ANNUAL REPORT COMPREHENSIVE RESEARCH ON RICE
January 1, 2018 - December 31, 2018

PROJECT TITLE:
Mercury in California rice systems

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OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

Background

The overall objective of this research is to determine if MeHg discharged from CA rice systems pose a health risk to humans and wildlife fish consumers, and if so, how we can cost-effectively minimize this risk. Specific objectives to meet this overall objective are:

1. Identify the annual cycle of MeHg concentration and loads in Sacramento Valley rivers.
2. Determine if MeHg production and discharge from rice systems (and associated health risks) are higher in certain parts of the region than in others (possibly due to Hg inputs from irrigation, soil or water management)
3. Compare data from the “typical” rice systems with those in the Delta.
4. If and where MeHg poses a risk, identify viable management practices that can cost-effectively minimize that risk.
5. If and where MeHg poses a risk, identify underlying causes.

In brief, between 2013 (when this project began) and current, this project has completed four studies towards addressing these objectives:

1. Assessment of MeHg export from rice at the valley scale using historical data
2. MeHg and THg budgets/loads at the field scale
3. Alternate wetting and drying as a potential MeHg management practice
4. A comparison of MeHg and THg dynamics in six representative Sacramento Valley rice fields receiving two types of irrigation water, fresh and recycled.

A summary (details in previous reports and publications) of our findings are as follows:

- Rice systems may be a source of mercury, however, loads from rice fields are small and much less than what is found in Delta rice systems where much of the previous work was conducted (Study 1, 2, and 4).
- Peak periods of drainage water MeHg concentration and export from rice fields occur during the fallow season and possibly during the early growing season. This pattern has been consistent across studies conducted in the Sacramento Valley, Cosumnes River Preserve and Yolo Bypass (Study 1, 2, and 4).
- Sacramento Valley rice fields have lower levels of Hg in soils and irrigation water than rice fields in the Yolo Bypass and Cosumnes River Preserve (Study 1 and 2).
- MeHg concentrations in rice drainage water from Sacramento Valley rice fields are lower than drainage water concentrations from the Yolo Bypass and Cosumnes River Preserve (Study 1, 2, and 4).
- MeHg and THg concentrations in rice grain from the Sacramento Valley are well below levels of concern for human health (Study 2, 3, and 4).
- Growing season rice drainage water MeHg concentrations are lower than in the fallow season (Study 1, 2 and 4).

- During the growing season, most rice fields are MeHg sinks (they export less MeHg than they import) (Study 2 and 4).
- During the fallow season, most rice fields are MeHg sources (they export more MeHg than they import) (Study 2 and 4).
- AWD Reduces MeHg concentrations in water, soil and rice grain and is a potential mitigation practice to reduce MeHg (Study 3).
- Inlet water for both fresh and recycled fields have similar MeHg and THg concentrations (Study 4).
- Outlet MeHg concentrations are slightly higher in recycled fields during the fallow season and early in the growing season. There is no significant difference between fresh and recycled outlet concentrations (Study 4).
- Generally, the fraction of MeHg and THg dissolved in the water is relatively larger than the fraction bound to sediment, and dissolved mercury is known to be more bioavailable than particulate mercury. (Study 4).
- While mercury concentrations are relatively low in these samples, there are some exceptions when total suspended solids (TSS) in the water samples is extremely high, usually due to a high wind event. In these cases, the concentration of mercury bound to sediment in the water column can be high because the total amount of solids suspended in the water column is high. Draining rice fields during periods of high TSS could lead to greater MeHg and THg export.

2018 Goals/objectives, experiments, and preliminary results:

<u>Goal 1: Quantify MeHg in filtered and particulate water samples going into and out of rice fields.</u>

The current regulatory focus on MeHg is all based on unfiltered water samples. Thus, all of our research to date has focused on analyzing MeHg and Hg in unfiltered water samples. However, much of the MeHg in these samples is likely to be bound to suspended sediment. This MeHg may be less bioavailable than MeHg that is dissolved in the water. Therefore, from an ecosystem standpoint, it is the dissolved MeHg that is a better indicator of ecosystem health.

With this in mind, 2017-18 research focused on evaluating in-field MeHg concentrations from filtered samples, while also quantifying the filtered MeHg concentrations in water leaving rice fields. We tested the hypothesis that higher levels of MeHg in irrigation water will result in higher MeHg concentrations in field flood water and tail water. To test this hypothesis, we identified 3 pairs of commercial rice fields consiting of a field receiving fresh irrigation water and the other receiving recycled irrigation water. Based on previous research findings, recycled irrigation water likely has higher MeHg concentrations than fresh irrigation water. Samples were taken from the fields over the course of a year (both winter and growing season).

Methods

Fields were identified in Richvale Irrigation District (Butte County), RD-1004 (Colusa County) and RD-108 (Colusa/Yolo County) (Figure 1). While the main criteria in identifying these fields was related to the type of irrigation water received, these fields also were:

1. Representative of major rice growing areas within California
2. Had rice grown on them in the previous season
3. Kept straw on the field during the winter and flooded the field

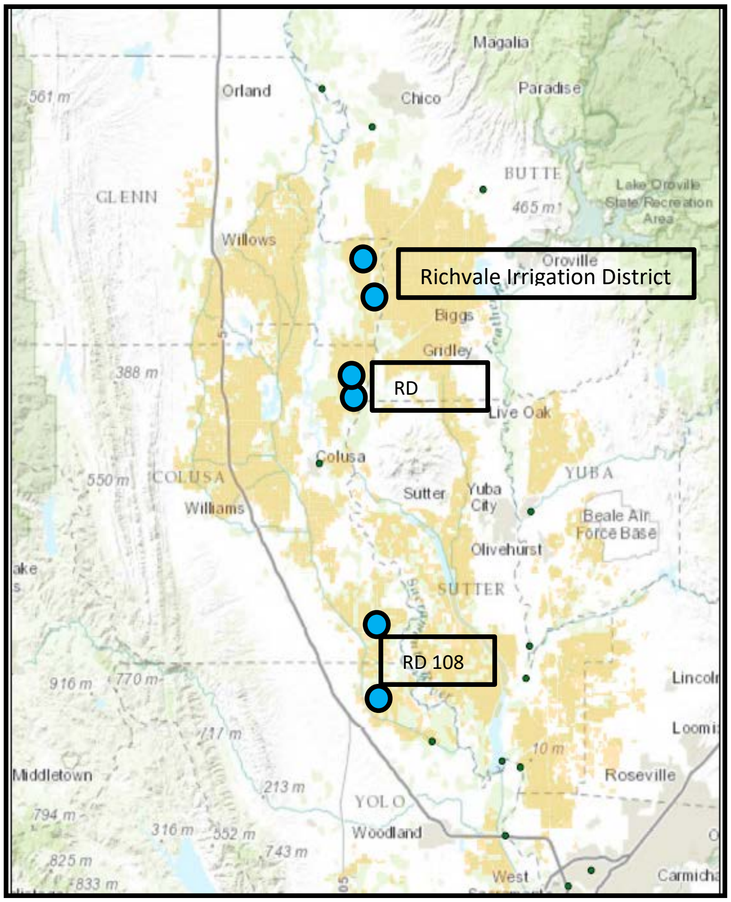

Figure 1. *Location of commercial fields for the MeHg 2017/2018 sampling campaign. Fields 1 and 2 are in RD 108, fields 3 and 4 are in RD 1004, and fields 5 and 6 are in Richvale Irrigation District.*

From these fields, water from the inlet, within the field, and outlet were sampled and analyzed to determine MeHg concentrations and loads in filtered and unfiltered samples. Three major sampling events were conducted in each season (growing and fallow). Soil samples were taken during the flooded period in each season. Grain was sampled in each field and analyzed for MeHg and Hg concentration.

The inlet and outlets were set up with equipment to measure water flow rate throughout the year. The type of equipment used varied depending on the field. Importantly, the equipment provides real time flow rates and cumulative flow. The equipment is also non-obtrusive, allowing the grower to manage irrigation water as usual. Water samples were collected throughout the year: 3 times in growing season and 3 times during winter fallow. Samples will be collected near the beginning, middle and end of each season. This was roughly once a month during each season.

Preliminary results

We do not have all samples back from the lab as of yet. Also, there remains a lot of further analysis on the data we have. That said, preliminary results from this study are discussed below.

MeHg water concentrations

There was no significant difference in filtered inlet water MeHg concentrations between fields that receive only fresh water and fields that receive recycled water (Figure 2a). Across the whole year, filtered inlet water MeHg concentrations were lowest in the winter (average 0.016 ng/L). In the spring MeHg inlet water concentrations started low (average 0.031 ng/L), increased in early summer (average 0.054 ng/L) and then declined to an average of 0.021 ng/L near the time when fields were to be drained (Figure 2a).

Outlet water MeHg concentrations were highest in the winter (avg 0.305 ng/L) and lowest in the late summer (pre-harvest) (avg 0.034 ng/L), and there was little difference between recycled and fresh fields during these times. MeHg concentrations are somewhat elevated during the summer maintenance drains, and during this time recycled fields have significantly higher outlet MeHg concentrations than do fresh fields (0.104 ng/L and 0.043 ng/L respectively) (Figure 2b).

Field water MeHg concentrations were generally highest in the fall flood (avg 0.249 ng/L) and lowest during the pre-harvest drain (avg 0.034 ng/L) and there was little difference between recycled and fresh fields during all sampling periods except during the winter drain and spring flood events when recycled fields had significantly higher field water MeHg concentrations than did fresh fields (0.482±0.61 ng/L and 0.033 ng/L for the winter drain, and 0.109 ng/L and 0.033 ng/L for the spring flood, respectively) (Figure 2c).

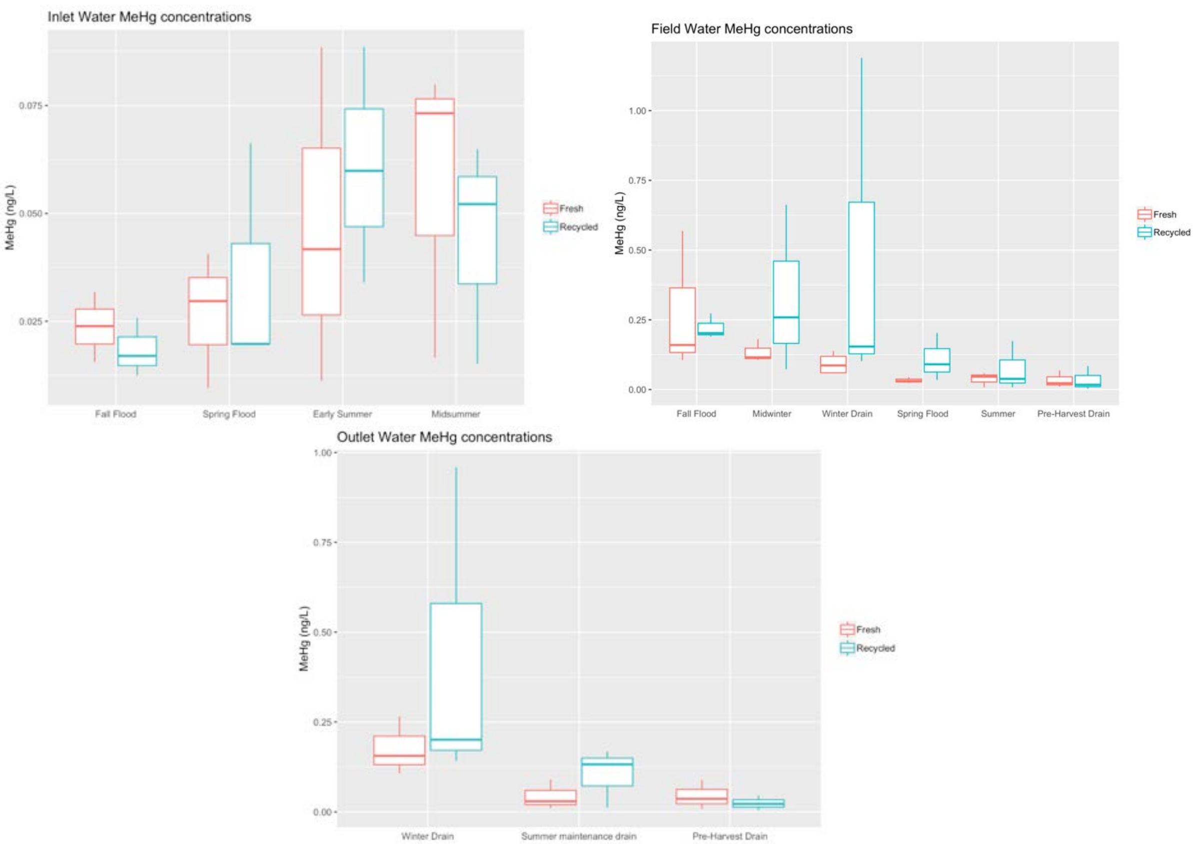

Figure 2a-c*: Filtered water inlet(a), outlet (b) and Field (c) MeHg concentrations for different seasonal events within the study period.*

Fields as sources or sinks of MeHg

Multiplying the concentrations by the amount of water, all six fields were net MeHg sources in the fallow season, and net sinks in the growing season (Figure 3a). Across all fields, filtered outlet water concentrations were about 3-8 times higher in the fallow season than in the growing season. Furthermore, because there is significant accumulation of rainfall in the field and relatively low rates of evapotranspiration in the winter, there are significantly larger volumes of water exported as drainage water during the fallow (40-60% of applied irrigation water), causing the field to act as a net exporter of MeHg. In the growing season, outlet concentrations of MeHg are relatively low and only 13-25% of irrigation water applied was exported as drainage water, causing the fields act as net sinks of mercury. (Table 1).

On an annual basis, fresh fields were net sinks of MeHg, while fields receiving recycled water were net sources of MeHg, although the magnitude of export and import varied greatly regardless of irrigation type (Figure 3b, Table 1).

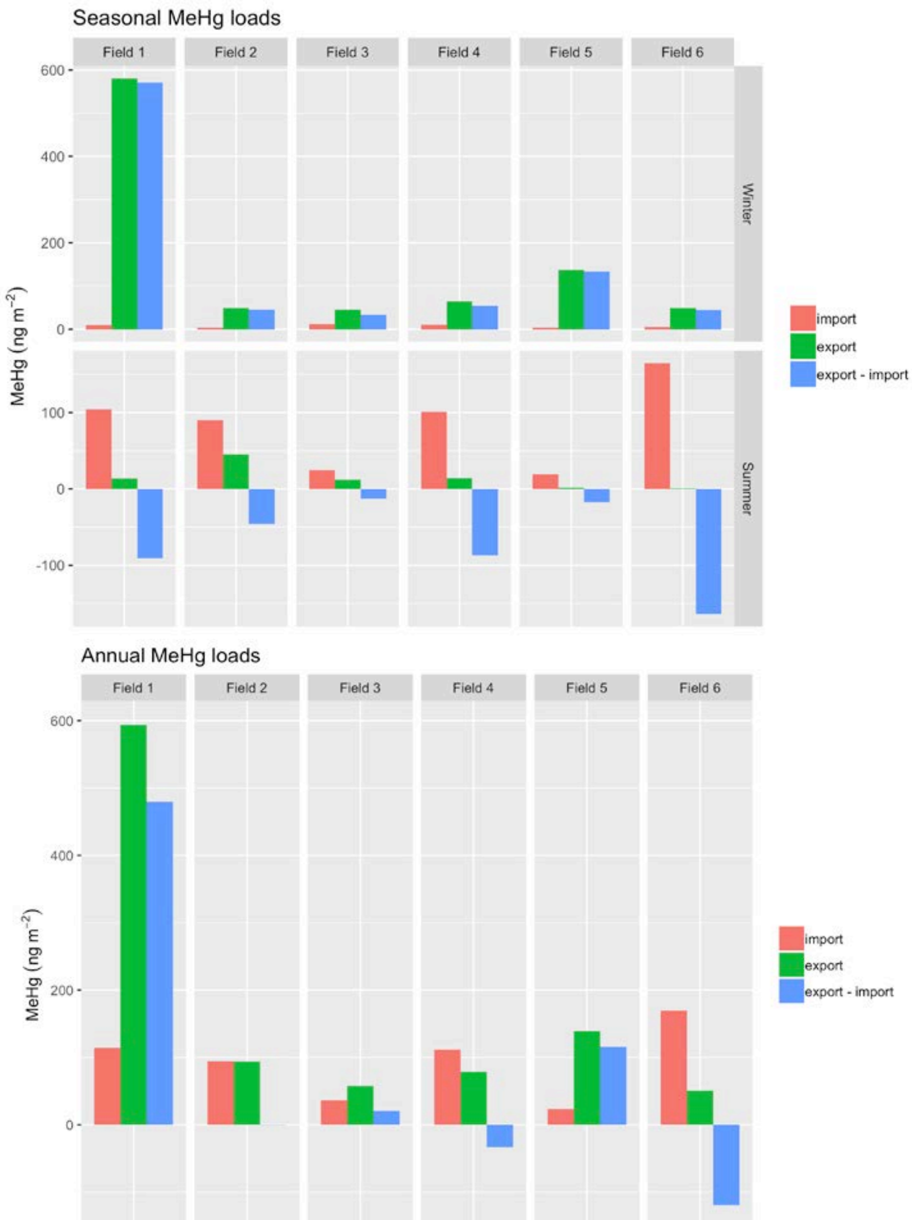

Figure 3a-b*: Seasonal (a) and annual (b) MeHg budgets per field, filtered water. Fields 1, 3, and 5 are recycled. Fields 2, 4, and 6 and fresh. Fields 1 and 2 are in RD 108, fields 3 and 4 are in RD 1004, and fields 5 and 6 are in Richvale Irrigation District.*

MeHg Water Budgets	Field 1 (R)	Field 2 (F)	Field 3 (R)	Field 4 (F)	Field 5 (R)	Field 6 (F)
Filtered surface water MeHg budgets (ng m^{-2})						
Fallow season						
Irrigation import	9.58	4.11	11.86	10.30	4.29	4.61
Export	580.29	49.22	45.59	64.27	137.13	49.26
Export – import	570.71	45.11	33.73	53.97	132.84	44.64
Growing season						
Irrigation import	104.67	90.38	24.66	100.86	18.98	164.78
Export	13.49	44.80	11.87	14.21	1.65	1.05
Export - import	-91.18	-45.58	-12.78	-86.65	-17.33	-163.73
Annual						
Irrigation import	114.25	94.49	36.52	111.16	23.27	169.39
Export	593.78	94.02	57.46	78.48	138.78	50.31
Export - import	479.53	-0.47	20.94	-32.68	115.551	-119.08

Table 1: *Fallow, Growing season, and annual MeHg budgets for all six fields. Note that (R) means recycled field, (F) means fresh field.*

Goal 2: Engagement with Stakeholders

In addition to these research activities, we are involved with various stakeholder groups that are concerned with MeHg in the delta. In conjunction with the California Rice Commission we have met several times with growers to discuss our findings and gather their thoughts on any mitigation options (at this point there is no foreseen need for mitigation given the relatively low levels). In addition, we attend meetings and are involved with the Delta Tributaries and Mercury Council (DTMC). This research was presented as a power point at the September DTMC meeting in West Sacramento and as a poster at the Rice Field Day in August in Biggs, CA.

Goal 3: Publish manuscripts

Publication of results are crucial as mercury in rice systems is likely to be more of a regulatory issue. As such, peer reviewed papers are critical in guiding scientifically based regulation. Our overall findings are that while rice systems may be a source of mercury, loads from rice fields are small; and certainly much less than what is found in Delta rice systems where much of the previous work was conducted. We further found that rice grain is very low in MeHg; that most of the MeHg leaves rice fields during winter fallow; and that if necessary, alternate wetting and drying of rice fields during growing season can reduce MeHg loads. Below are a list of publications from previous research funded by this grant. The list does not include the current 2017/18 research described above.

Tanner K.C., L. Windham-Myers, J.A. Fleck, K.W. Tate, S. McCord, B.A. Linquist (2017) The contribution of rice agriculture to methylmercury in surface waters: a review of data from the Sacramento Valley, California. *Journal of Environmental Quality* 46:133-142.

Tanner K., Windham-Myers, L., Marvin-DiPasquale, M., Fleck, J.A. and Linquist, B.A. (2018). Alternate wetting and drying decreases methylmercury in flooded rice (*Oryza sativa*) systems. Soil Science Society of America Journal 82:115-125.

Tanner K.C., L. Windham-Myers, M. Marvin-DiPasquale, J.A. Fleck, K.W. Tate, and B.A. Linquist (2018) Methylmercury dynamics in upper Sacramento Valley rice fields with low background soil mercury levels. *Journal of Environmental Quality* 47:830-838 doi: 10.2134/jeq2017.10.0390.

PUBLICATIONS OR REPORTS:

L. Salvato, M. Marvin-DiPasquale, J.A. Fleck, S. McCord, B.A. Linquist. Methylmercury Dynamics in Agricultural Wetlands in the Sacramento Valley, CA. Presentation at the Delta Tributaries Mercury Council (DTMC). September 25, 2018. West Sacramento, CA.

L. Salvato, M. Marvin-DiPasquale, J.A. Fleck, S. McCord, B.A. Linquist. Methylmercury Dynamics in Agricultural Wetlands in the Sacramento Valley, CA. Poster at the Rice Field Day. Aug 29, 2018. Rice Experiment Station. Biggs, CA.

Tanner K.C., L. Windham-Myers, J.A. Fleck, K.W. Tate, S. McCord, B.A. Linquist (2017) The contribution of rice agriculture to methylmercury in surface waters: a review of data from the Sacramento Valley, California. *Journal of Environmental Quality* 46:133-142.

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Tanner, K. C., Windham-Myers, L., Fleck, J. A., Tate, K. W., McCord, S., Linquist, B. A. 2016.The Contribution of Sacramento Valley Rice Systems to Methylmercury in the Sacramento River. Poster at the Revisiting the 2003 Mercury Strategy for the Bay-Delta Ecosystem, Sources Workshop (January 26-28th, 2016)

Tanner, K. C., Windham-Myers, L., Fleck, J. A., Tate, K. W., McCord, S., Linquist, B. A. 2016. Methylmercury Export From Rice: Field Scale Methylmercry Budgets for the Sacramento Valley. Poster at the Revisiting the 2003 Mercury Strategy for the Bay-Delta Ecosystem, Biogeochemistry Workshop (January 26-28th, 2016)

Tanner, K. C., Windham-Myers, L., Marvin-DiPasquale, M., Fleck, J. A., Tate, K. W., Linquist, B. A, 2016. Alternate wetting and drying decreases methylmercury in rice ecosystems.

Presentation at the American Society of Agronomy, Crops Science Society of America and Soil Science Society of America annual meeting. Phoenix, AZ. November 9th, 2016.

Tanner, K. C., Windham-Myers, L., Jacob Fleck, J. A., Tate, K. W., McCord, S., Linquist, B. A. The Contribution of Sacramento Valley Rice Systems to Methylmercury in the Sacramento River. Poster at the Rice Field Day. Aug 26, 2015. Rice Experiment Station. Biggs, CA.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

- Six commercial fields were monitored for the 2017-18 fallow and growing seasons. These fields are in three different irrigation districts and are in pairs where one pair received fresh water and one pair received recycled water. All water samples were filtered to determine the relative form of MeHg and THg in the water samples (dissolved or particulate).
- MeHg concentrations of **inlet** irrigation water were low (less than 0.1 ng/L) and did not vary between fields receiving fresh or recycled irrigation water. However, during the middle of the growing season, recycled fields tended to have higher MeHg concentration than fields receiving fresh water. This is expected as it is during the growing season when recycling is most likely to take place. , in-field and outlet water concentrations across fields.
- **In-field** MeHg water concentrations were higher in recycled fields from mid-winter until the initial spring flood. MeHg concentrations averaged less than 0.25 ng/L but some values exceeded 1 ng/L.
- MeHg concentrations from the rice field **outlets** were similar to what was measured in the in-field. As seen in other studies, MeHg concentrations were highest in rice field outlet water during the winter.
- Regarding MeHg loads, as other studies have shown, rice fields were sources of MeHg during the winter and sinks for MeHg during the growing season. On an annual basis, rice fields receiving recycled water tended to be sources of MeHg while those receiving fresh water were sinks.