A Synthesis of Mercury Science to Support TMDL Implementation (Phase 1 Control Studies) for San Francisco Bay - Delta Wetlands and Irrigated Agriculture

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USGS

Goal: Provide a comprehensive, pooled-resource planning document

Steering Group

Stephen McCord (McCord Environmental, Inc.)
Mary Lee Knecht (Sac. River Watershed Program)
Sally Liu (The Nature Conservancy)
Mark Stephenson, Wes Heim (Moss Landing)
Carol Atkins (CA Dept. Fish & Game)
Josh Ackerman, Lisamarie Windham-Myers (USGS)
Kevin Petrik, Aaron Will (Ducks Unlimited)

NPS Wetlands and Irrigated Agriculture Workgroup

Land Owners and Managers (C-DFG, C-DWR,
U.S. BLM, U.S. FWS, TNC, DU, CWA, WES
Mercury Researchers (CDFG-MLML, USGS)
Regulatory Agencies (CVRWQCB, U.S.EPA)

Synthesis of Literature:

DRERIP MCM (2008)

Sacramento-San Joaquin Delta
Regional Ecosystem Restoration Implementation Plan

Ecosystem Conceptual Model

Mercury

Prepared by: Charles N. Alpers,, U.S. Geological Survey
cnalpers@usgs.gov

and
Collin Eagles-Smith, U.S. Geological Survey and U.S. Fish Wildlife Service
Chris Foe, CA Regional Water Quality Control Board – Central Valley Region
Susan Klasing, California Office of Environmental Health Hazard Assessment
Mark C. Marvin-DiPasquale, U.S. Geological Survey
Darell G. Slotton, University of California, Davis
Lisamarie Windham-Myers, U.S. Geological Survey

Date of Model: January 24, 2008

Status of Peer Review: Completed peer review on January 22, 2008. Model content and format are suitable and model is ready for use in identifying and evaluating restoration actions.

Suggested Citation: Alpers C, Eagles-Smith C, Foe C, Klasing S, Marvin-DiPasquale M, Slotton D, and Winham-Myers L. 2008. Mercury conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

For further inquiries on the DRERIP conceptual models, please contact Brad Burkholder at BBURKHOLDER@dfg.ca.gov or Steve Detwiler at Steven_Detwiler@fws.gov.

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- Peer-reviewed local-national-global literature
- with a focus on publications relevant to processes in Delta MeHg production and export
- Focus on new literature 2008 to "in review"

+

Review of findings from 14 recent projects studying MeHg in SFB-Delta wetlands (managed or natural) and irrigated agriculture

This literature review and synthesis is not exhaustive.
This is targeted on Delta MeHg TMDL needs.

- Relative importance of different Hg sources
- Environmental conditions regulating methylation
- Improved monitoring techniques for loads (mass/time)

BUT

- Limited section on biotic uptake and effects:

Should biota be a bigger part of TMDL implementation?

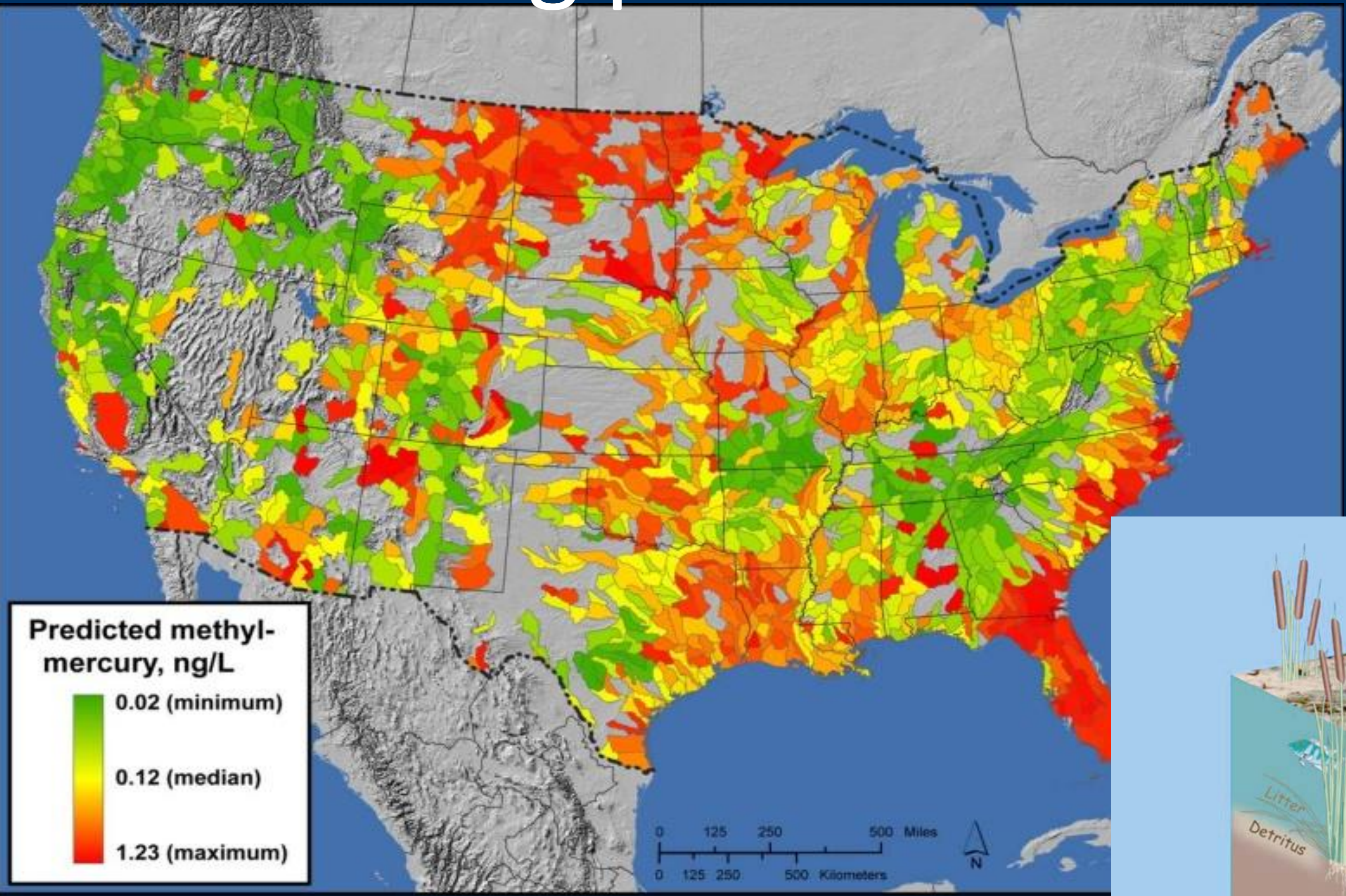
Other updated literature reviews:

C-MERC review article on SFB (Davis et al in review)

Website Links to Delta-specific studies

MLML , USGS, UCDavis, DTMC, new NPS website

Wetlands and DOC are important to MeHg production and export



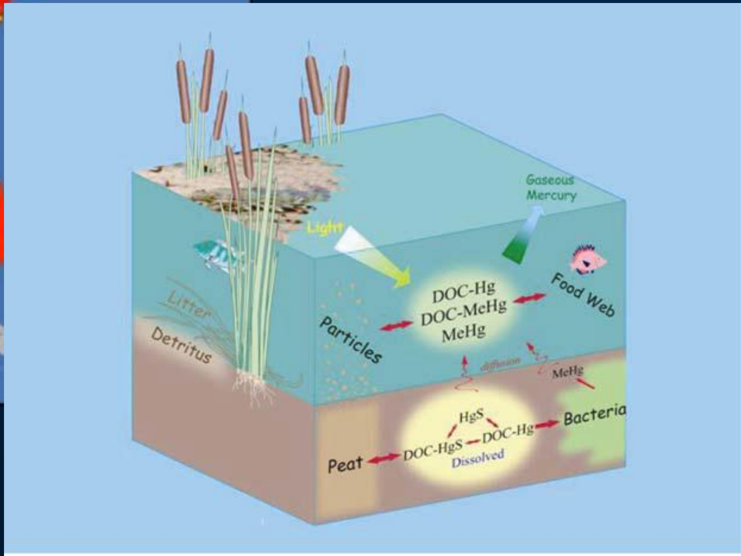
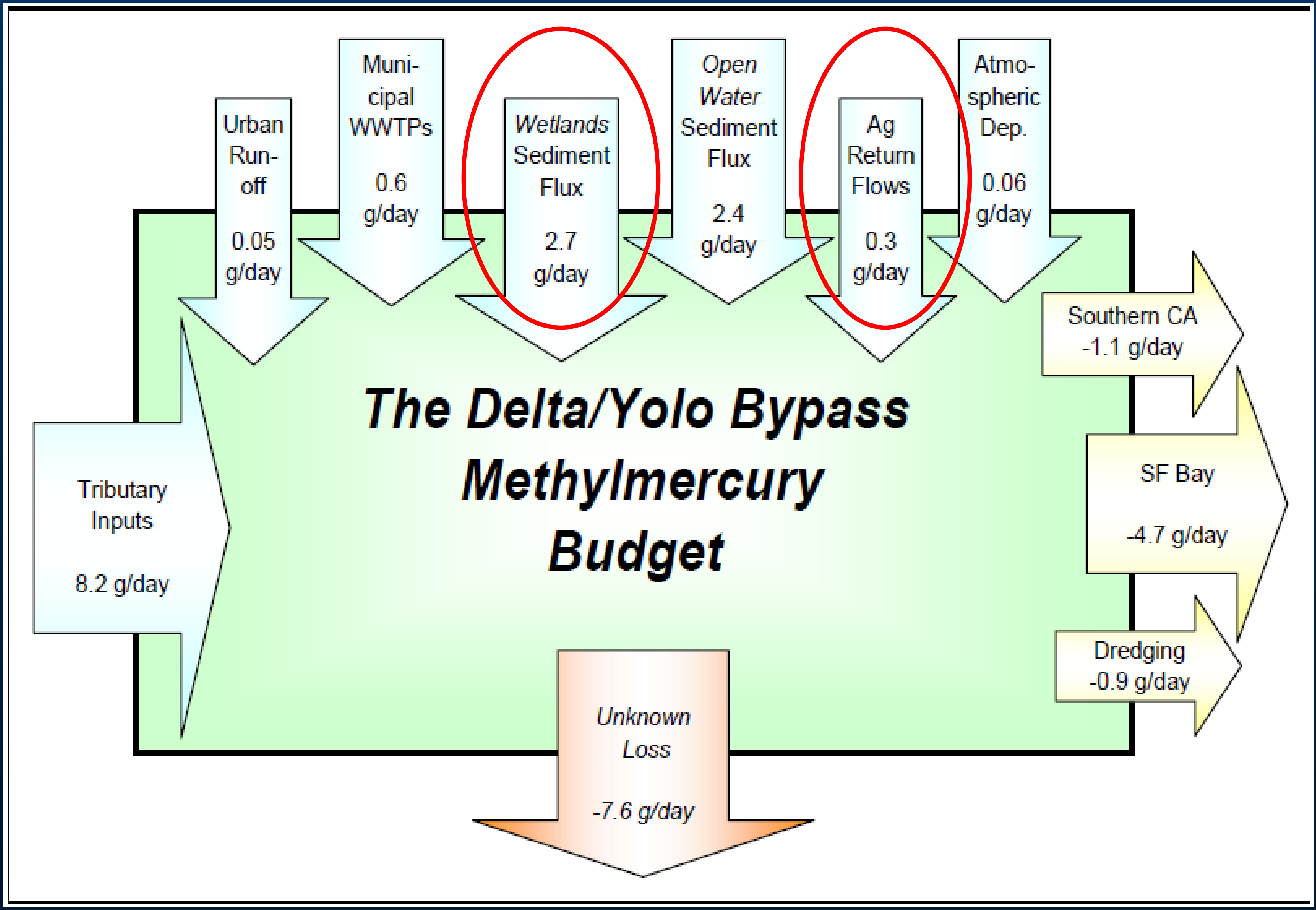


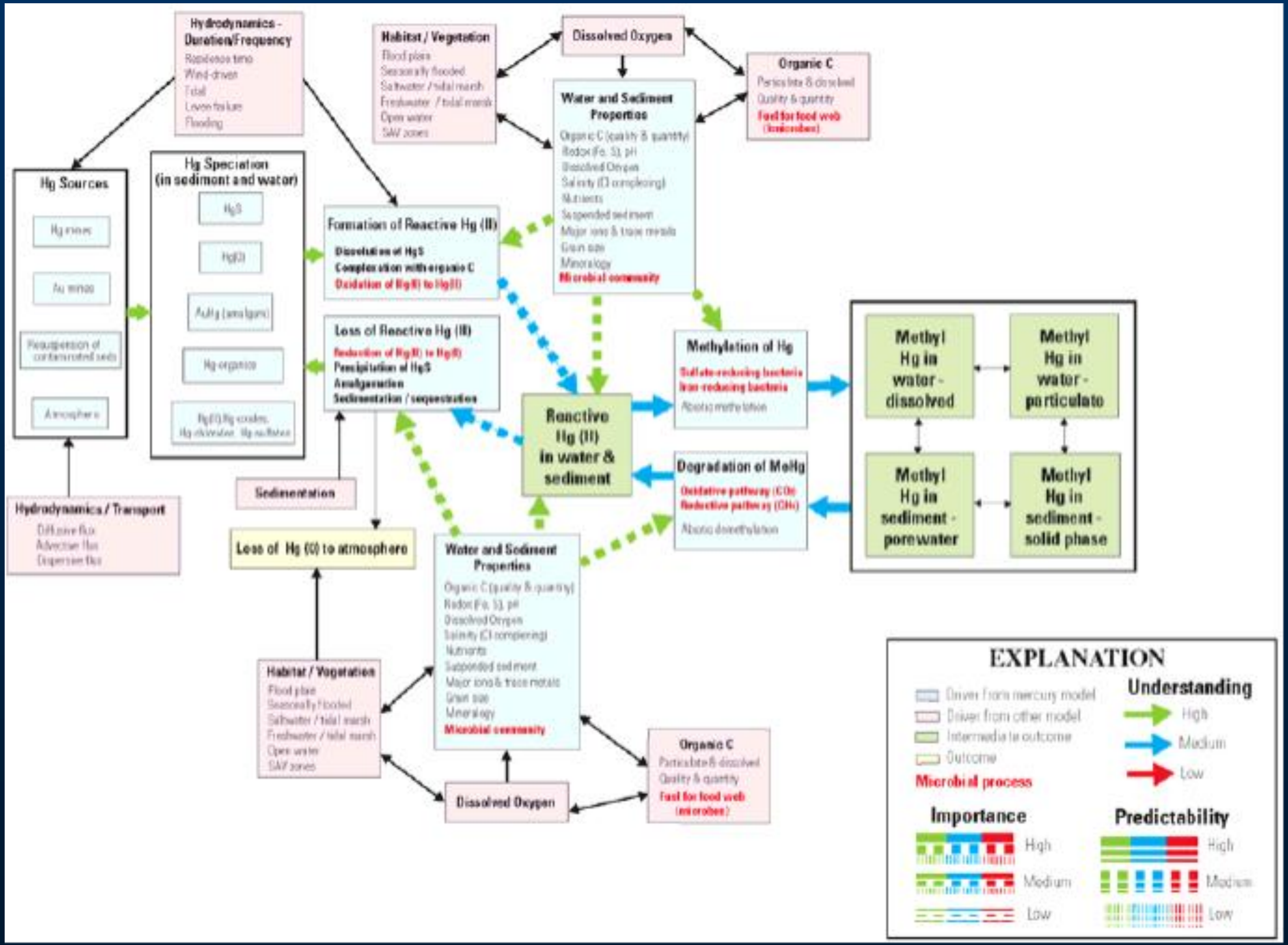
Fig. 1. Conceptual model of mercury-DOM interaction in peat sediments

USGS

Box Model - Foe et al. 2008



DRERIP-MCM – Methylation Submodel (#1)

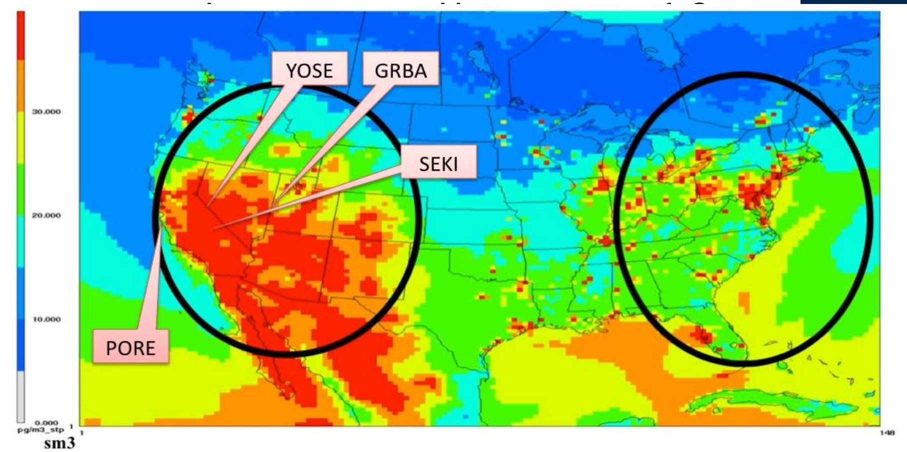


Sources of Hg to Delta

Table 1. Relative magnitude, reactivity, and importance of mercury sources to methylmercury production to the SFB-Delta, revised from DRERIP (Alpers et al., 2008)
[L, low; M, moderate; H, high; NA, not applicable]

Source	Hg Speciation	Magnitude of Total Hg Load to Delta	Reactivity (susceptibility to methylation)	Importance to MeHg Production in Delta	Uncertainty	References
PRIMARY SOURCES						
Atmospheric	Hg(II)	L	H	M	M	1
Urban runoff	Various	L	M			
Wastewater	Various	L	M			
Mercury mines	HgS +	H	L			
Gold mines	Hg(0)	H	L – M			
SECONDARY SOURCES						
Resuspension	Various	H	L – M			

References: 1, Stephenson et al. 2007; 2, Wood et al.



Map of proposed NAAMEX flight areas in the Western and Eastern US with locations of proposed parks (YOSE, SEKI, GRBA, PORE), adapted from http://research.uwb.edu/jaffegroup/publications/NAAMEX_Whitepaper_v14.pdf.

The map colors correspond to RGM at the surface calculated with the CMAQ model. High concentrations of RGM in the Western US are a result of tropospheric oxidation (in the model) and high RGM concentrations in the Eastern US are from direct industrial emissions (R.Bullock personal communication).

Table 2. Expected habitat-specific methylmercury concentrations in sediment and overlying water in the San Francisco Bay-Delta region. From DRERIP-MCM, by Alpers et al. (2008)
[L, low; M, moderate; H, high; NA, not applicable]

Habitat	MeHg Overlying water	MeHg Sediment	Flooding Characteristics: Flooding mode	Months typically flooded (wet year)	Conditions during episodic flooding Cool / Warm / Hot (wet year)	References
Managed Wetlands						
Permanently Flooded Wetlands (Submerged Aquatic Vegetation)	L – H	M	Perennial	All	All	1
Permanently Flooded Wetlands (Emergent Vegetation)	L – H	M	Perennial	All	All	1,8
Permanently Flooded Wetlands: Floating Vegetation	M	?	Perennial	All	All	10
Seasonal wetlands, winter flooded	H	H	Seasonal	Oct-Mar	Cool	6
Seasonal wetlands, "reverse cycle"summer flooded	H	?	Seasonal	May-Aug	Hot	11
Agricultural Lands						
Agricultural wetlands: seasonally flooded (rice, wildrice, fallow)	M – H	M – H	Seasonal	Apr-Sep	Warm to Hot	5,6
Row Crops, winter flooded	M	M – H	Irrigated	Oct-Mar	Cool	9
Row Crops	NA	L	Irrigated	NA	NA	9
Natural Hydrology Wetlands						
Freshwater Tidal Marsh: High Elevation	M	L-H	Episodic (2x/month)	All	All	2,3,4
Freshwater Tidal Marsh: Low-Med Elevation	L – M	L – M	Episodic (2x/day)	All	All	4
Floodplains	H	H	Episodic (seasonal)	Jan-May	Cool to Warm	1

References: 1,Marvin-DiPasquale et al. 2007; 2, Stephenson et al. 2007; 3, Heim, 2003; 4, Yee et al. 2007; 5, M. Marvin-DiPasquale, U.S. Geological Survey, written commun., 2007; 6, M. Stephenson, California Dept. of Fish and Game, written commun. 2007; [7]Alpers et al., 2008; [8] Windham-Myers et al. 2009, [9]Heim et al. 2009, [10]Sassone et al. 2008, [11]Eagles-Smith et al, preliminary data, CRP

MeHg Production in Delta

- Not always predictable
- Local production
  - Sediment and Surface Water track each other
- Seasonal/Episodic flooding is important
  - Wetlands that DRY OUT

Key findings of synthesis:

- **Hydrologic Control**
    - Slowing water flow may increase rates of storage and degradation of MeHg more than production.

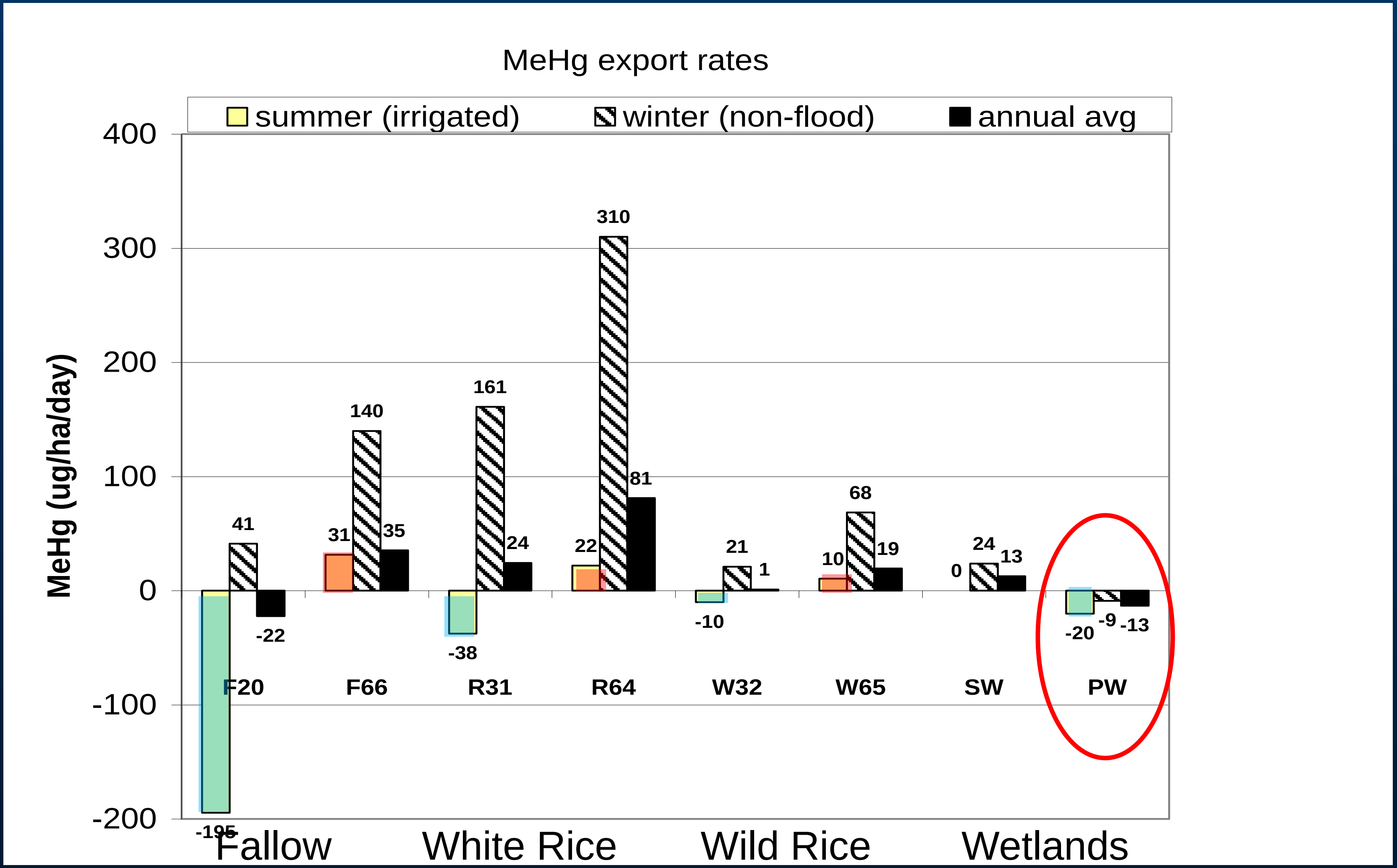
  BUT

    - Slowing water may concentrate surface water MeHg and enhance *in situ* bioaccumulation in fish.
- **Permanent Wetlands**
    - Rates of MeHg storage and degradation may exceed processes of MeHg production (net sink).

  BUT

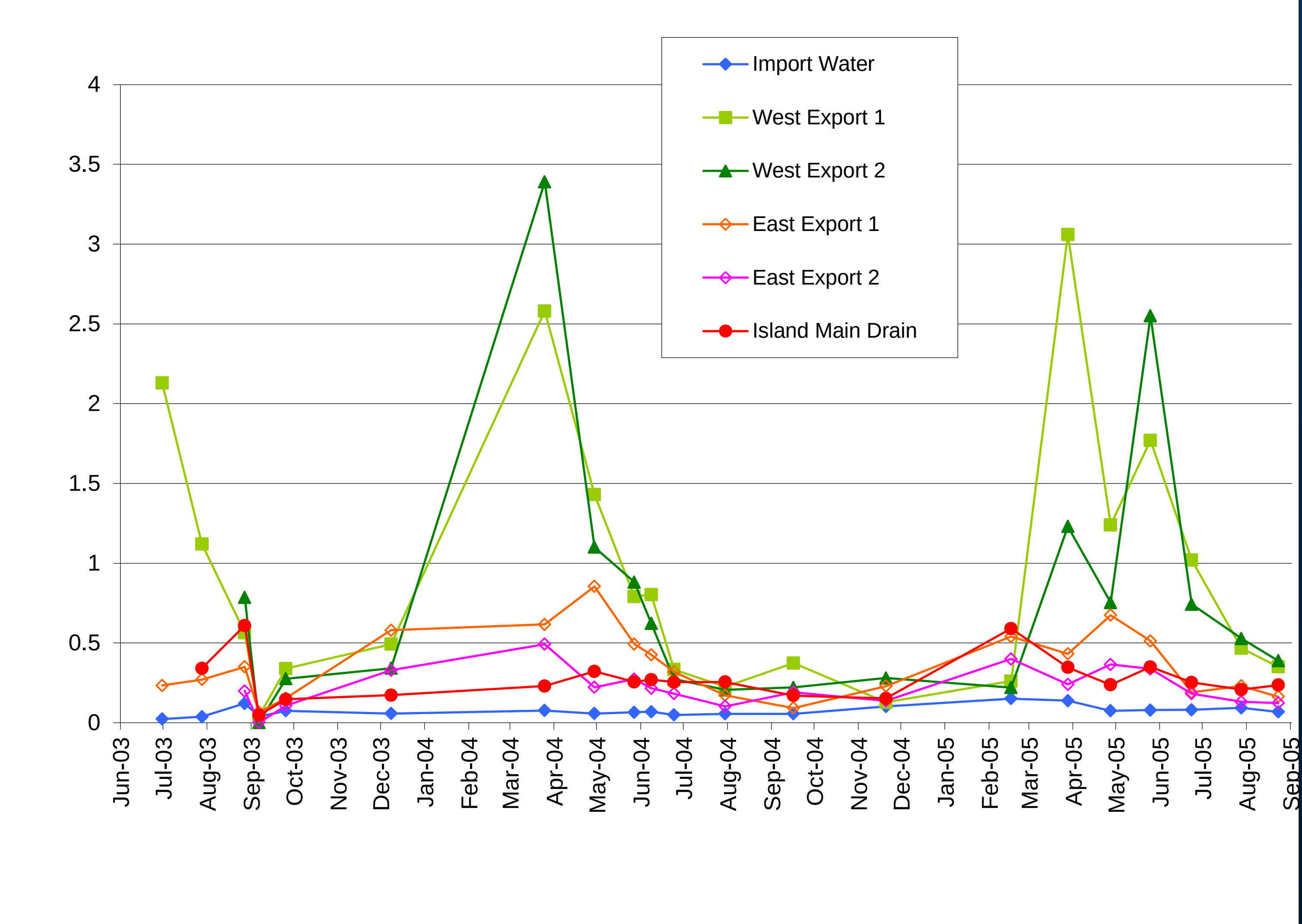
    - Organic soils (peat) may generate greater rates of MeHg release than removal (net source).
- **Seasonal Wetlands**
    - Rewetting of dried wetlands regenerates biogeochemical species that enhance MeHg production.
        - reactive Hg
        - ferric iron (FeIII)
        - sulfate (SO_4)
        - labile carbon
    - Flood-up of dried wetlands can generate an initial pulse of MeHg from sediment to surface waters.
- **TEMPORAL VARIABILITY:** matrix concentrations can vary over time by orders of magnitude
    - “Hot moments” drive annual patterns of MeHg production and export in seasonal wetlands.
    - Diel patterns in surface water – lower concentrations during daylight, higher concentrations at night – may be important in shallow vegetated habitats, due to dominant effects of photodemethylation and/or downward advective storage of MeHg through transpiration.
    - Biota MeHg concentrations vary over time, and breeding season is when wildlife is most vulnerable.
- **SPATIAL VARIABILITY** can relate to different initial conditions or management practices.
    - Total Hg concentrations are often poorly correlated with MeHg concentrations.
    - Soil organic matter is often associated with MeHg in wetlands and irrigated agriculture.
    - Wetlands can be a MeHg sink or source based on the <u>relative</u> loads of sourcewater and tailwater.

Yolo Bypass – Seasonal wetlands are all sources in winter except Permanent Wetland is a sink year-round



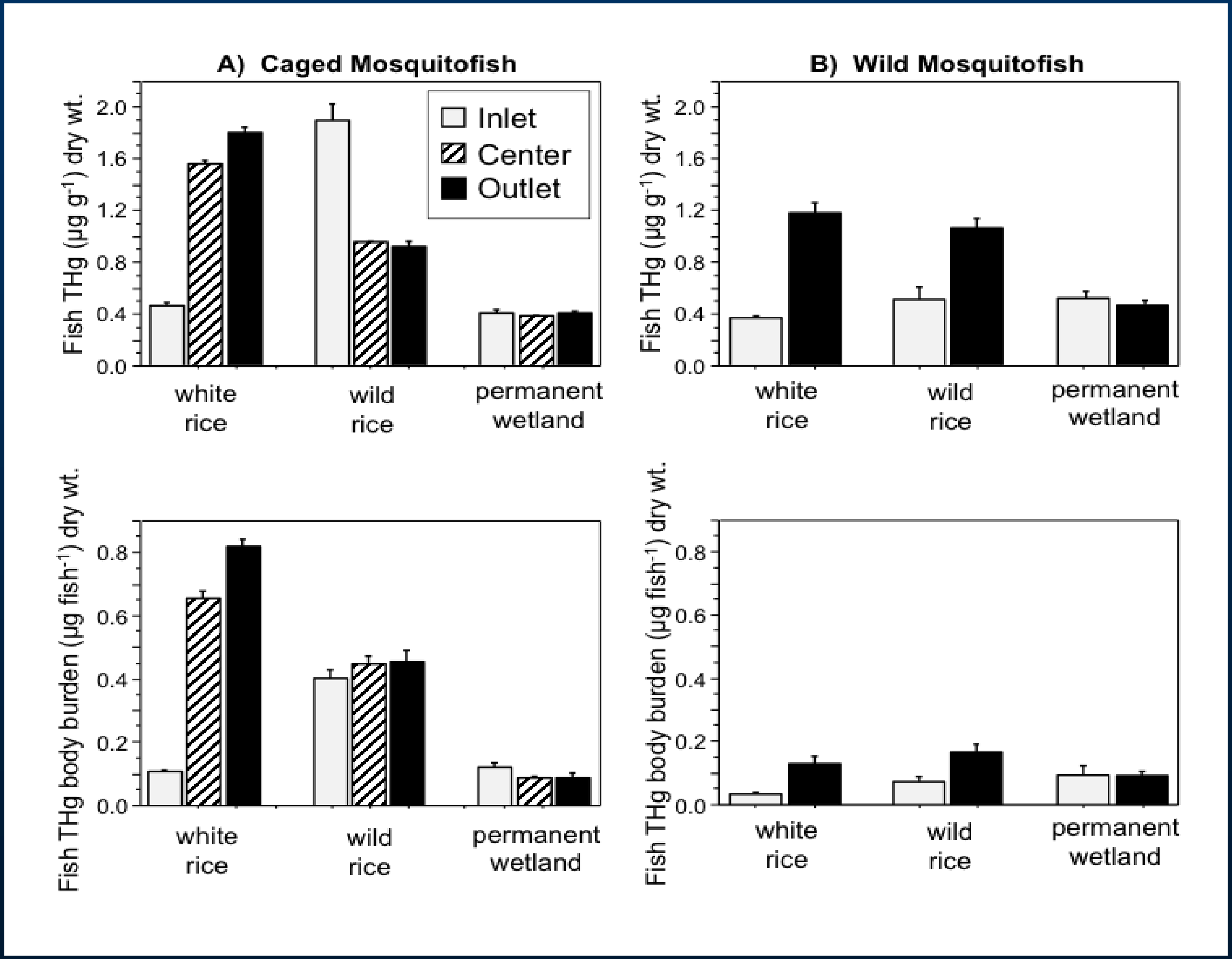
Windham-Myers et al , 2010 SWRCB report

Twitchell Island Permanent Wetlands: Presumably a net source of MeHg



Sassone et al. , 2008 SWRCB report

Holding water increases MeHg exposure with *in situ* fish (YBWA and Twitchell)

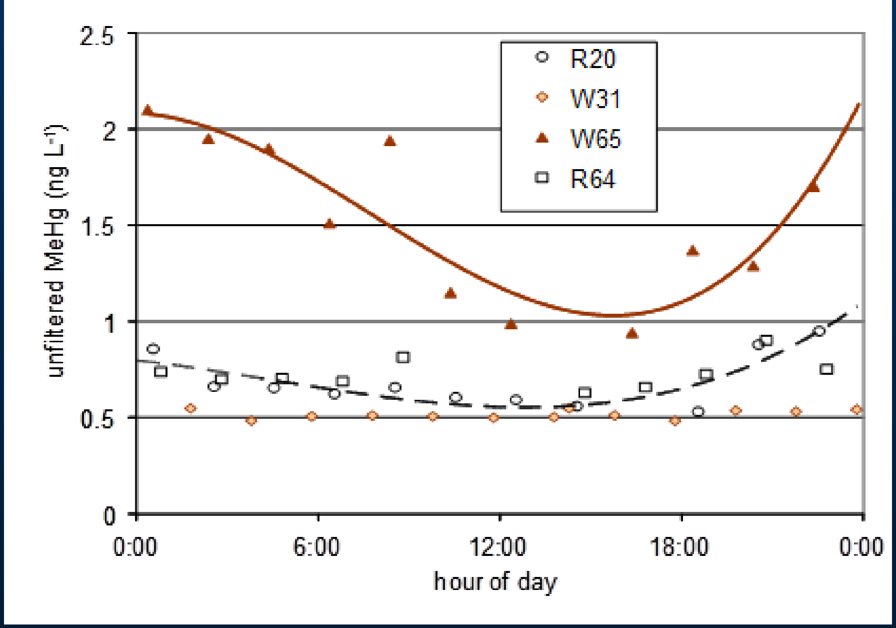


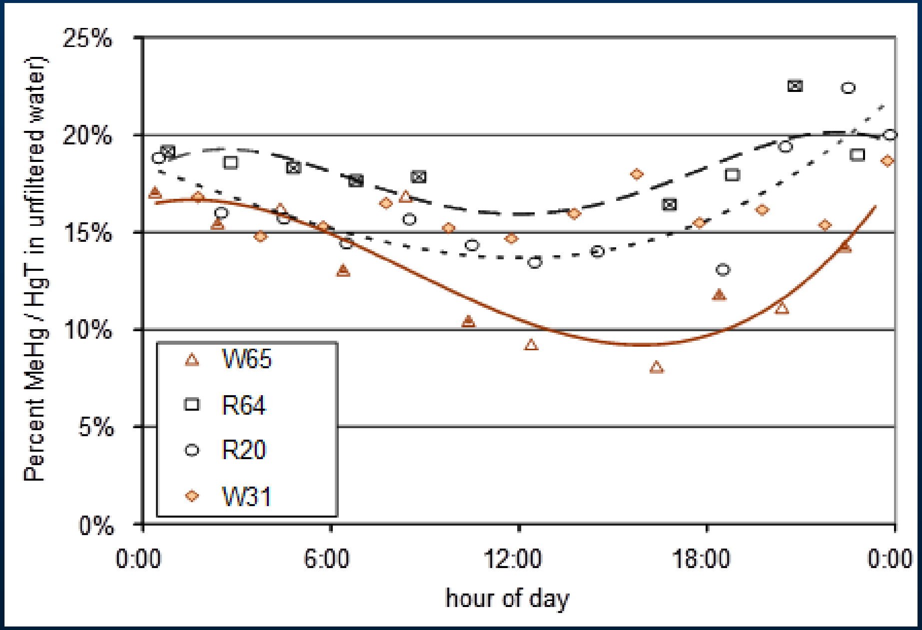
Ackerman and Eagles-Smith 2009

Surface water concentrations change over 24hour diel cycle

Photodemethylation

Effects are greatest during summer



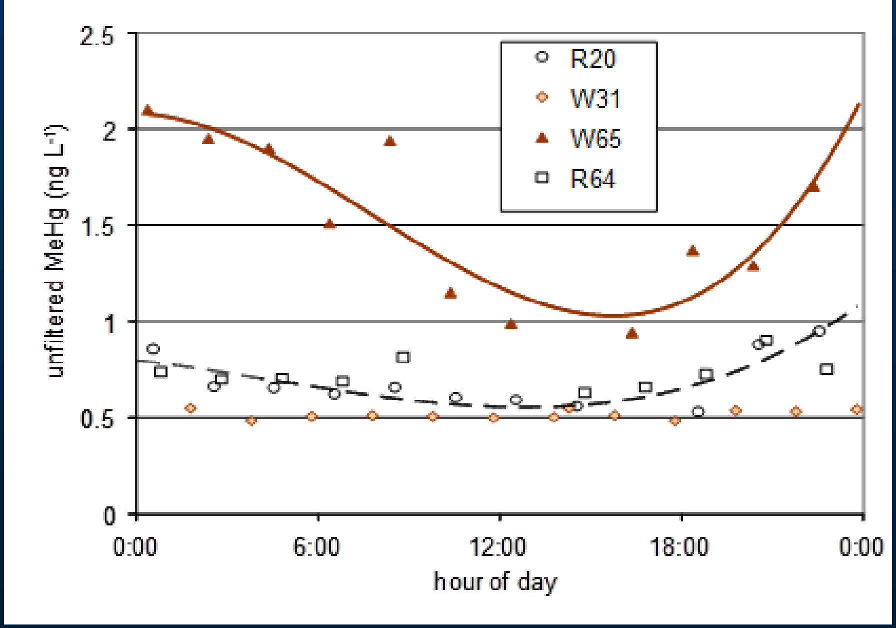


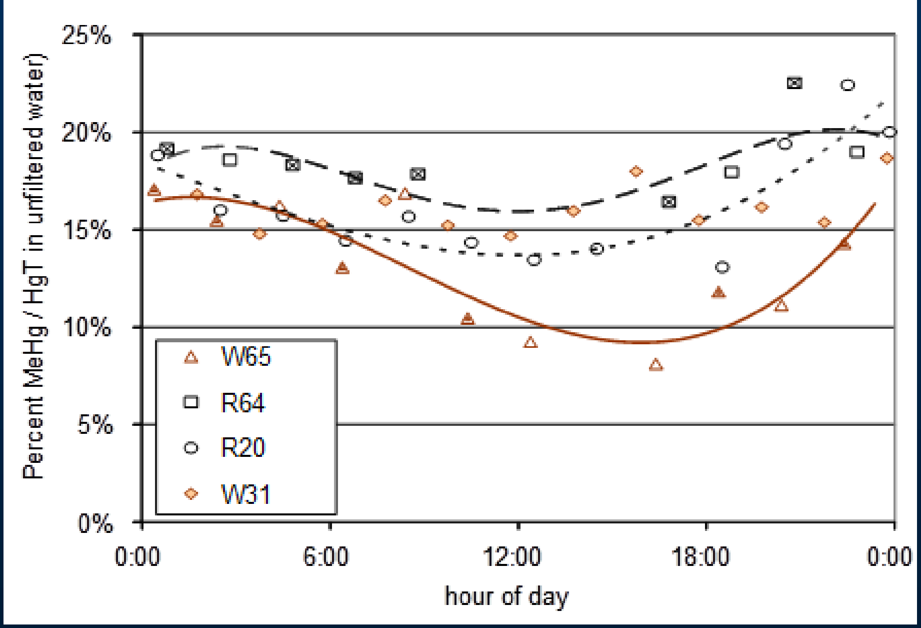
Fleck et al, in review

Surface water concentrations change over 24hour diel cycle

Photodemethylation and Transpirative Demand

Effects are greatest during summer





Fleck et al, in review

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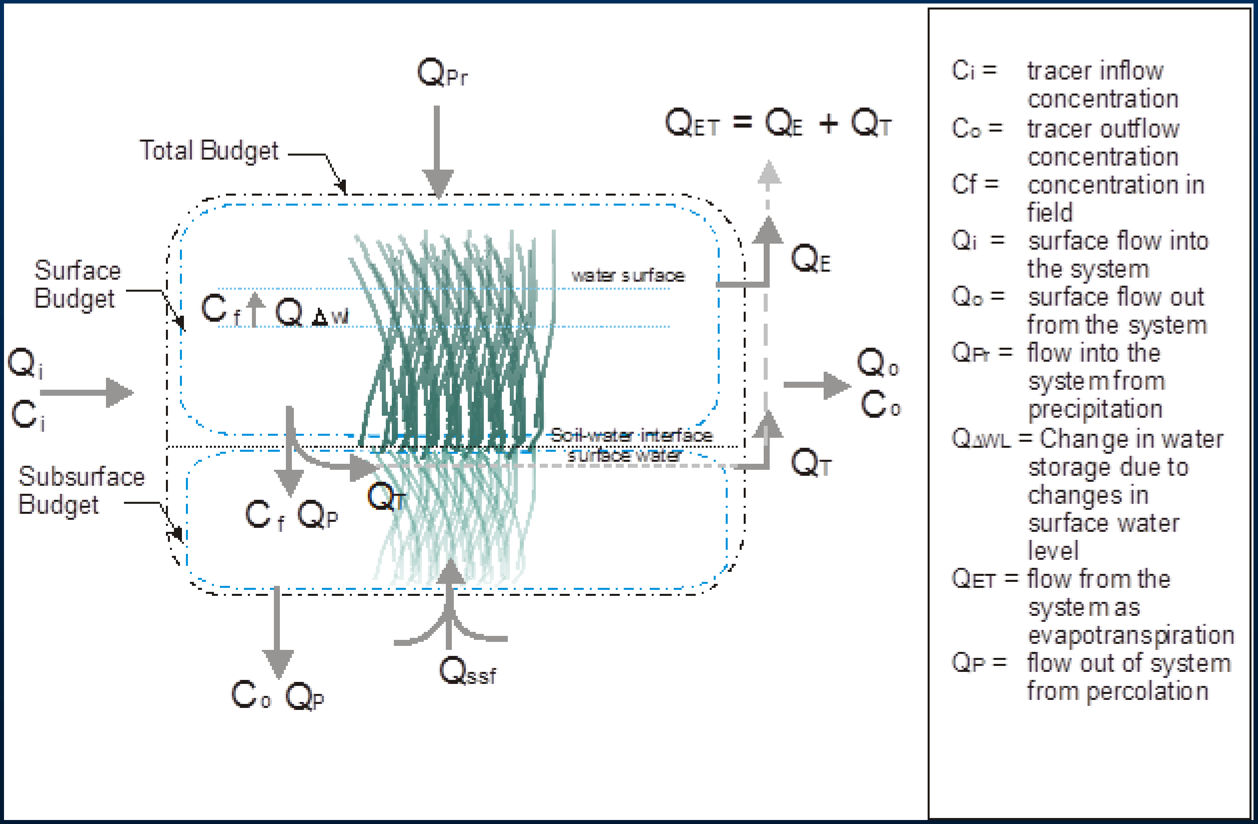
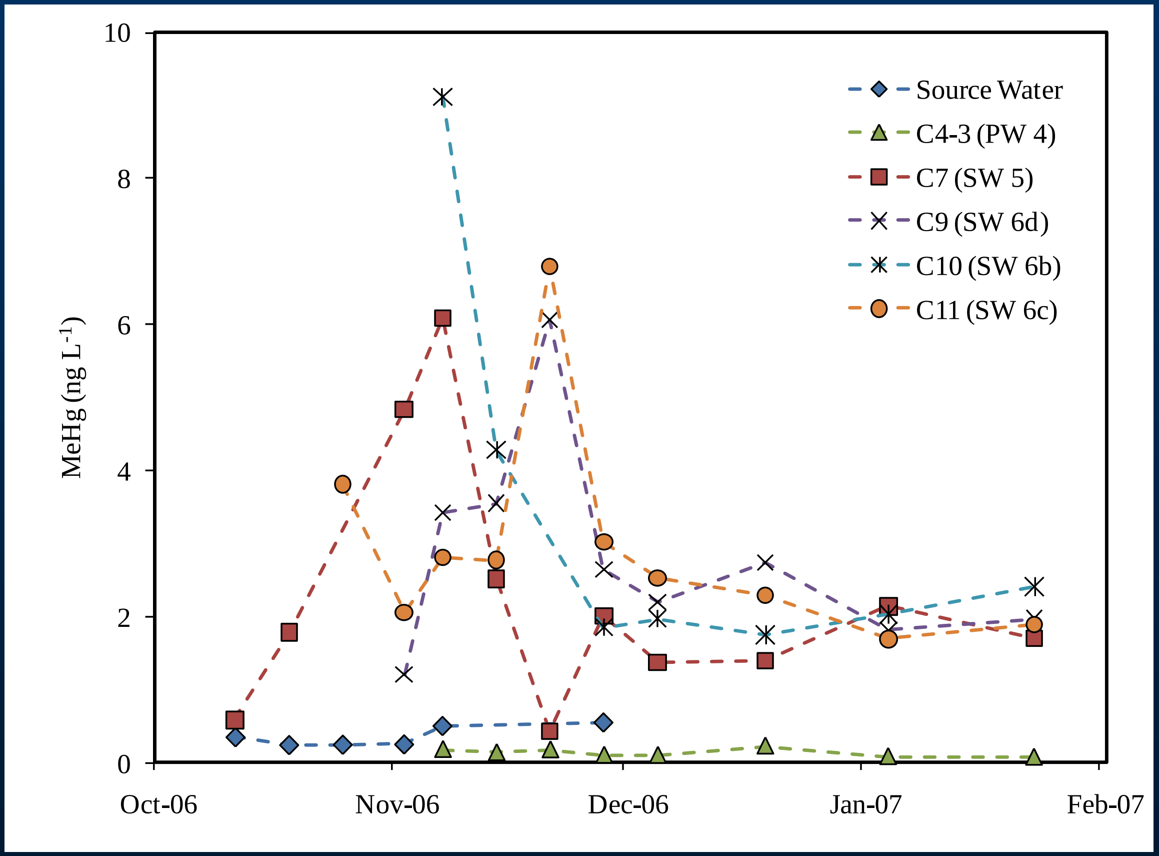


Bachand et al, in review

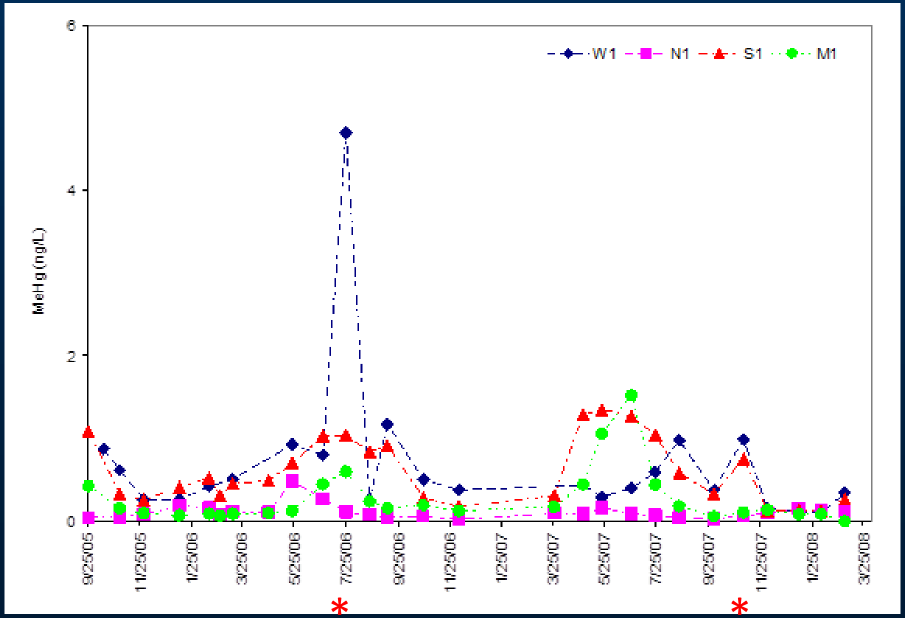
Seasonal Wetland/Permanent Wetland BMP - Heim et al. (in review)



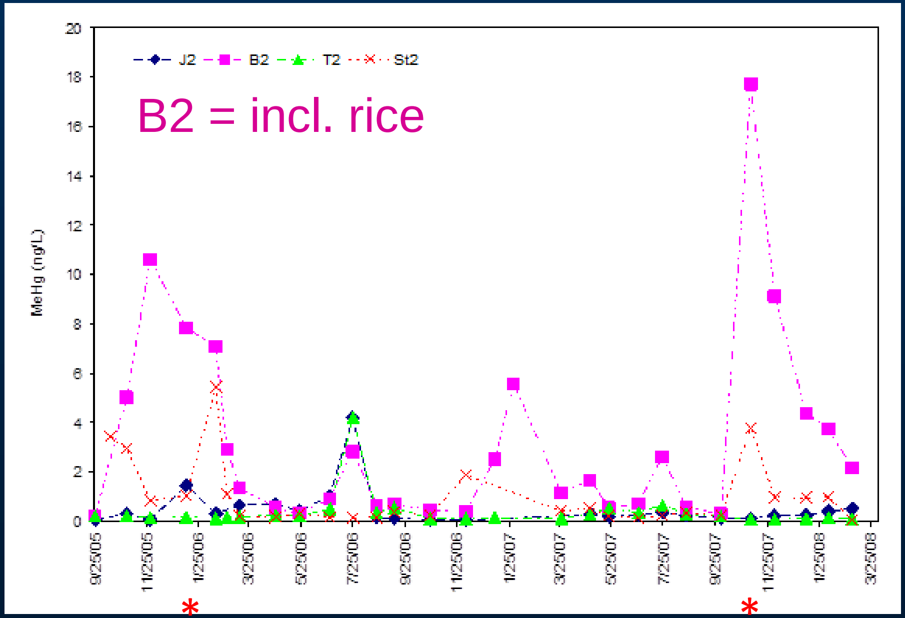
*Winter

Farmed Island Drainages (Heim et al)
Pulsed hydrologic events

Mineral



Organic



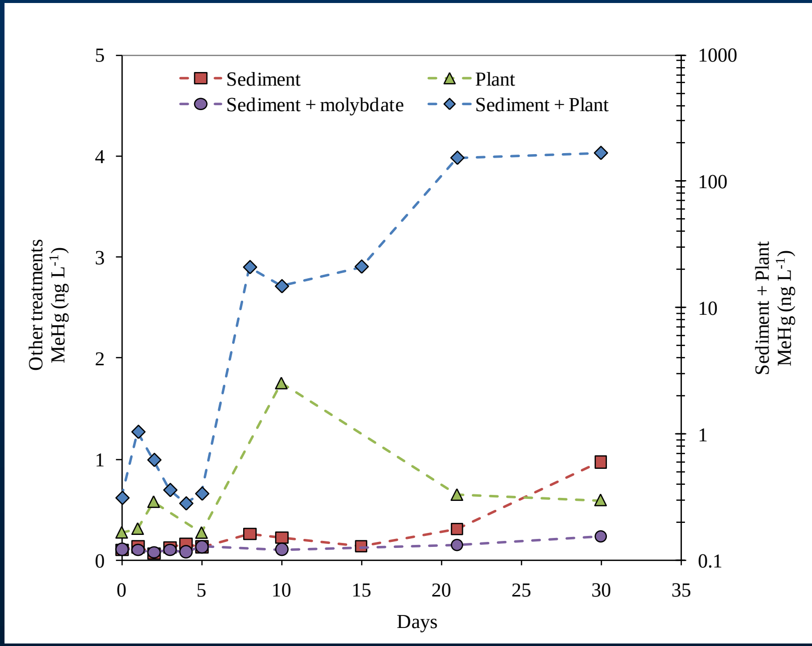
*Winter

Experimental evidence of importance of labile carbon: Amendments

Treatment	YB PW NOV'05	YB SW NOV'05	YB PW MAY'06	YB SW MAY'06
Sulfate (SO_4^{2-})				
Sulfide (S^{2-})				
Acetate (CH_3COOH^-)				
Ferrous Iron (Fe^{+2})				
Ferric Iron (Fe^{+3})				

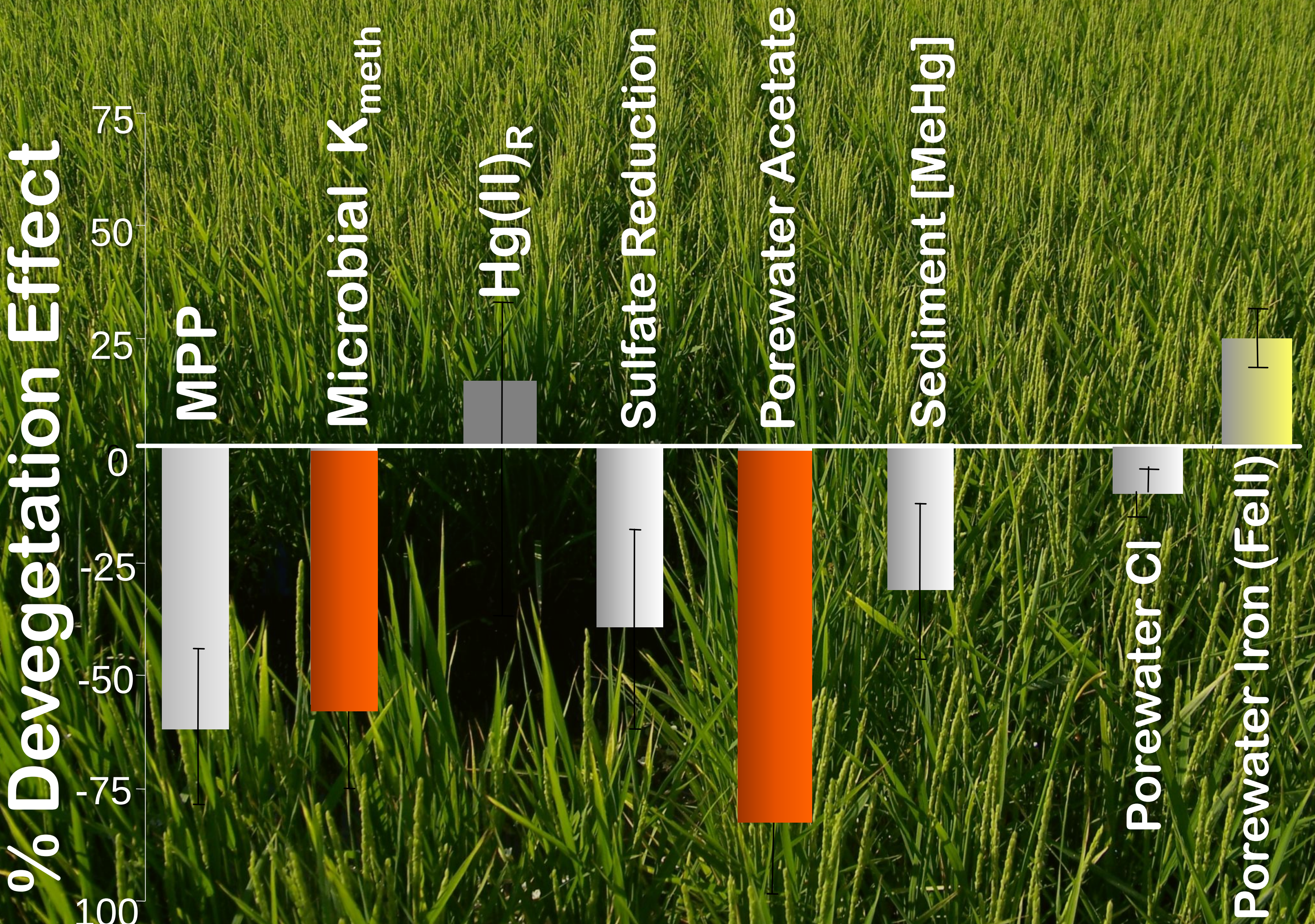
Treatment	CCSB-PW FEB'06	CCSB-SW FEB'06	CCSB-PW MAY'06	CCSB-SW MAY'06
Sulfate (SO_4^{2-})				
Sulfide (S^{2-})				
Acetate (CH_3COOH^-)				
Ferrous Iron (Fe^{+2})				
Ferric Iron (Fe^{+3})				

Marvin DiPasquale et al (unpublished)

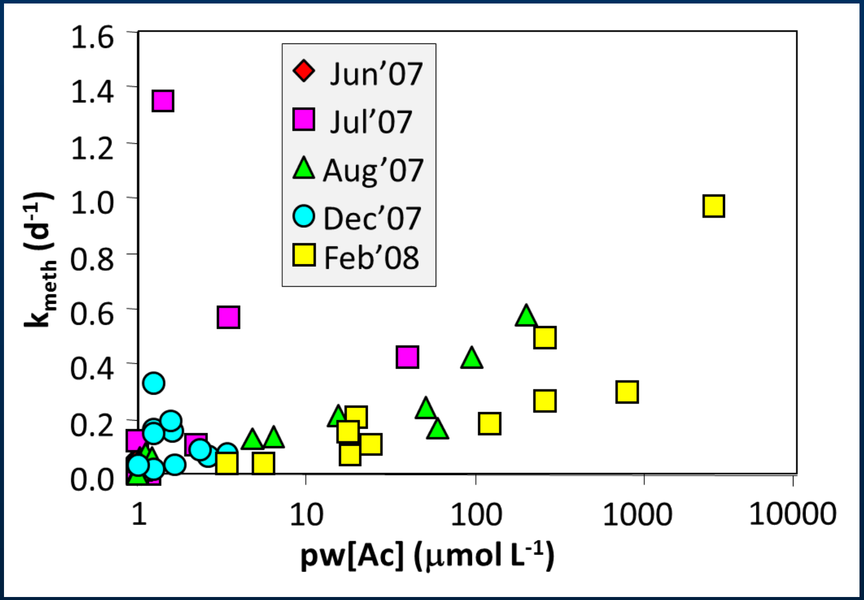


Heim et al (in review)

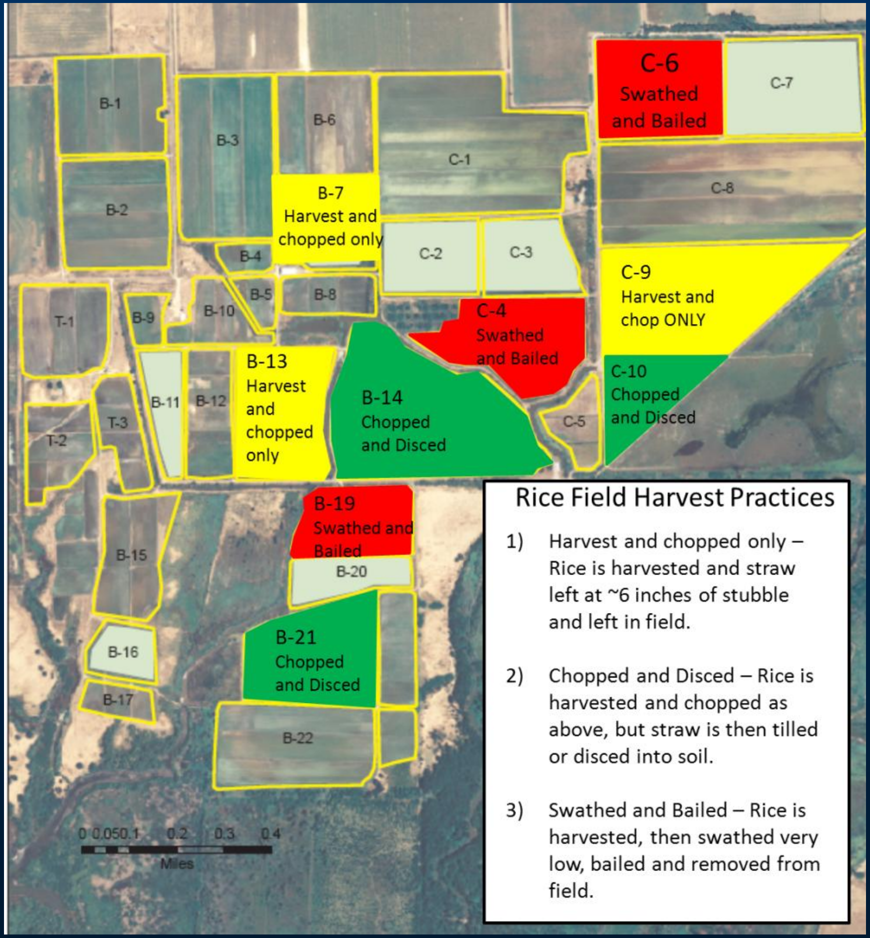
YBWA Ag Devegetation, August 2007



Field evidence of importance of labile carbon

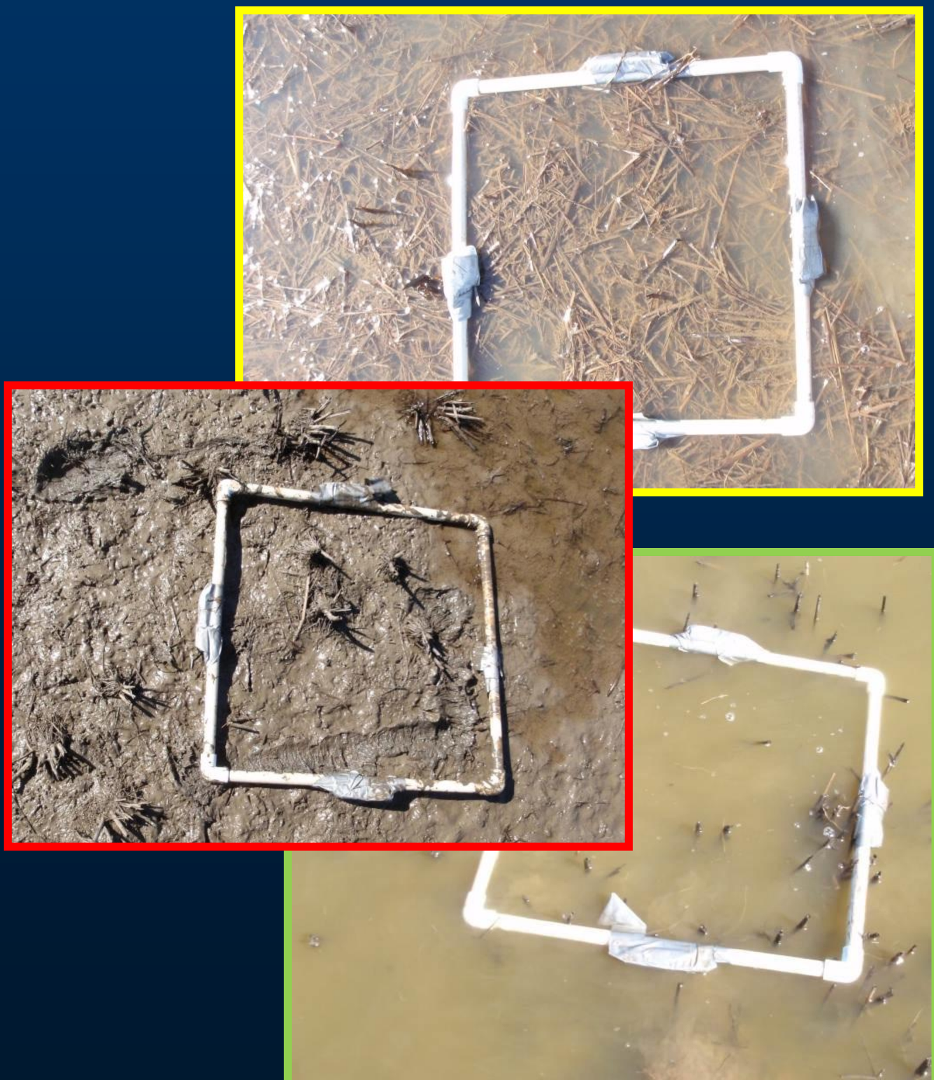


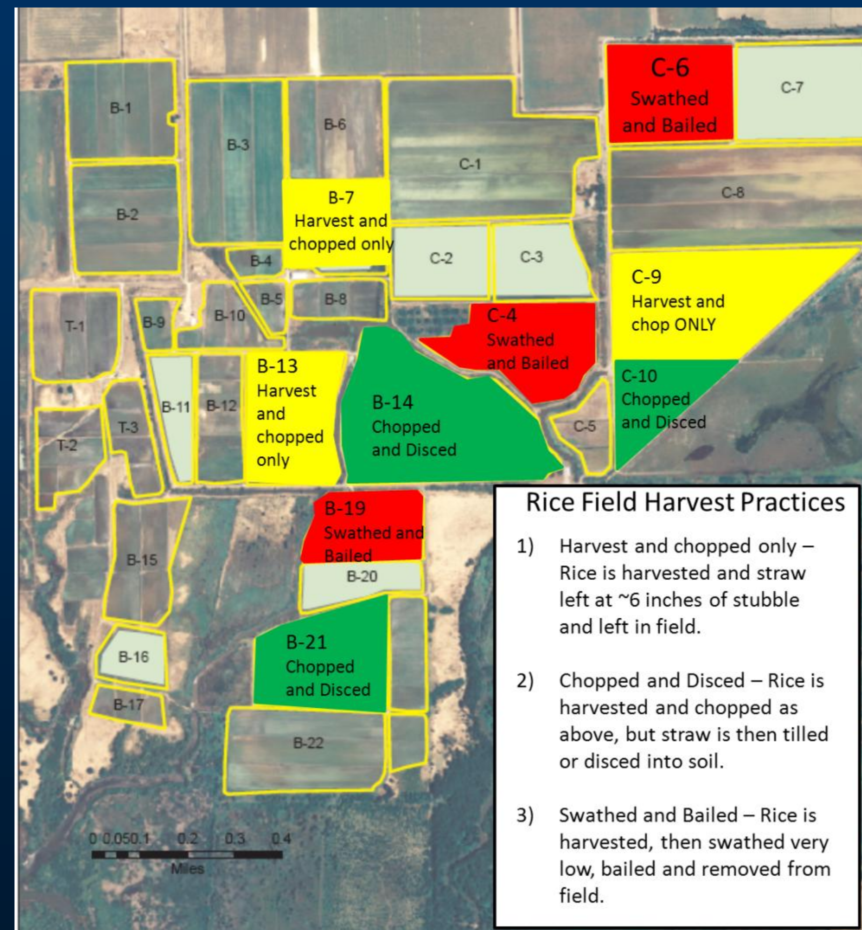
Yolo Bypass
Windham-Myers et al (in review)



Field Design (Cosumnes River Project)

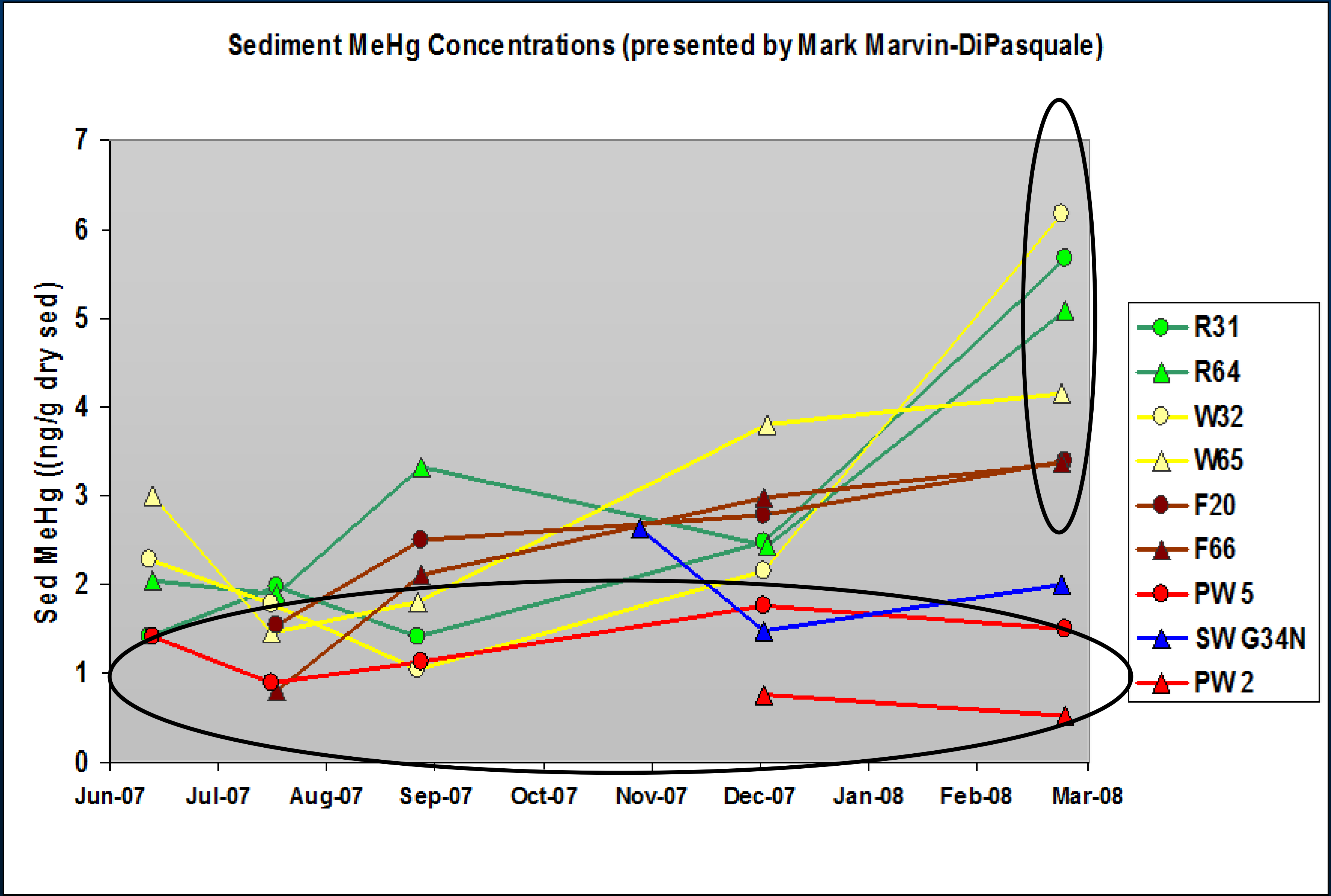
Field evidence of importance of labile carbon

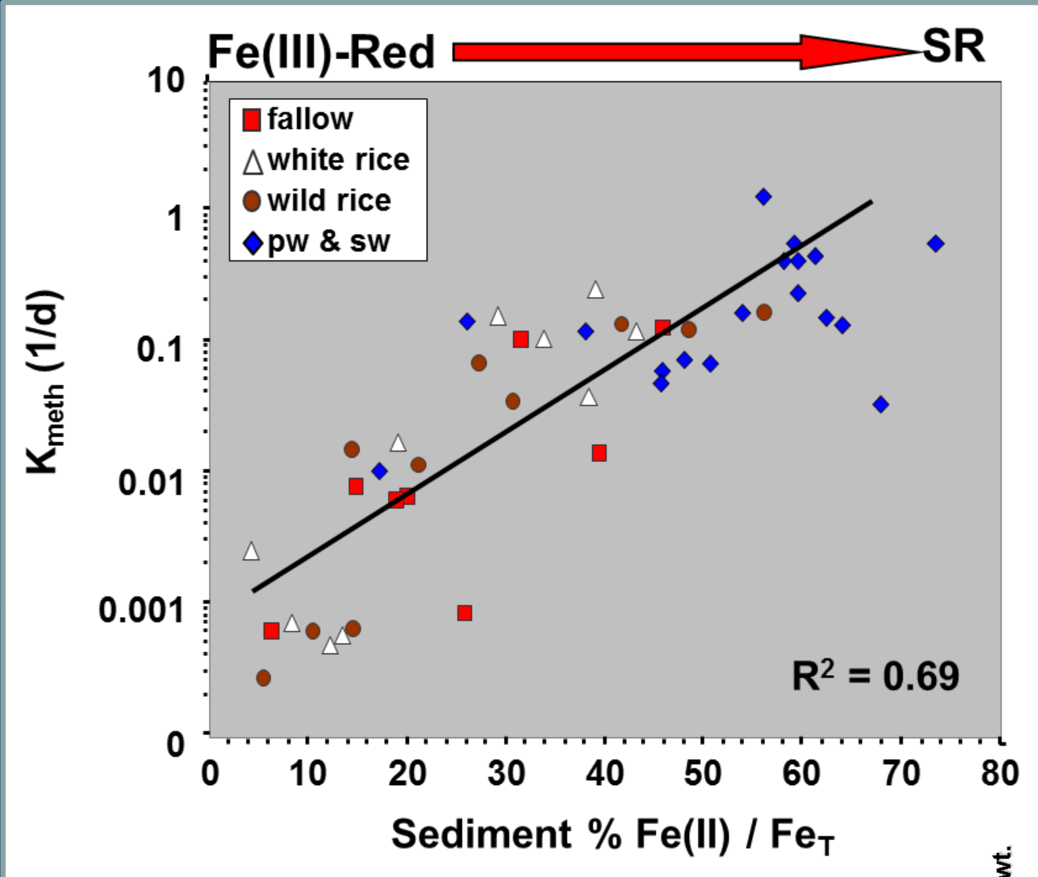




Field Design (Cosumnes River Project)

Seasonal Wetlands = Hot Moments   Temporal Variability

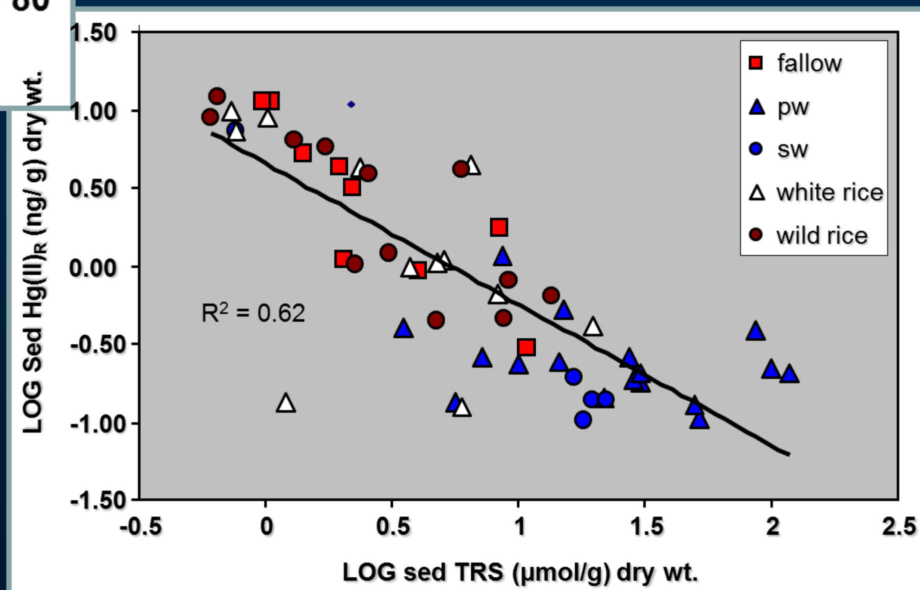




Hot moments: due to Fe/S/ C

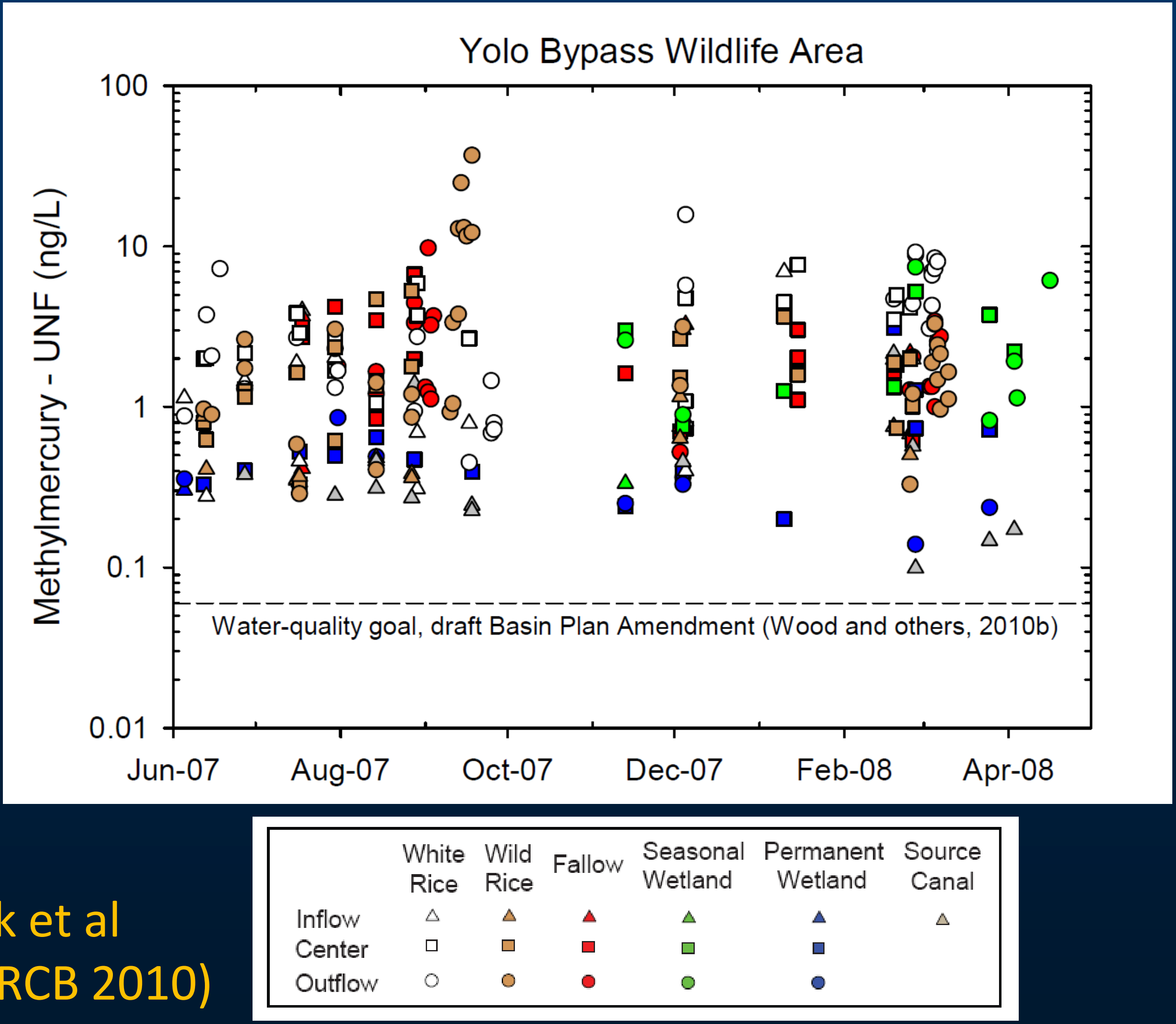
"Goldilocks" principle

- Relative iron availability controls Kmeth
- Relative TRS controls $Hg(II)_R$



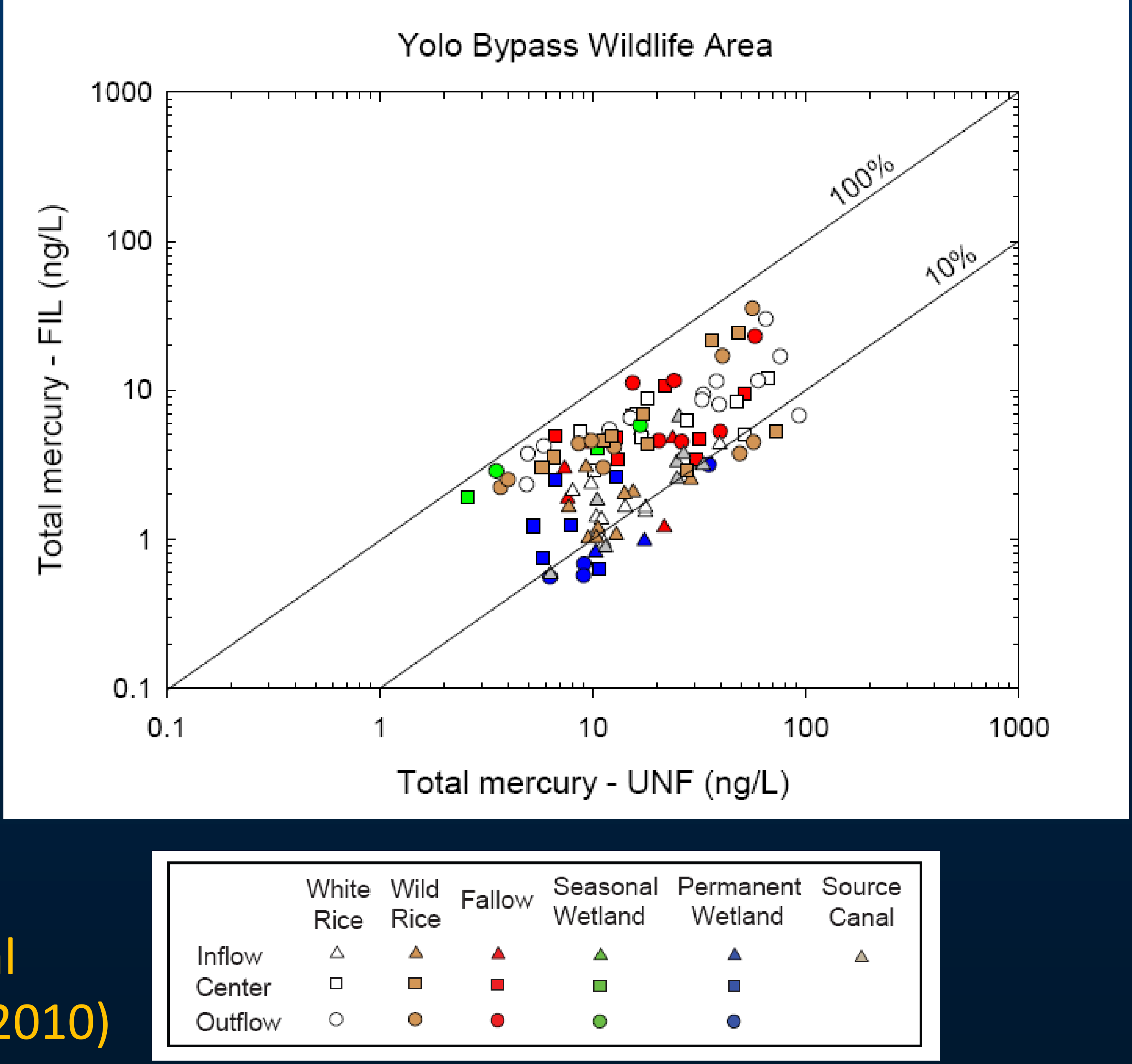
Marvin-DiPasquale et al. (SWRCB 2010)

Pulse of MeHg in surface water upon flood up



Fleck et al
(SWRCB 2010)

MeHg is primarily in filter-passing (dissolved) phase

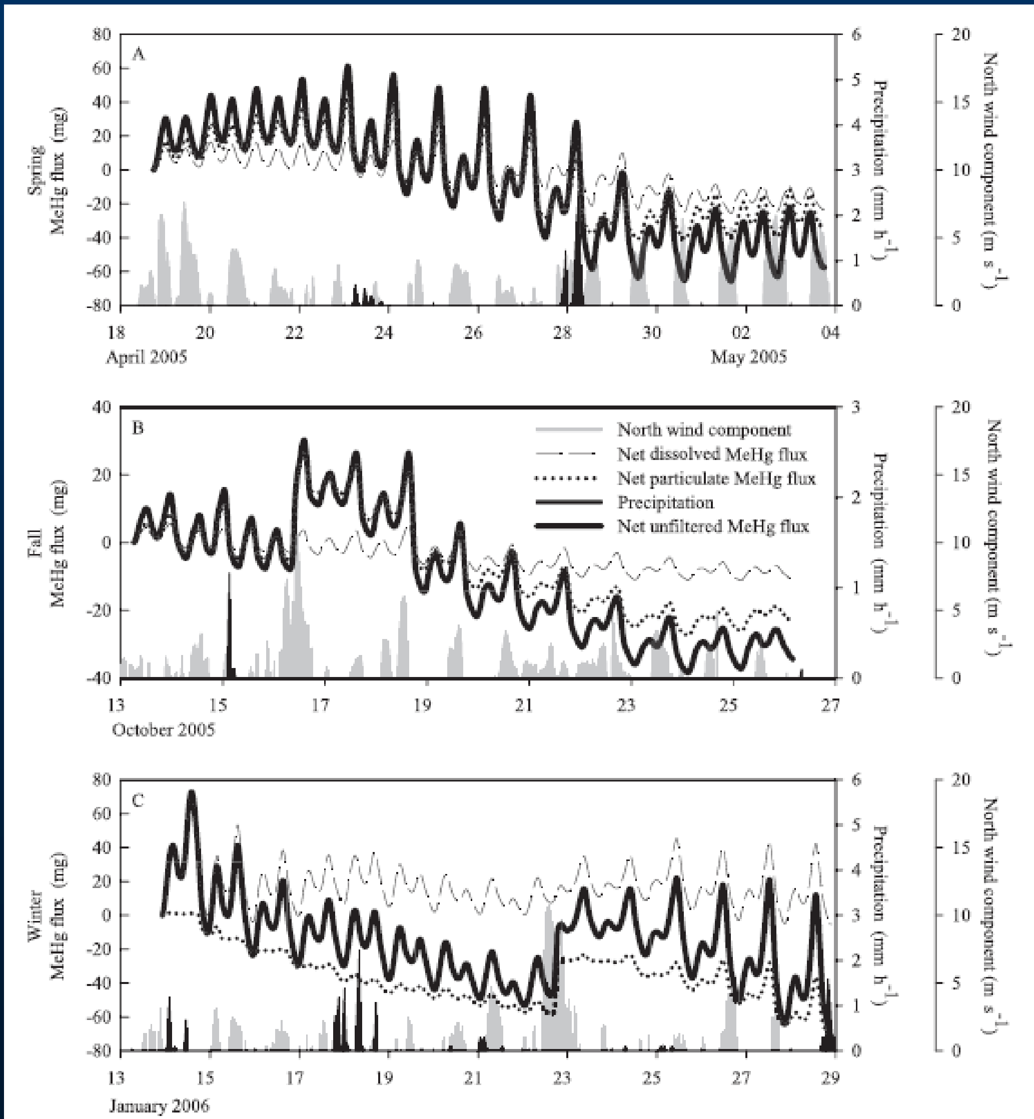


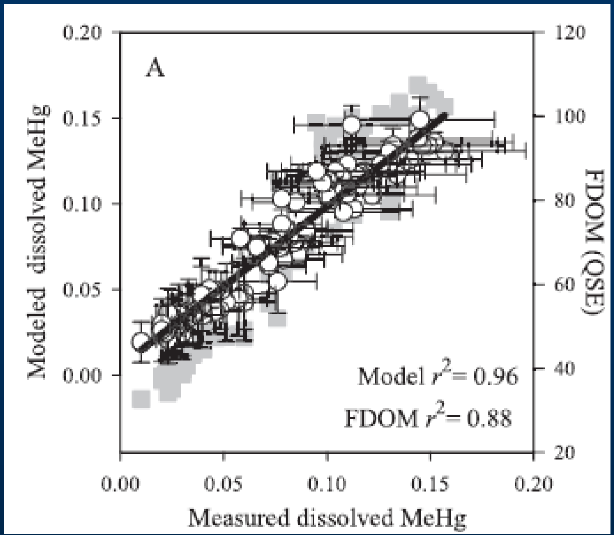
Fleck et al
(SWRCB 2010)

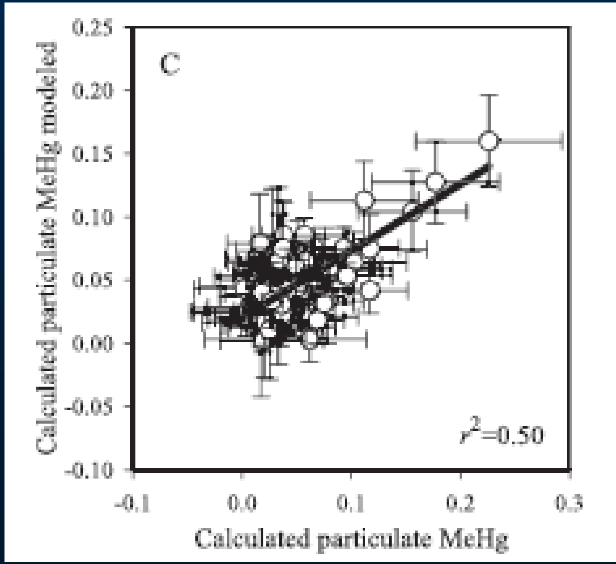
Temporal Variability

Remote, continuous monitoring best for loads

(Bergamaschi et al. 2011)







Open for discussion:

Role of biota monitoring in TMDL

Source water and soil conditions that alter success of management practices

Climate and water routing changes to success of MeHg controls