4
- Extreme Event
- Calibration
- Verification
- Ongoing Work
- Conclusions
- Recommendations



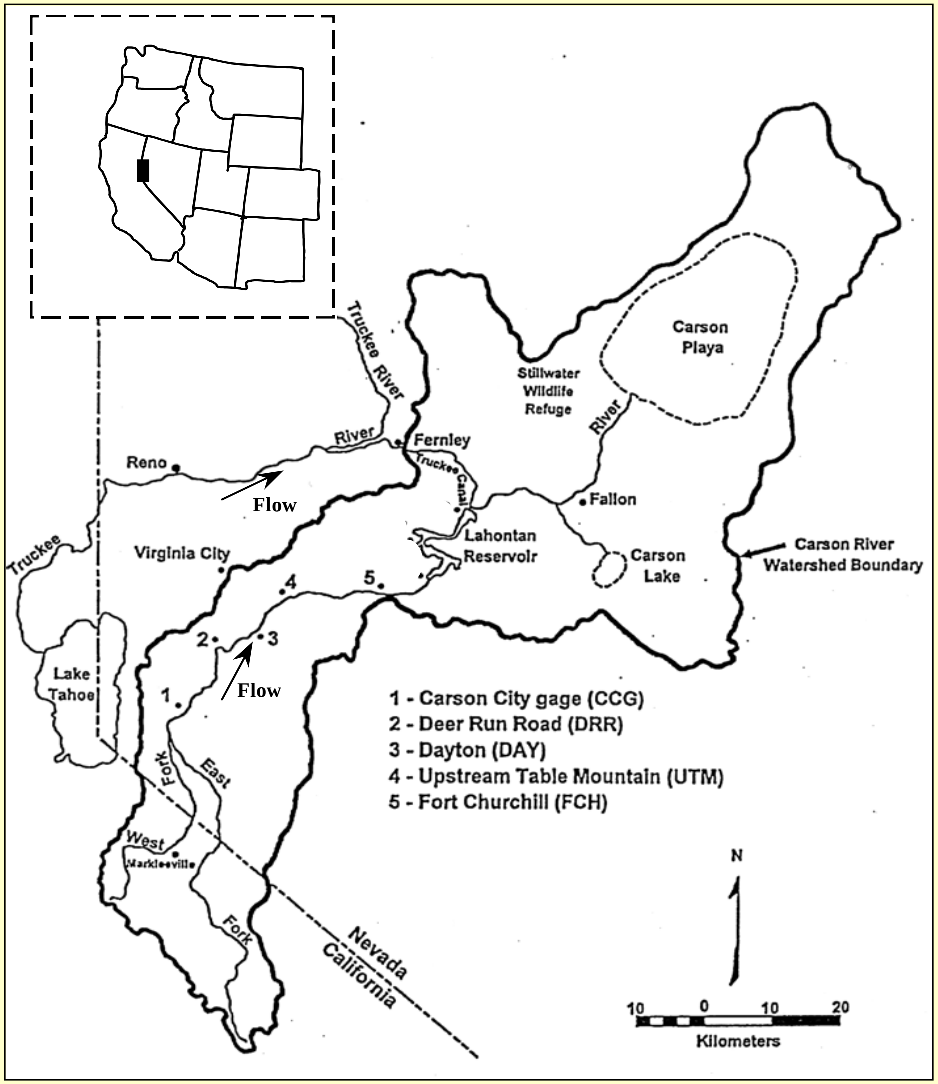
Collaborators

Tamar Barkay
Jean-Claude Bonzongo
Rosemary Carroll
Dan Crawford
Jadran Faganeli
Ken Heim
Mark Hines
Milena Horvat
Paul Lechler
Berry Lyons
Jerry Miller
Gregor Petkovsek
Rudi Rajar
David Wayne
Dusan Zagar

Funding Sources

- NIEHS
- NSF
- USEPA
- NSF
- NSF

Carson River



- Modeled domain from USGS gage CCG through Lahontan Reservoir (~110 Km)
- Semi-arid river with peak flows generally occurring in the spring
- Catastrophic floods (e.g.. 1997-flood) are generated with rare, rain-on-snow events that occur during the winter months
- The meandering river is entrenched with steep sides of complexly structured alluvial fill

WASP5

- RIVMOD
- WASP5
- MERC4

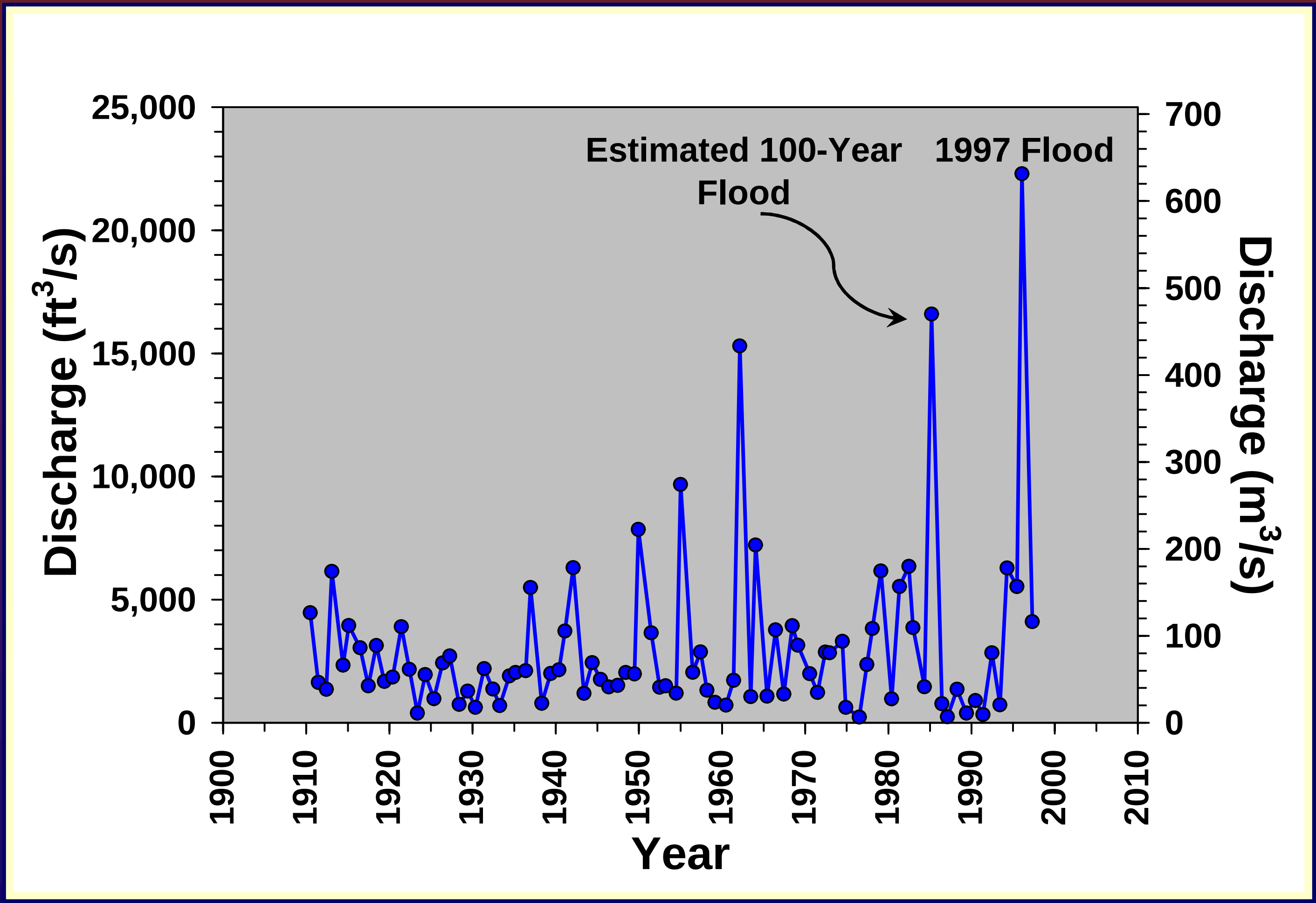
Model Augmentation

- RIVMOD
  - Floodplain flow
- WASP
  - Real sediment transport capabilities (3 separate particles and colloids)
  - Bank moisture history
  - Overbank Deposition
- MERC4
  - No changes

Minimal Calibration

- Bank Erosion
  - Evaluate fine sediment and areal erosion estimates
  - Adjust 3 parameters
- Mercury
  - May 1994 (Med. Flow)
  - June 1995 (High Flow)
  - Adjust 2 parameters

1997 Flood



Estimated 100-Year Flood
1997 Flood
Discharge (ft³/s)
Discharge (m³/s)
Year
25,000
20,000
15,000
10,000
5,000
0
700
600
500
400
300
200
100
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

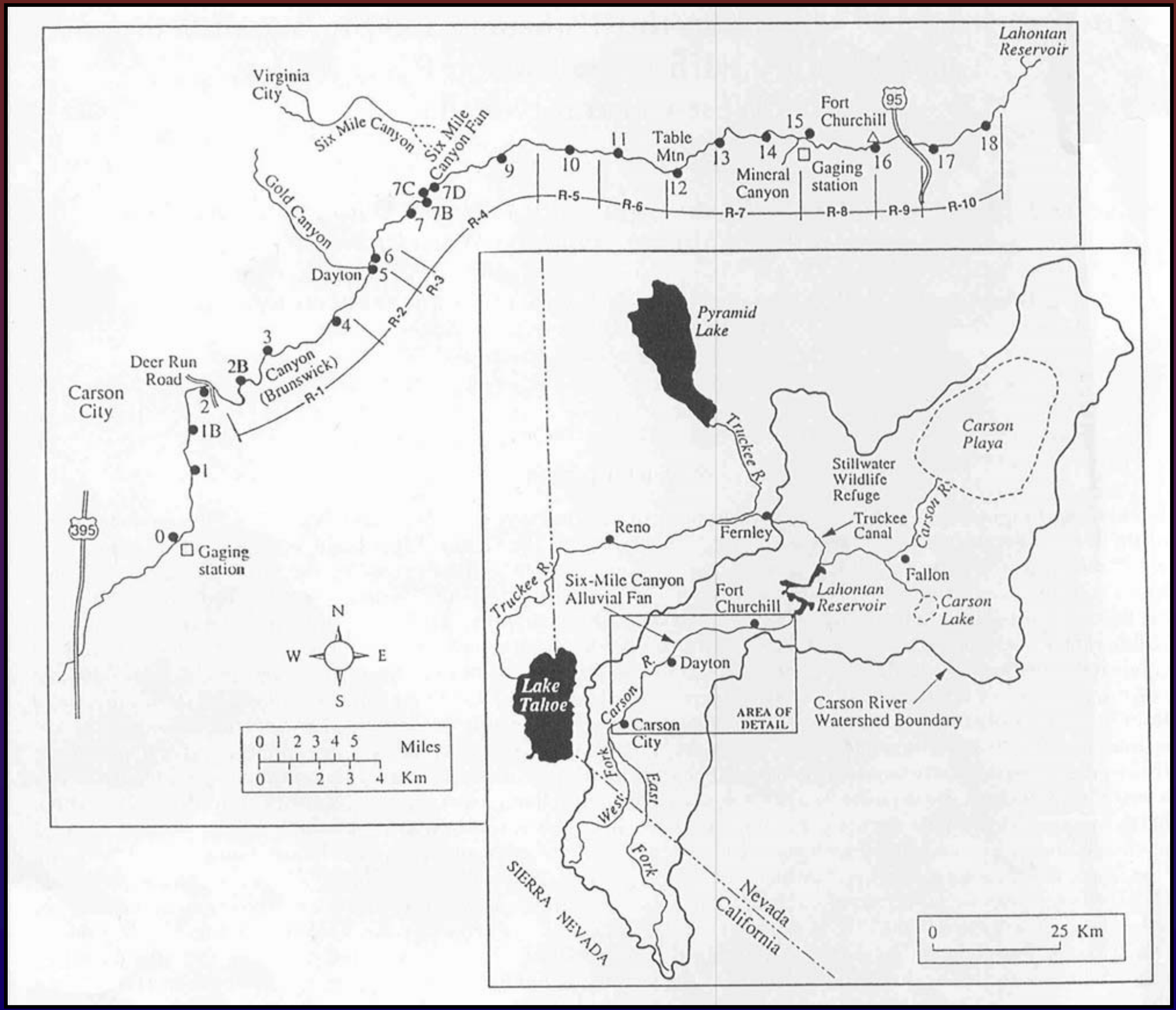
1997 Flood

Photos by Rhea Williams, USGS

Geomorphic Survey

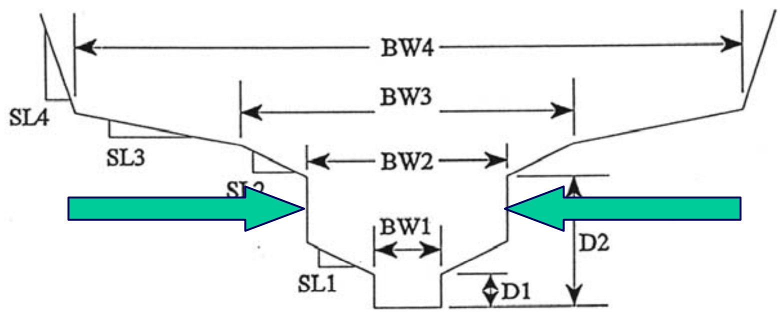
- Extensive survey conducted in the spring of 1997 using geomorphic techniques of aerial photography (taken in 1991 and 1997) and floodplain mapping

- River divided into 10 reaches based on valley slope and floodplain width



Modifications to RIVMOD

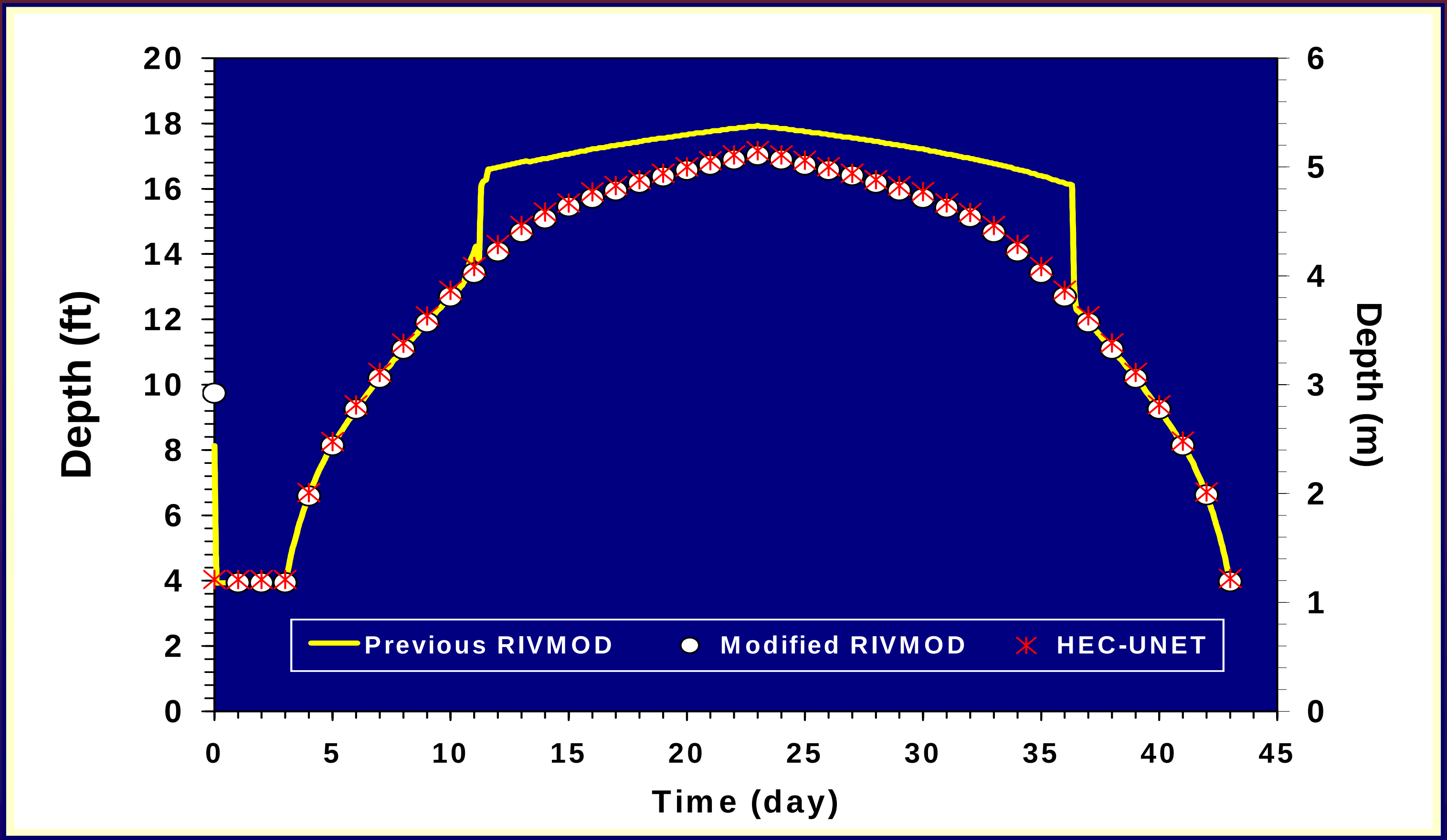
1. Handles a more complex shape
2. Computes dynamic width adjustment in which eroded mass updates channel width
3. Divided channel approach was applied to the momentum equation



D1 = Low flow inner channel depth (ft, m)
D2 = Intermediate flow channel depth (ft, m)
BW1 = Low flow inner channel width (ft, m)
BW2 = Intermediate flow channel top width (ft, m)
BW3 = Main Channel width (ft, m)
BW4 = Inner floodplain width (ft, m)

SL1 = Intermediate flow transition slope
SL2 = High flow transition slope
SL3 = Inner floodplain slope
SL4 = Outer floodplain slope

Validation of RIVMOD Code Modifications



Modeling Bank Erosion: *In-Channel Flows*

Assumptions

- The mass erosion rate, *MER* (Kg/s) is proportional to the shear stress applied to the bank
- *MER* is inversely proportional to the square-root of the channel bottom slope

$$MER = \frac{\psi_1 \rho_s \gamma_w n^2 D^{2/3} v^2 L_s}{S_0^{1/2}}$$

Where D is the water depth starting at the vertical face of the channel bank (m), and S_o is the bottom slope, v is the water velocity (m/s), n is Manning's coefficient, *and* L_S is the segment length (m)

Modeling Bank Erosion: *Overbank Flows*

A second term was added to account for the underlying change of character as the river exceeds bankfull flow (Ervine et al., 2000) such that, when D>h

$$MER_{OB} = \frac{\psi_1 \rho_s \gamma_w n^2 D^{2/3} v^2 L_s}{S_0^{1/2}} + \frac{\psi_2 \rho_s \gamma_w n^2 (D-h) v^2 L_s}{h^{1/3} S_0^{1/2}}$$

Where *h* is the height of the vertical bank face.

Modeling Overbank Deposition

Course Suspended Load

Modified version of Walling and He (1997)

$$R_s^c = \kappa V_s^c C_{main}^c \left(1 - e^{-X_f / \kappa}\right)$$

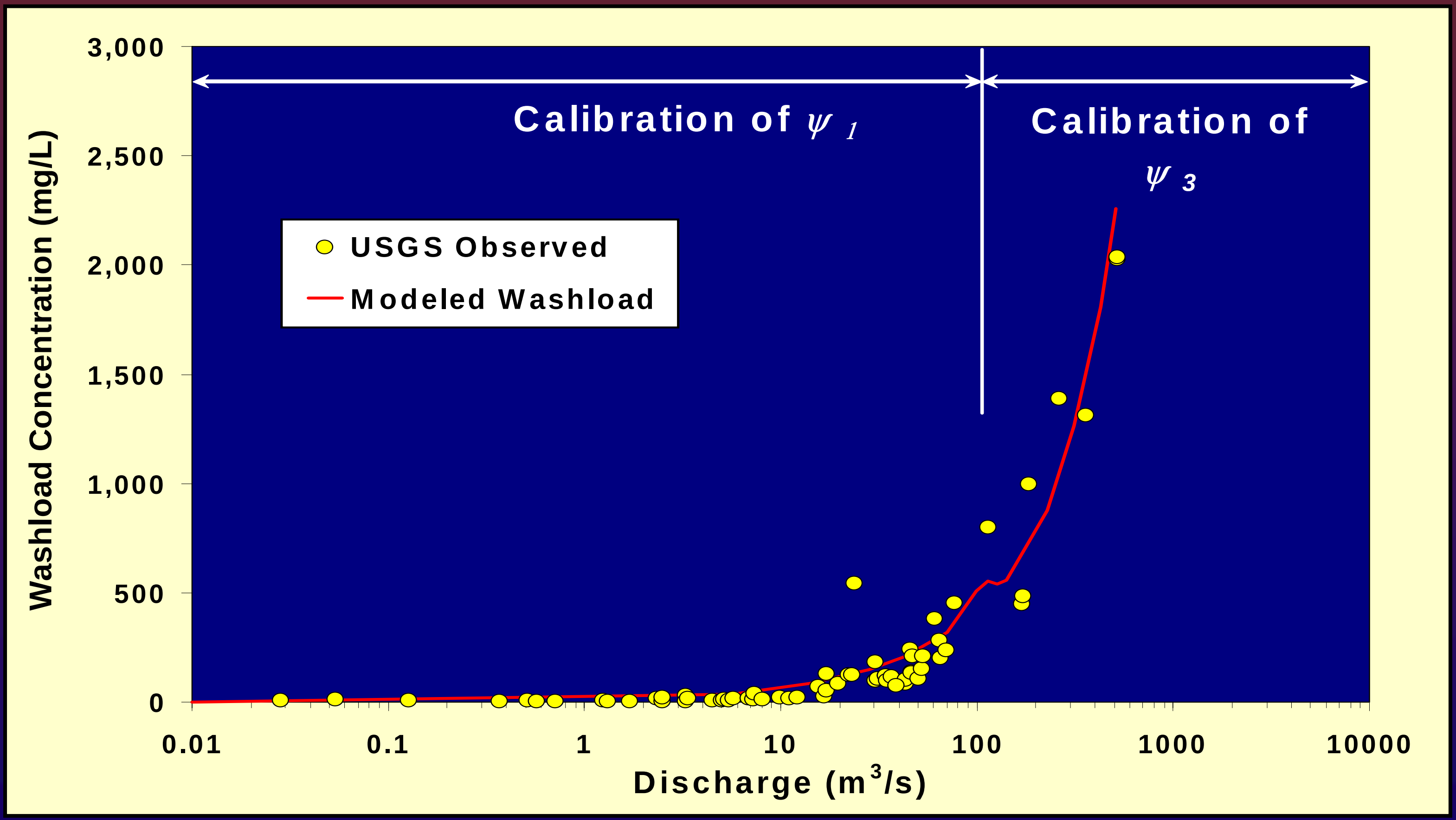
Washload

WEPP (Foster et al., 1995)

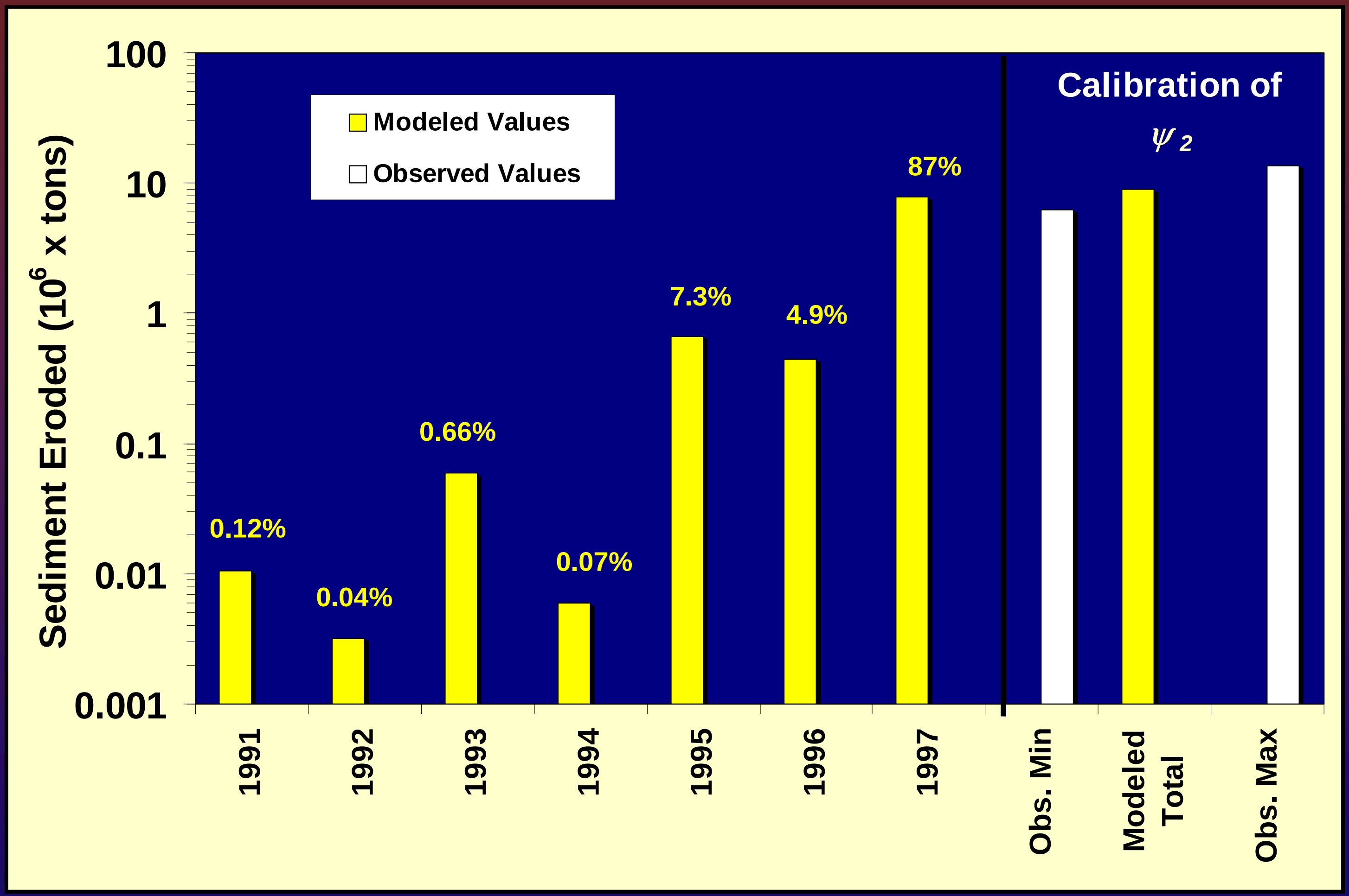
$$R_s^w = \frac{\bar{\beta} V_s^w}{q_f}\left(G_{main}^w - T_c\right)$$

$$T_c = \psi_3 q_f^2 S_0^{1.66}$$

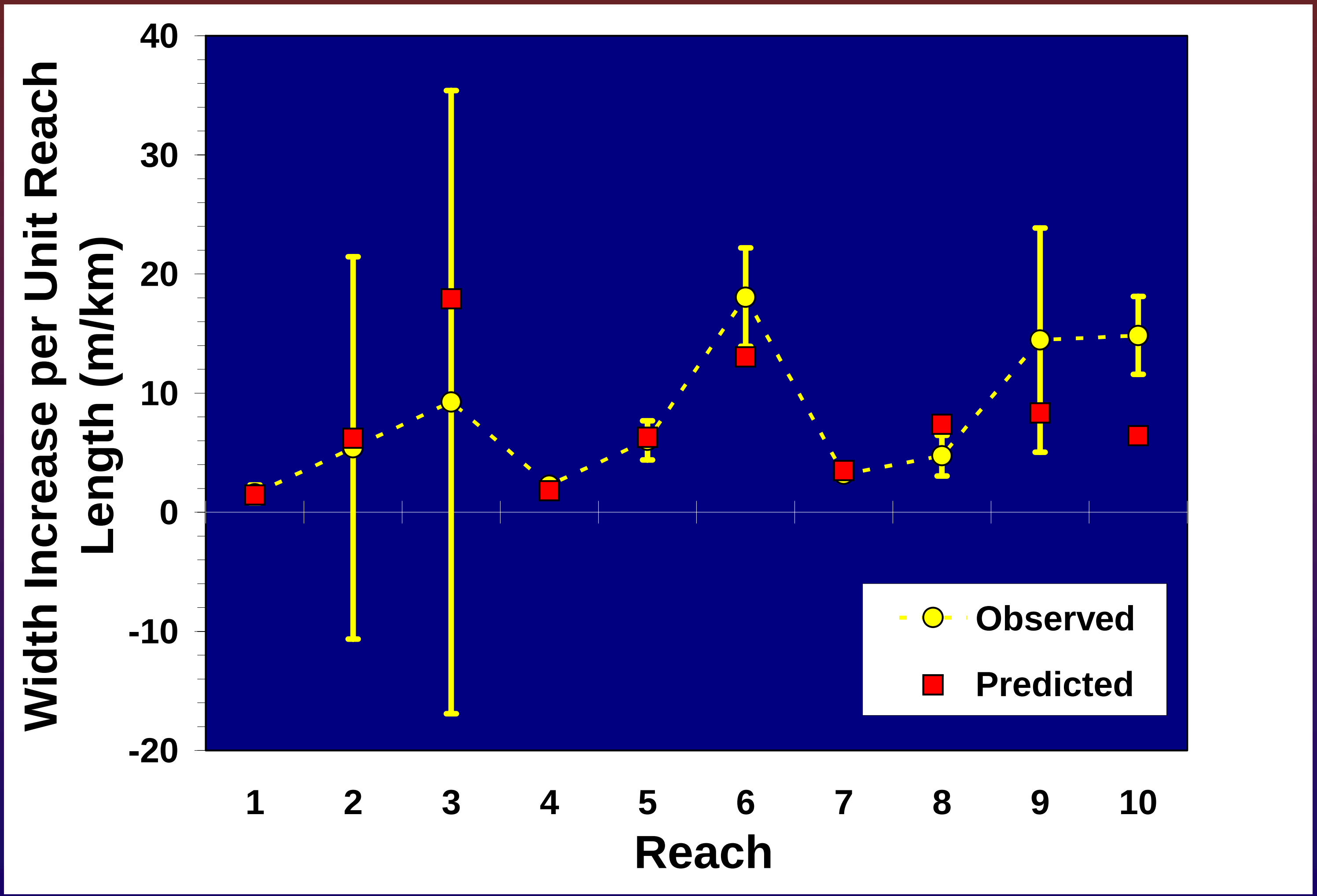
Calibration In-Channel Bank Erosion (Ψ_1) and Washload Overbank Deposition (Ψ_3)



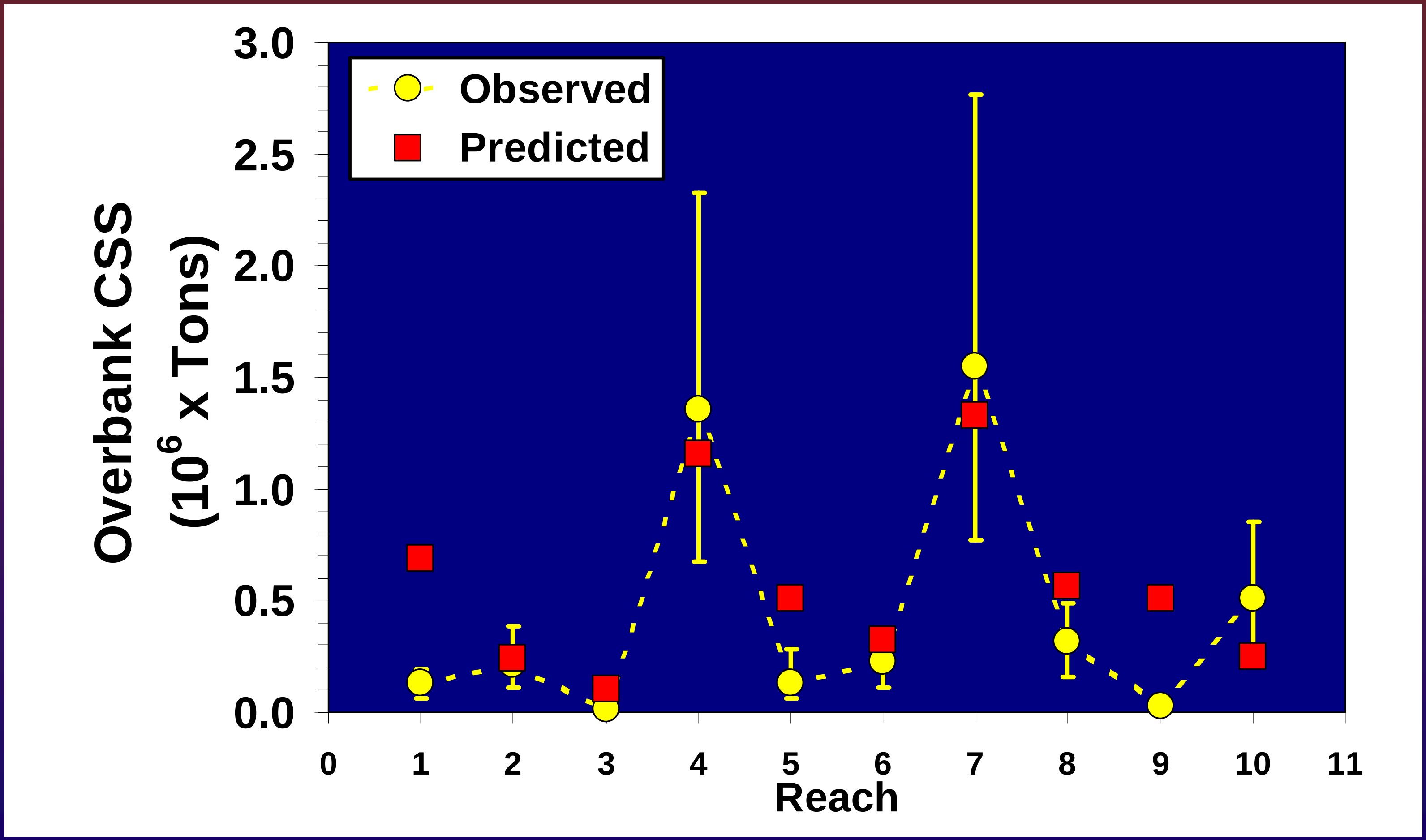
Calibration Overbank Bank Erosion (Ψ_2)



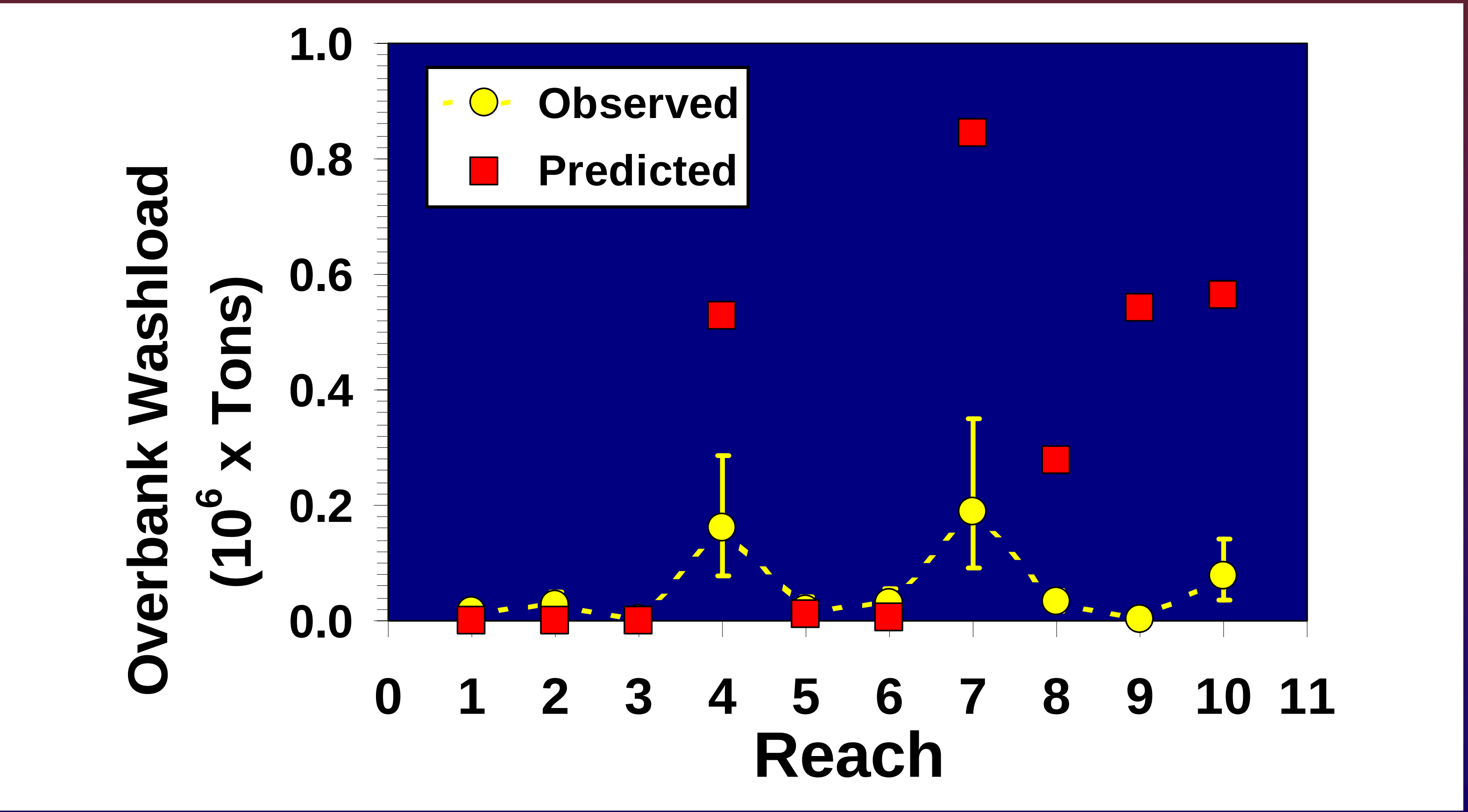
Channel Width Increases



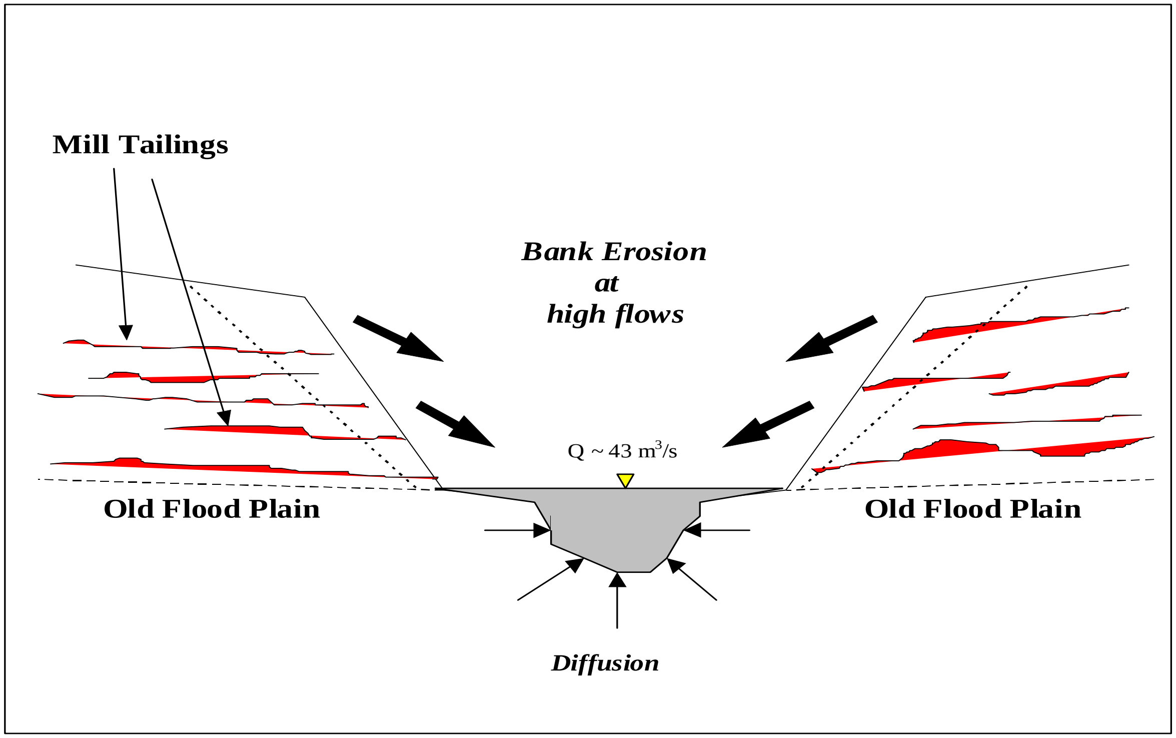
Overbank CSS Deposition



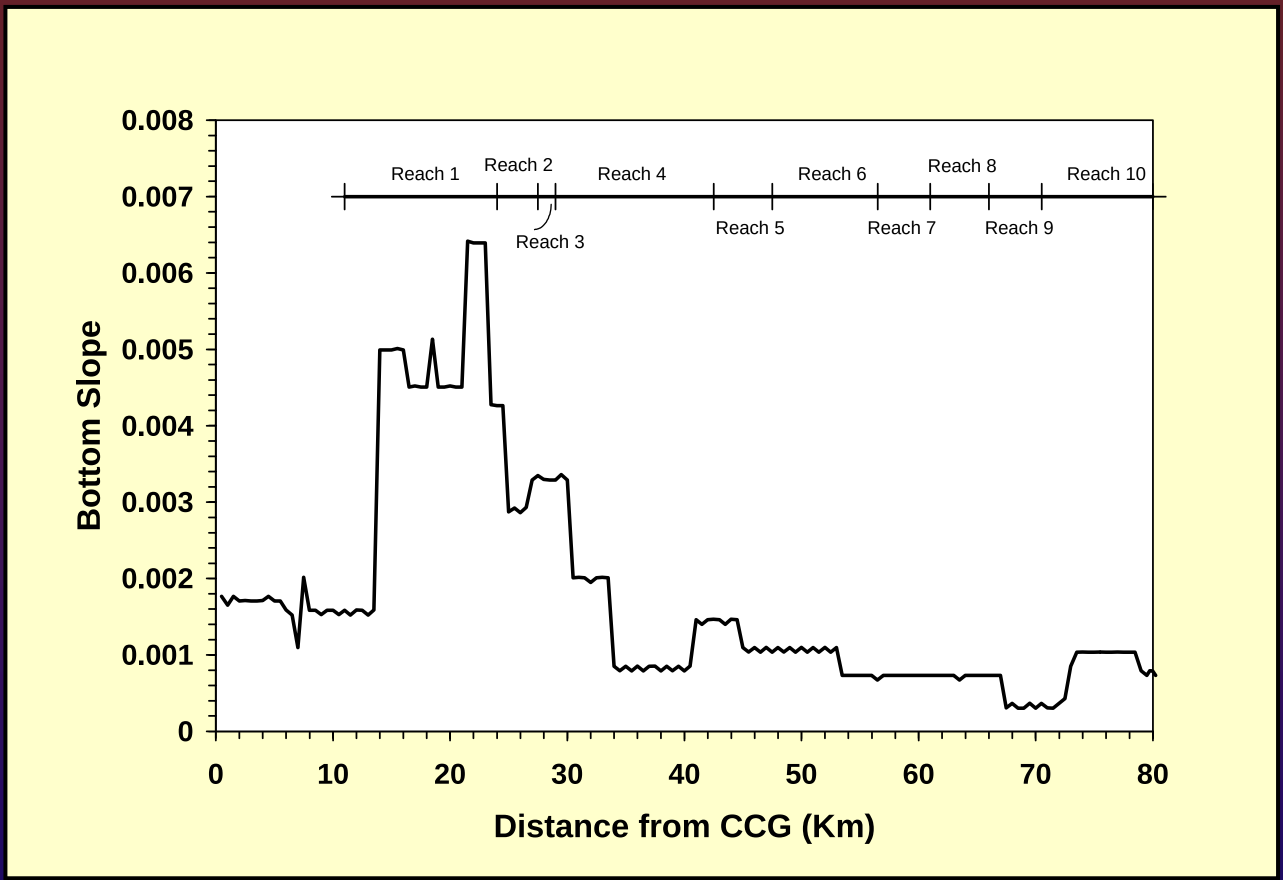
Overbank Washload Deposition



Sources of Hg to the Water Column

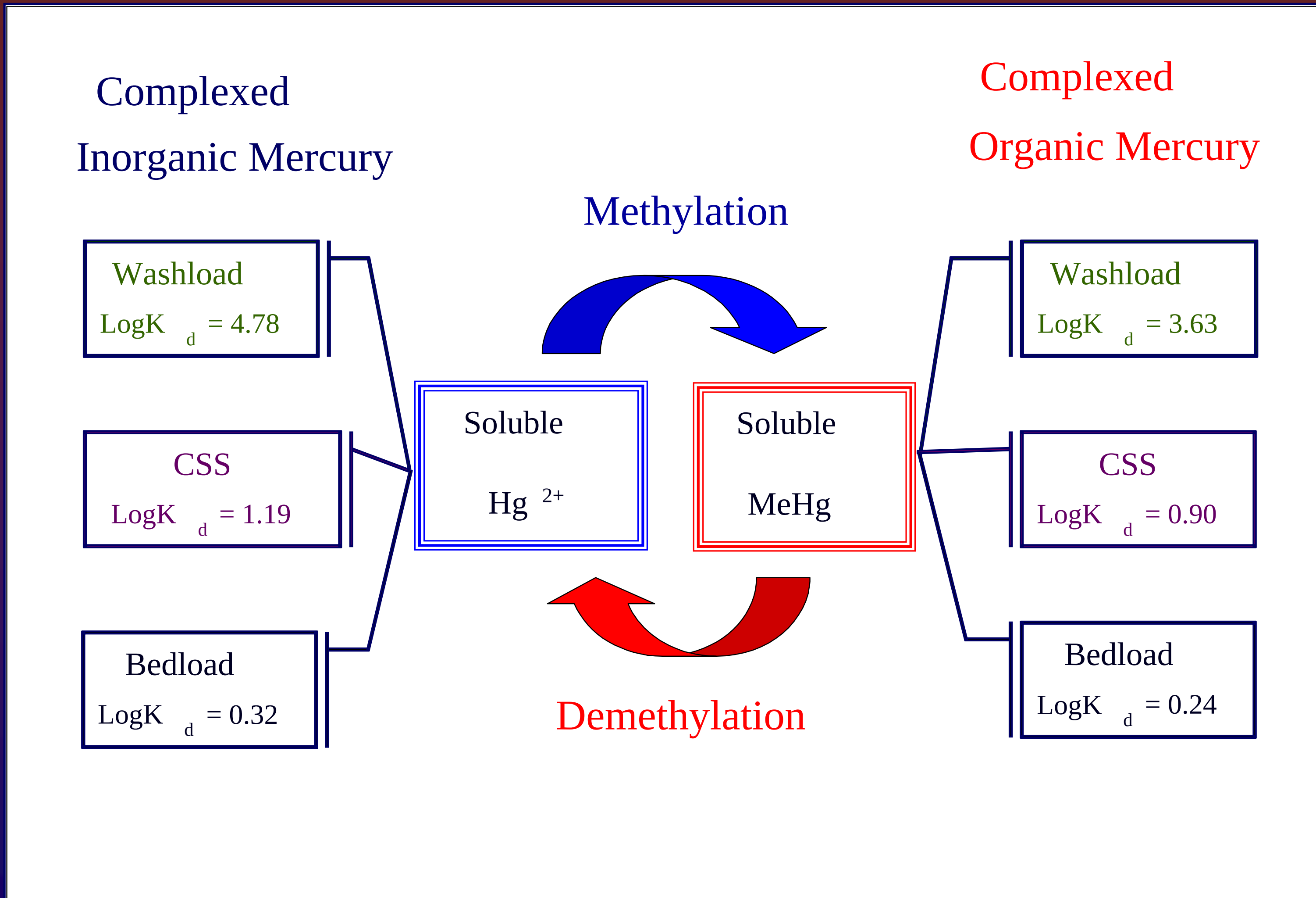


Inorganic Hg from Bank Erosion



$$[Hg_{in}]_{bank} = \frac{\lambda_1}{S_0^{0.5}}$$

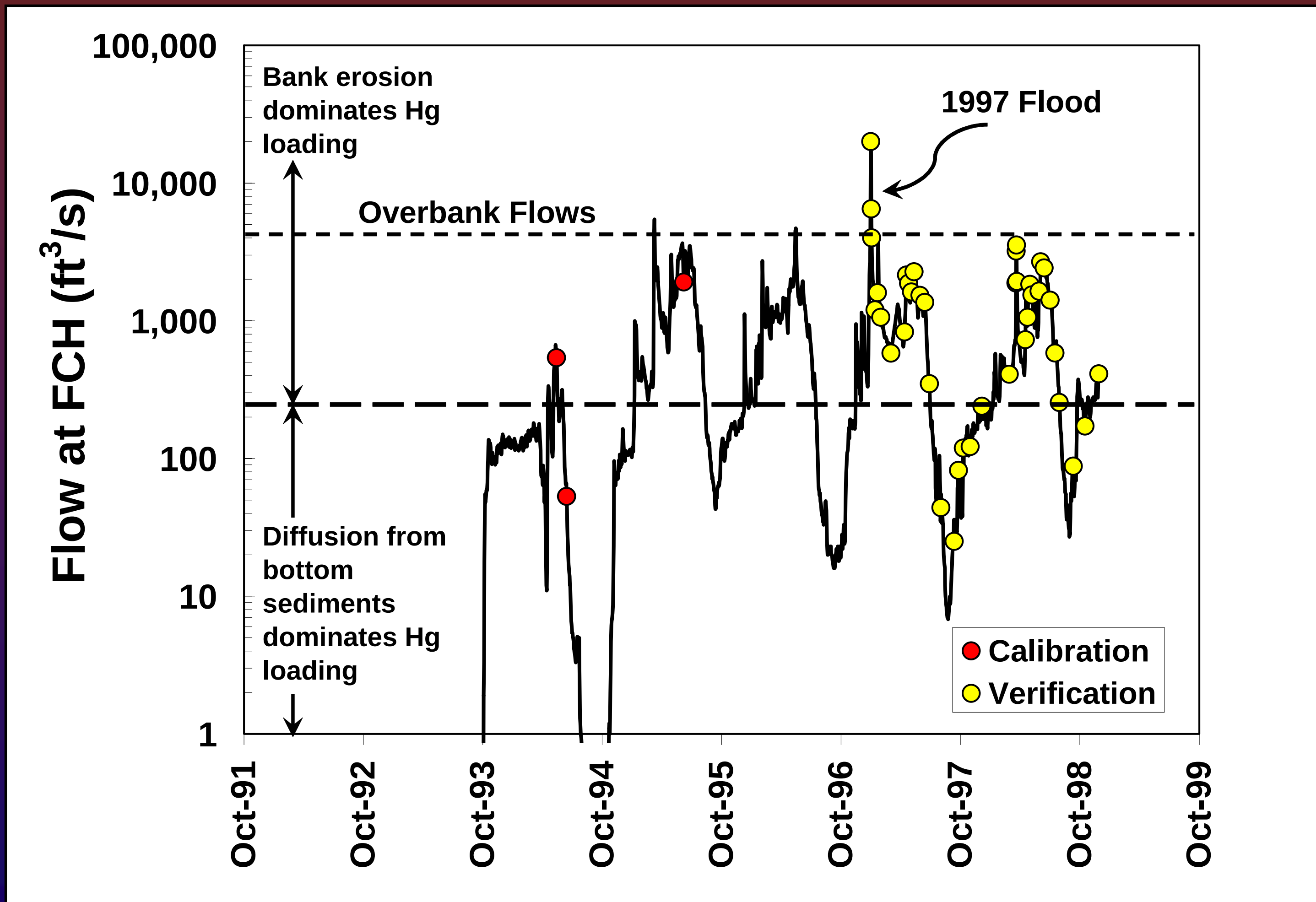
Mercury Speciation



MeHg Bank Concentrations

- Water content
- Percent MeHg
- Methylation rates
- Non-linear contribution of MeHg from bank erosion?

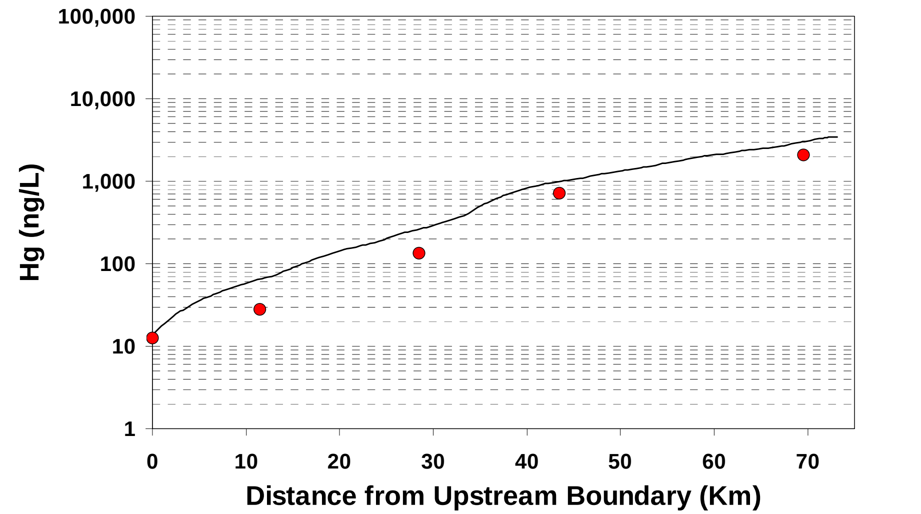
Inorganic Mercury & MeHg Calibration & Verification

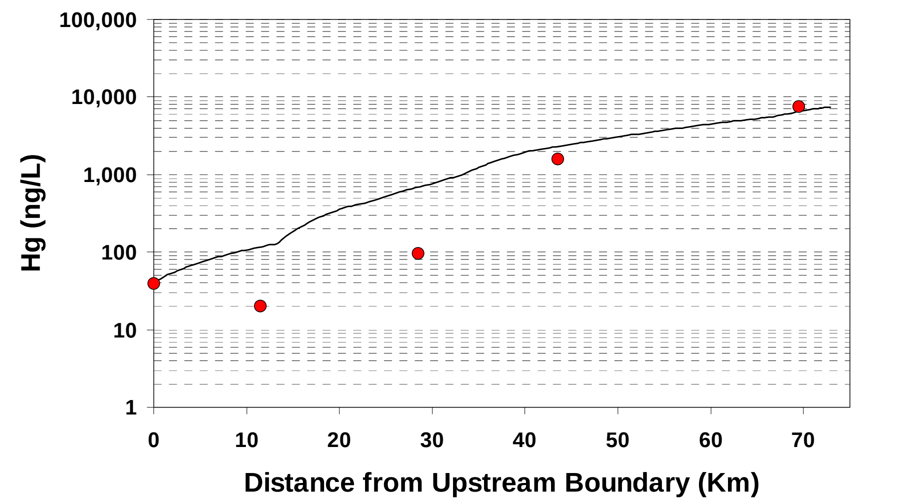


Calibration Hg_{in} Transport: Pre-1997 flood

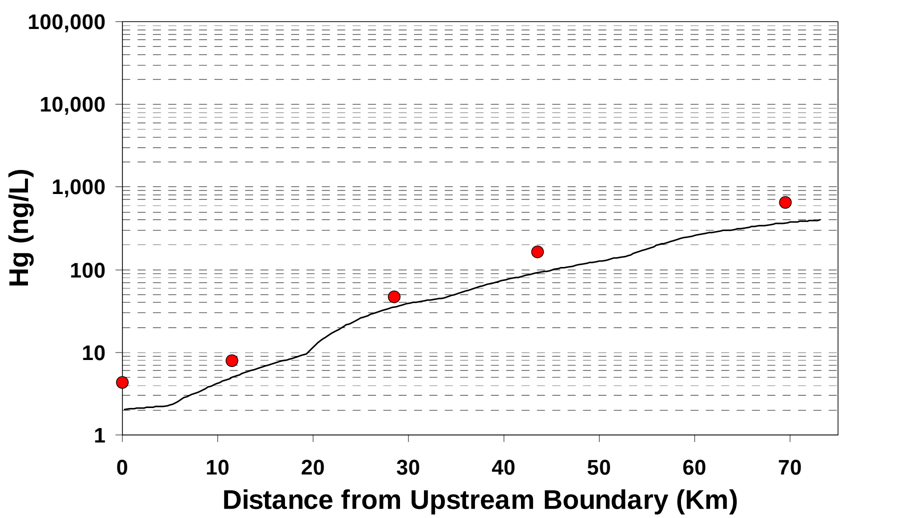
λ_1 = 2,500 µg/kg

May 16, 1994 (medium flow Q = 600 ft^3/s)



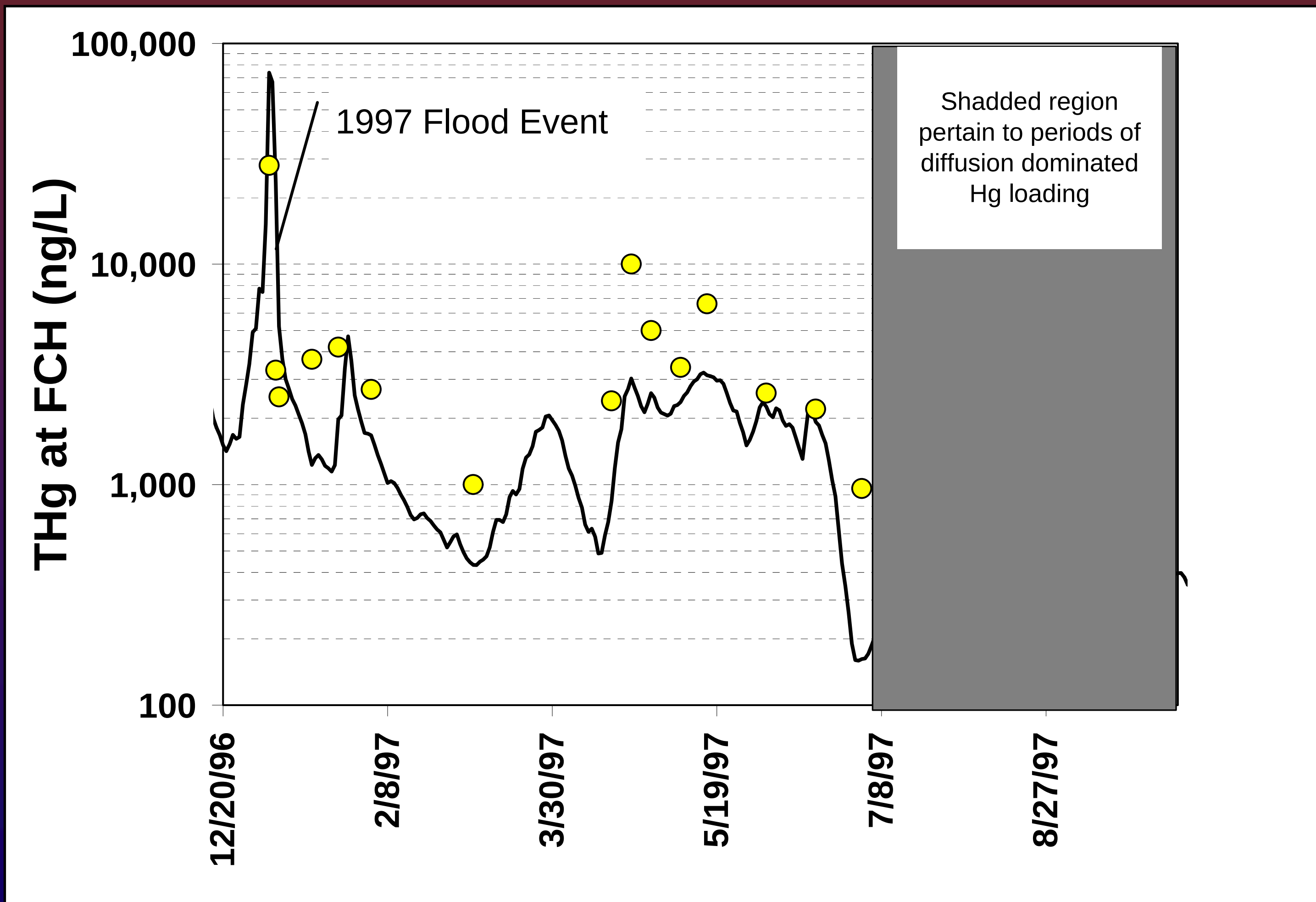


June 10, 1995 (higher flow Q = 1,960 ft^3/s)

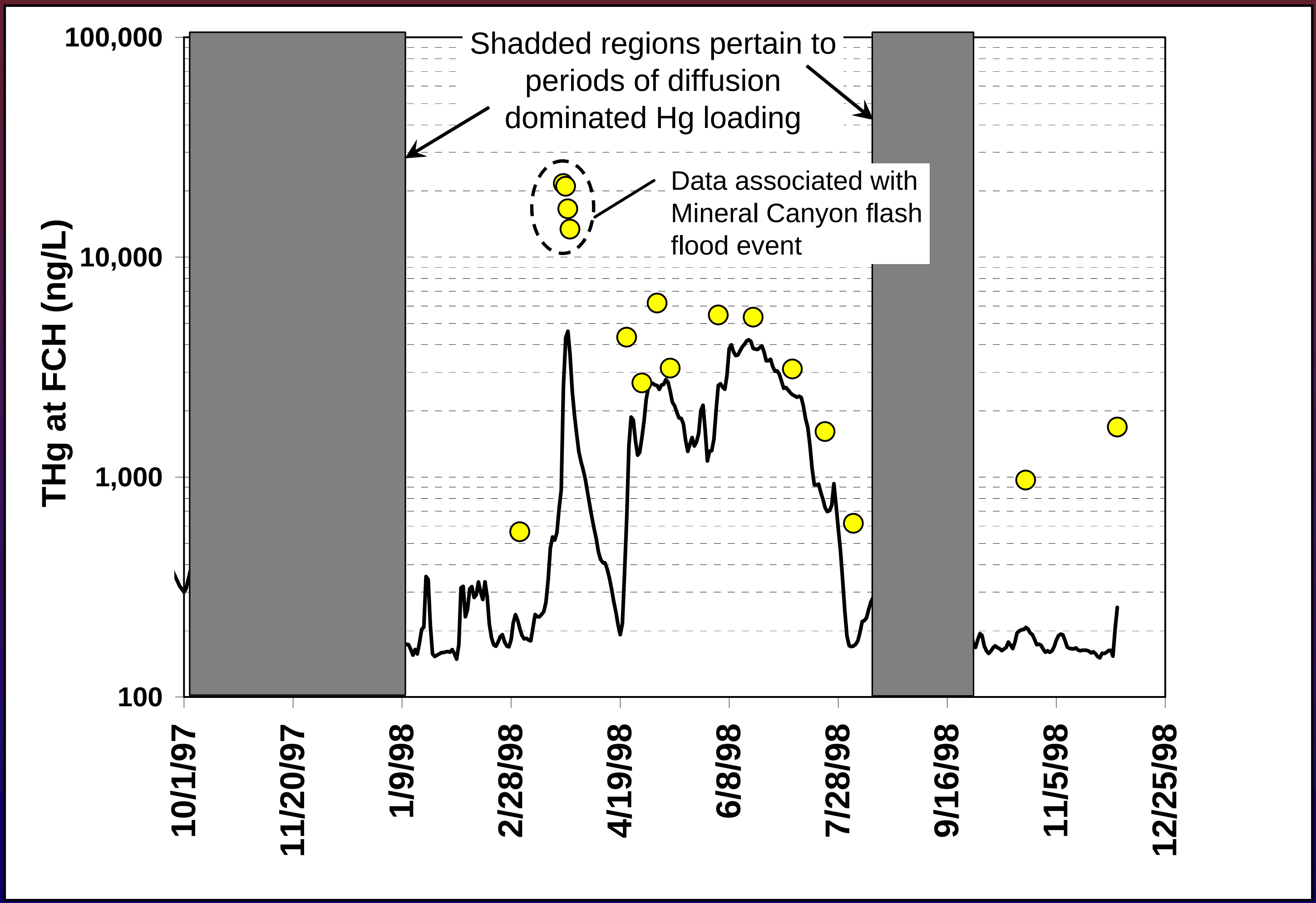


June 16, 1994 (low flow Q = 62 ft^3/s)

Verification Hg_{in} Transport: 1997 flood and beyond

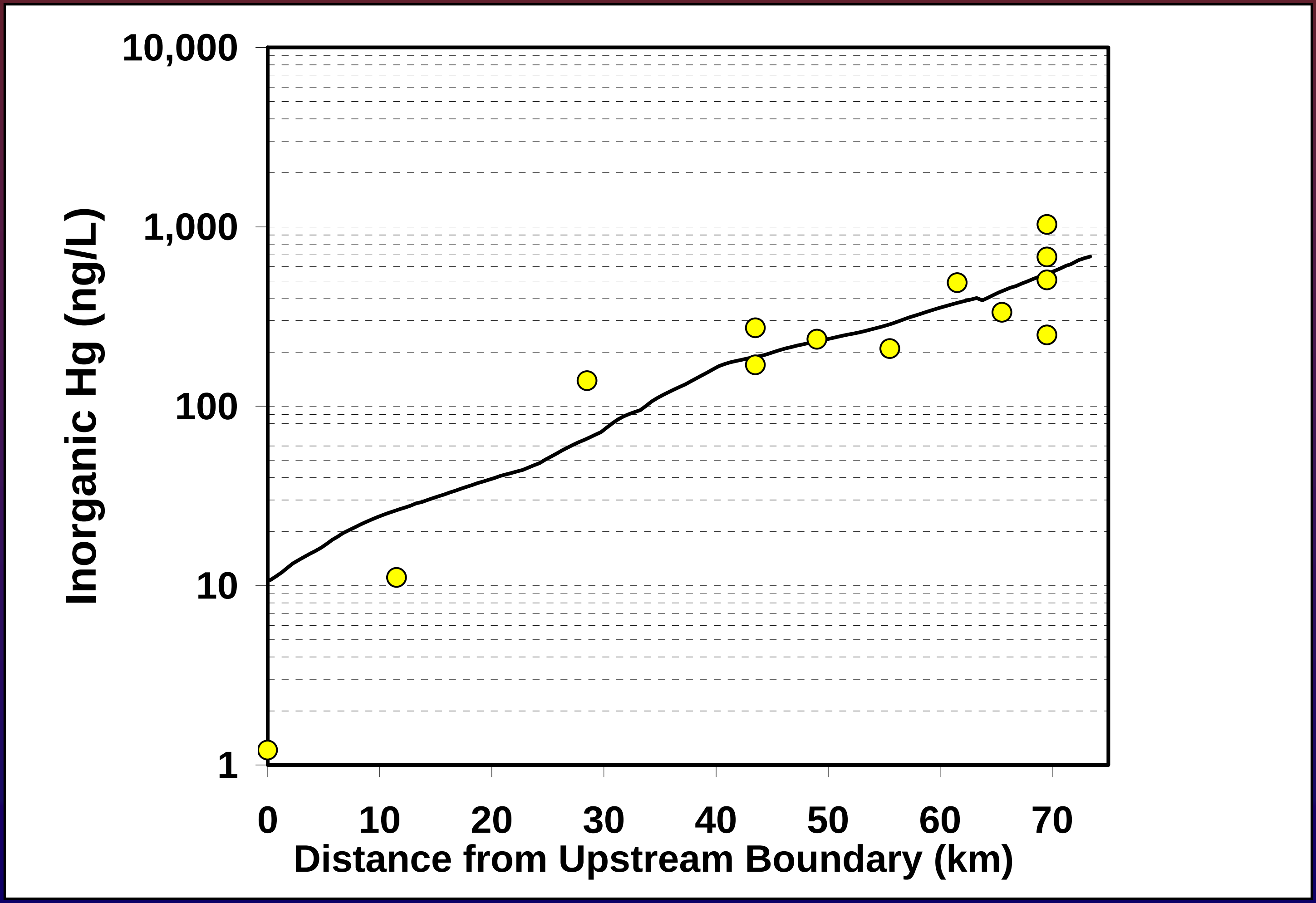


Verification Hg_{in} Transport: 1997 flood and beyond



Verification using July 23-29, 1997

(low flow Q = 43 ft^3/s)



Mercury Rates and Calibration

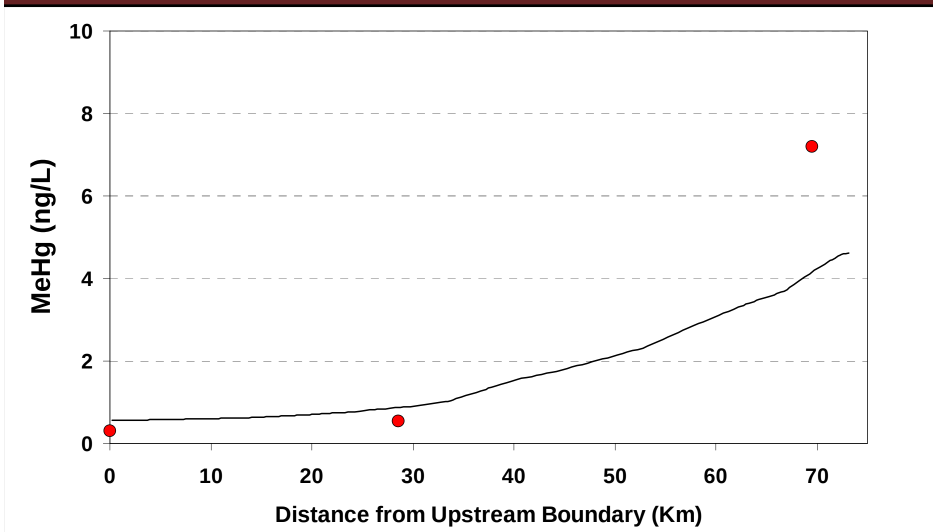
Location	Methylation $K_{20}(day^{-1})$	Methylation Q_{10}	Demethylation $K_{20}(day^{-1})$	Demethylation Q_{10}	Range (Km)
Water Column	0	2.03	0	2.03	0 - 115.0
River Bed	0.0041	2.03	0.4483	2.03	0 - 79.25
River Bank	0.0060*	2.03	0.4483	2.03	0 - 79.25
Reservoir Bed	0.0028	2.03	1.2522	2.03	79.25 - 115.0

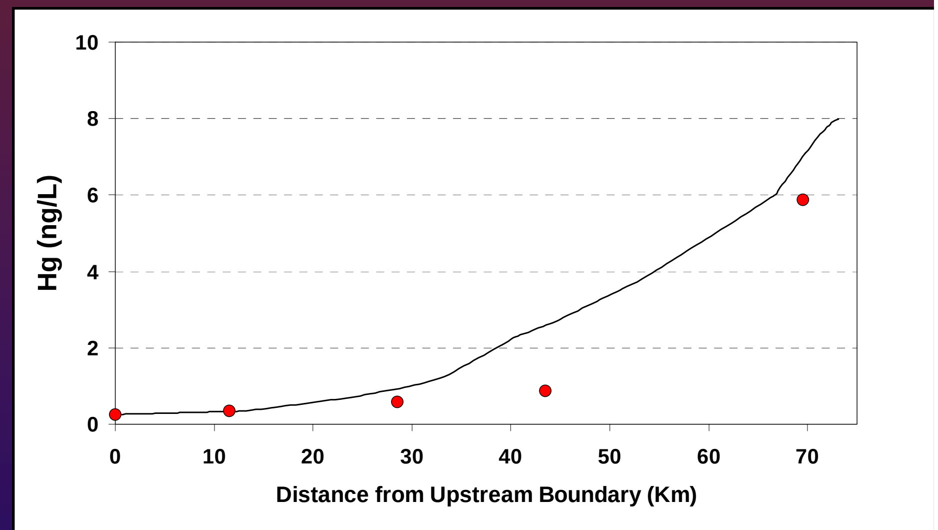
* calibrated

Calibration MeHg Transport: Pre-1997 flood

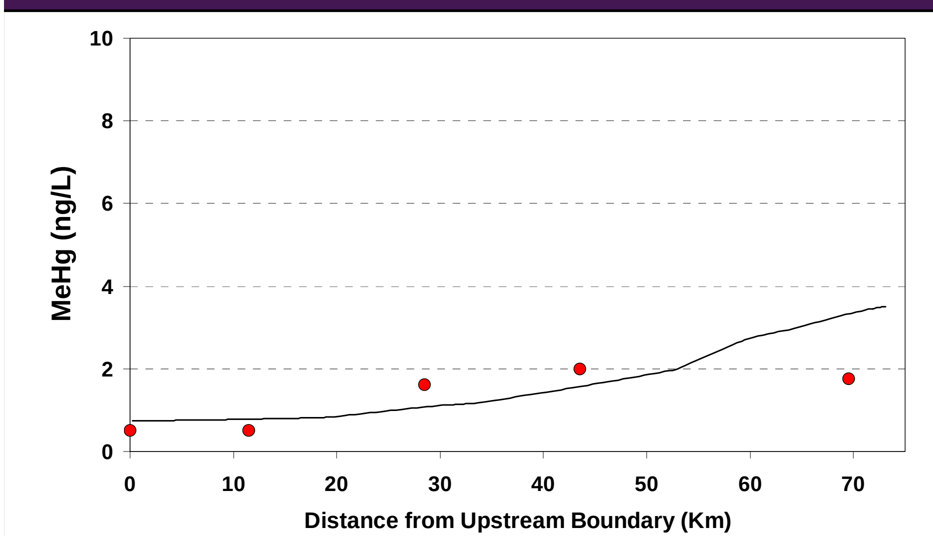
$K_{20}(M_{bank}) = 0.0060 \text{ day}^{-1}$

May 16, 1994 (medium flow Q = 600 ft^3/s)



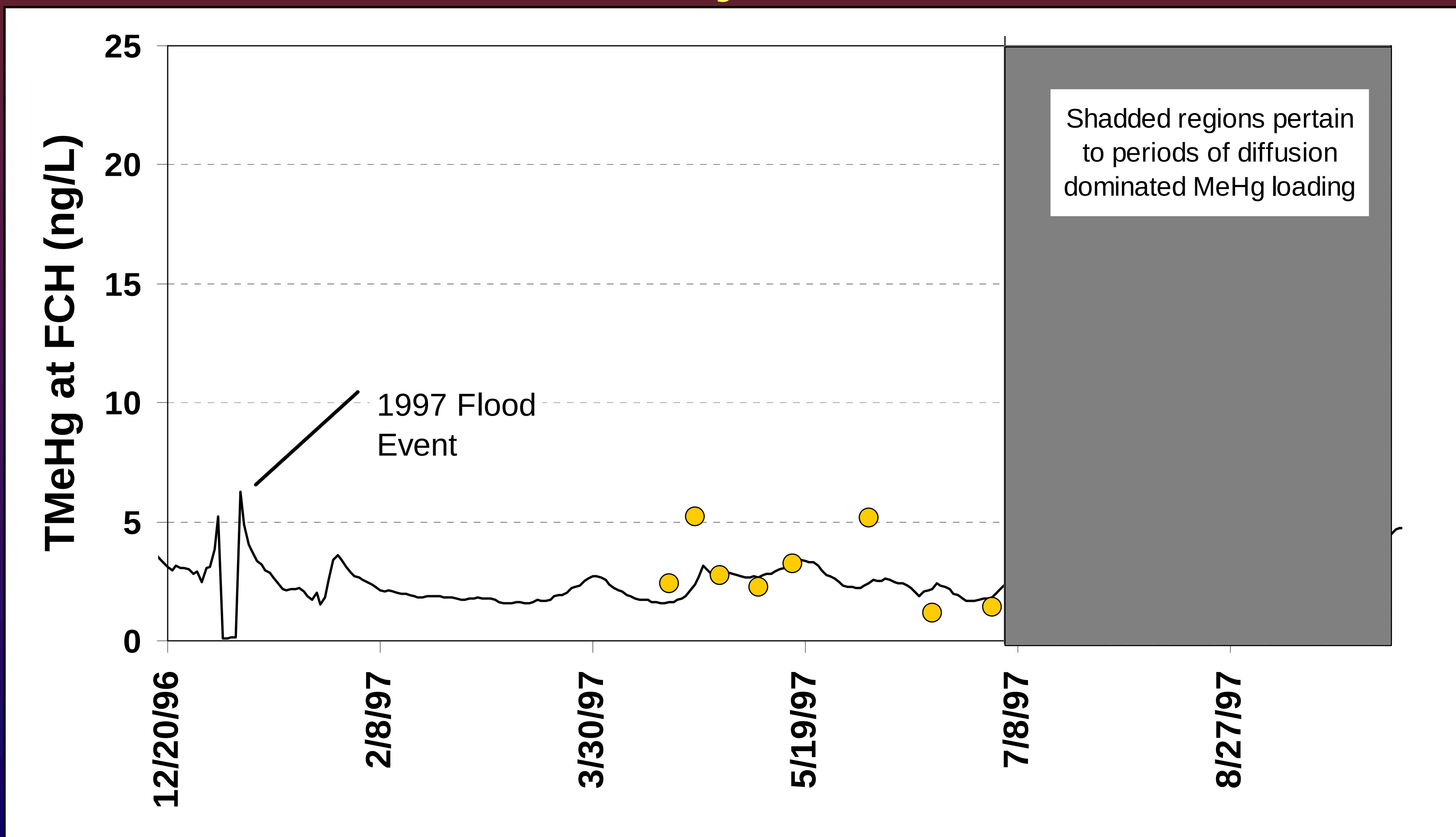


June 10, 1995 (higher flow Q = 1,960 ft^3/s)

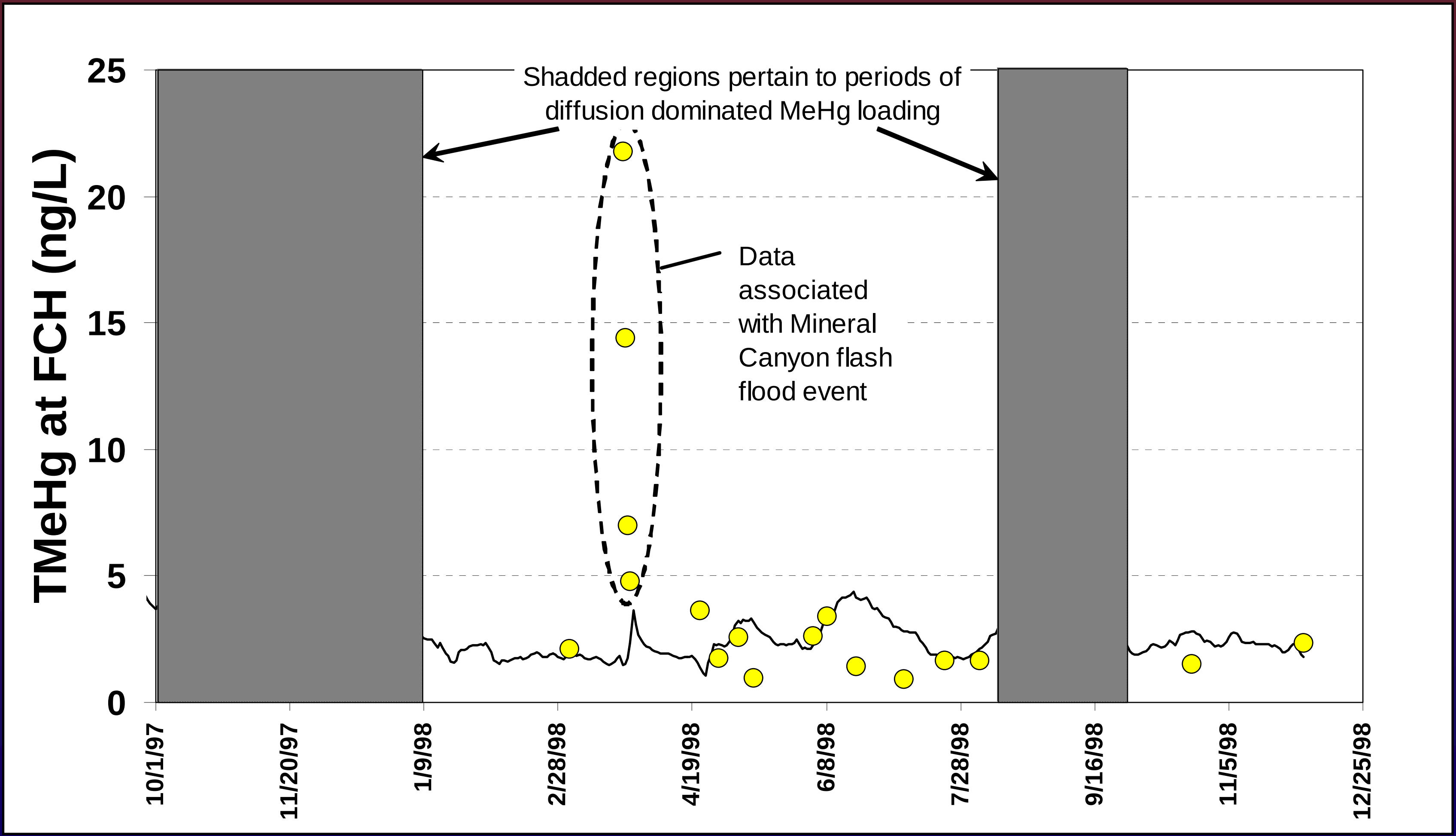


June 16, 1994 (low flow Q = 62 ft^3/s)

Verification MeHg Transport: 1997 flood and beyond

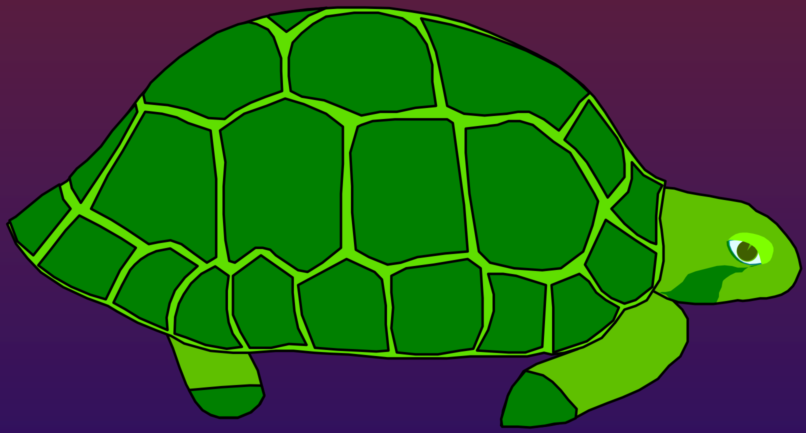


Verification MeHg Transport: 1997 flood and beyond



Ongoing Activities

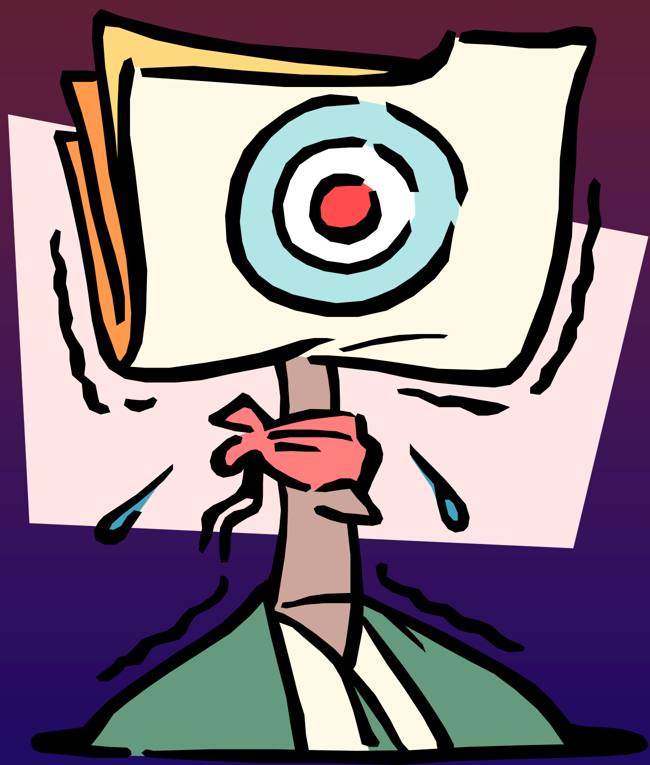
- Reservoir physical characterization
- Reservoir net settling
- Characterize erosion uncertainty
- Perform Monte Carlo analysis to determine probable range of predicted system behavior



Conclusions

- Simplistic model of bank erosion predicts in-stream sediment concentrations well over a large flow domain and channel widening well over a large spatial domain
- Overbank deposition of Course Suspended Sediment is predicted well without calibration over a large spatial domain
- Overbank deposition of Washload is correctly over-predicted, but this does not validate the approach
- In-stream inorganic and methyl mercury concentrations are predicted well over a large spatial and flow domain

Recommendations



- Determine measures of mercury bioavailability
- Re-define mercury methylation and demethylation kinetics
  - First-order?
  - Important environmental factors and associated corrections
- Deal with and express impacts from parameter uncertainties