Progress Report for Twitchell Rice Project, 2008-2009

1.0 Executive Summary

The overall objective for the Subsidence Mitigation through Rice Cultivation Project on Twitchell Island (TW-08-03) is to address the question: is wide spread rice production sustainable and environmentally and economically viable in the Sacramento-San Joaquin Delta? Sustainability implies stopping subsidence. We initially hypothesized that rice cultivation in the Delta will stop subsidence of organic soils.

However, increasing rice acreage in the Delta raises water-quality concerns due to the potential for increased loads to Delta channels of dissolved organic carbon (DOC) and disinfection byproduct precursors (DBPs), pesticides and methyl mercury (MeHg). Mercury also presents a biological and human health concern if it accumulates to a greater degree in the food chain as the result of rice cultivation. Higher greenhouse gas emissions (methane and nitrous oxides) relative to current land uses may also be problematic.

Reclamation District 1601 and DWR began preparation for planting rice on 180 acres on Twitchell Island in summer 2008. Rice was planted in April 2009. Starting in fall 2008, in cooperation with Reclamation District 1601 and DWR, representatives from UC Davis, UC Cooperative Extension, UC Berkeley, US Geological Survey, Bachand and Associates and HydroFocus, Inc. collected and analyzed data to assess water and air quality, mercury in biota, alternate rice varieties and factors affecting yields and subsidence mitigation in rice.

Results of hydrologic and water-quality monitoring showed increased drain flow and drain-water DOC and MeHg concentrations and loads for rice relative to other crops such as corn and oats. Non-irrigation season rice loads were comparable with those for corn and oat fields. We expect that the rice loads will decrease over time due to the flushing of DOC for the soils and a lack of additional oxidation. Also, due to extensive use of island drain water and recirculation of rice drain water for irrigation, the Twitchell rice fields were a net sink for DOC and MeHg. The highest MeHg concentrations occurred during non-flooded periods in the rice drains. The lowest concentrations occurred shortly after field inundation from intentional flooding or periods of increased rainfall.

Two herbicides were applied to the rice fields prior to planting; bispyribac sodium and pendimethalin. Concentrations of these herbicides in rice drain water within a week after flooding were below levels of aquatic life concern and concentrations decreased during two additional sampling events.

Rice and corn extensometer data indicate that rice will stop subsidence. Specifically, the rice extensometer measured 19.9 mm (0.78 in) of accretion during a 121-day period from early in the flooding (5/31/09) to soon after draining

(9/29/09). The corn extensometer measured 7.3 mm (0.3 inches) of inelastic subsidence during a 63-day period from mid-August to mid-October. More data is required for verification of the rice subsidence mitigation potential.

Air quality measurements using eddy covariance methodology for Twitchell rice and pasture on Sherman Island demonstrated rice uses more than twice the amount of water during the day relative to the Sherman pasture, and is an active source of water vapor at night. However, based on ET measurements on Twitchell, rice water consumption is about 3.2 feet during the growing season or about 22 % greater than the 2.5 feet required by corn. Results indicate rice growing Delta organic soils are a significant carbon dioxide sink and a weak methane source. Chamber flux measurements generally agreed with the eddy-covariance results. In addition, chamber flux results showed nitrous oxide fluxes occurred prior to flooding of the rice fields but larger nitrous oxide fluxes were measured in the corn field after harvest. Methane fluxes were larger in rice than corn.

Overall, Twitchell rice production was low relative to the Sacramento Valley and other Delta rice growing areas. The average yield was about 25 hundred weight (cwt) per acre. Typical yields for the Delta and Sacramento Valley are 80 to 100 cwt per acre. High moisture, shattering, blanking, non-uniform water distribution and bird consumption appear to be the primary reasons for low yields. Yields in the rice variety trials were generally consistent with typical yields for the Delta and Sacramento Valley.

2.0 Background, Project Overview and Objectives

The overall objective for the Subsidence Mitigation through Rice Cultivation Project on Twitchell Island (TW-08-03) is to answer essential questions about Delta rice farming with an emphasis on the western Delta. These questions are parts of the larger essential question: **Is wide spread rice production sustainable and environmentally and economically viable in the Sacramento-San Joaquin Delta?** In addition to economic viability, sustainability also means to effectively stop subsidence. Current Delta agricultural land uses are not sustainable primarily because they cause subsidence of organic soils. Environmental viability means no net addition of deleterious exports to the water supply or negative effects on biota.

2.1 Background

Farming is the predominant land use in the Delta. It is important to the local economy and provides wildlife habitat and funding for levee maintenance. However, current farming practices cause subsidence by exposing organic soils to oxygen. Because subsidence is a predominant force that affects Delta water supply and biological resources, there is a need to stop and reverse its effects. Farming practices that stop subsidence are therefore highly desirable. Rice farming can potentially be implemented in the short term to stop the daily loss of tens of thousands of cubic yards of soil from the Delta.

Carbon loss due to soil organic-matter oxidation is the primary cause of subsidence[1]. Miller and others[2] demonstrated that wetlands which were flooded from early spring through midsummer resulted in a net carbon gain. Rice growers use a similar water management practice, flooding rice fields during the warmest months when soil oxidation rates are highest. Data presented in Miller and others indicate that rice is a viable crop for stopping subsidence, thus making rice potentially the only sustainable Delta agricultural land use.

In the past, cool night temperatures precluded rice from growing in the Delta. However, development of new rice varieties tolerant of low air and water temperatures within the last 10 to 15 years has resulted in rice production in the Delta with yields comparable to the Sacramento Valley. Available data indicates the combination of in-season and off-season flooding and addition of up to 7 to 10 tons of rice residues annually will stop and possibly reverse oxidative soil loss.

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[1] Deverel SJ, Rojstaczer SA. 1996. Subsidence of Agricultural lands in the Sacramento–San Joaquin Delta, California: role of aqueous and gaseous carbon fluxes. Water Resources Research 32:2359–2367.
[2] Miller, R.L. Hastings, Lauren and Fujii, Roger, 2000, Hydrologic Treatments Affect Gaseous Carbon Loss From Organic Soils, Twitchell Island, California, October 1995–December 1997, U.S. Geological Survey Water Resources Investigations Report 00-4042.

The incorporation of rice residue resulted in soil carbon increases in the Sacramento Valley[3].

Recent interest in subsidence mitigation prompted further investigation of rice production potential on State-owned Sherman and Twitchell islands. Rice has been successfully grown on over 3,000 acres of rice on several Delta islands: Bouldin Island, Brack Tract, Wright-Elmwood Tract, and Rindge Tract. However, questions need answering before wide-spread rice farming can be implemented in the western Delta because lower air and water temperatures and higher soil and water salinity and wind speeds may affect rice production. Also, possible deleterious water- and air-quality effects require consideration. To assess rice as a subsidence mitigation strategy, a consortium of public and private organizations proposed to the Department of Water Resources (DWR) to conduct research and plant rice on a farm-scale demonstration rice field on Twitchell Island in the western Delta. The project was funded and began in mid-2008.

2.2 Project Location

About 318 acres were delineated for rice growing on Twitchell Island in 2008. 180 acres were planted to rice in spring 2009. Figure 1 shows the field location and areas planted to rice in 2009 and scheduled for planting in 2010.

[3] Bird, J.A., C. van Kessel, and W.R. Horwath, 2003, Stabilization and ^{13}C-Carbon and immobilization of ^{15}N-Nitrogen from rice straw in humic fractions. Soil Sci. Soc. Am. J. 67:806-816.

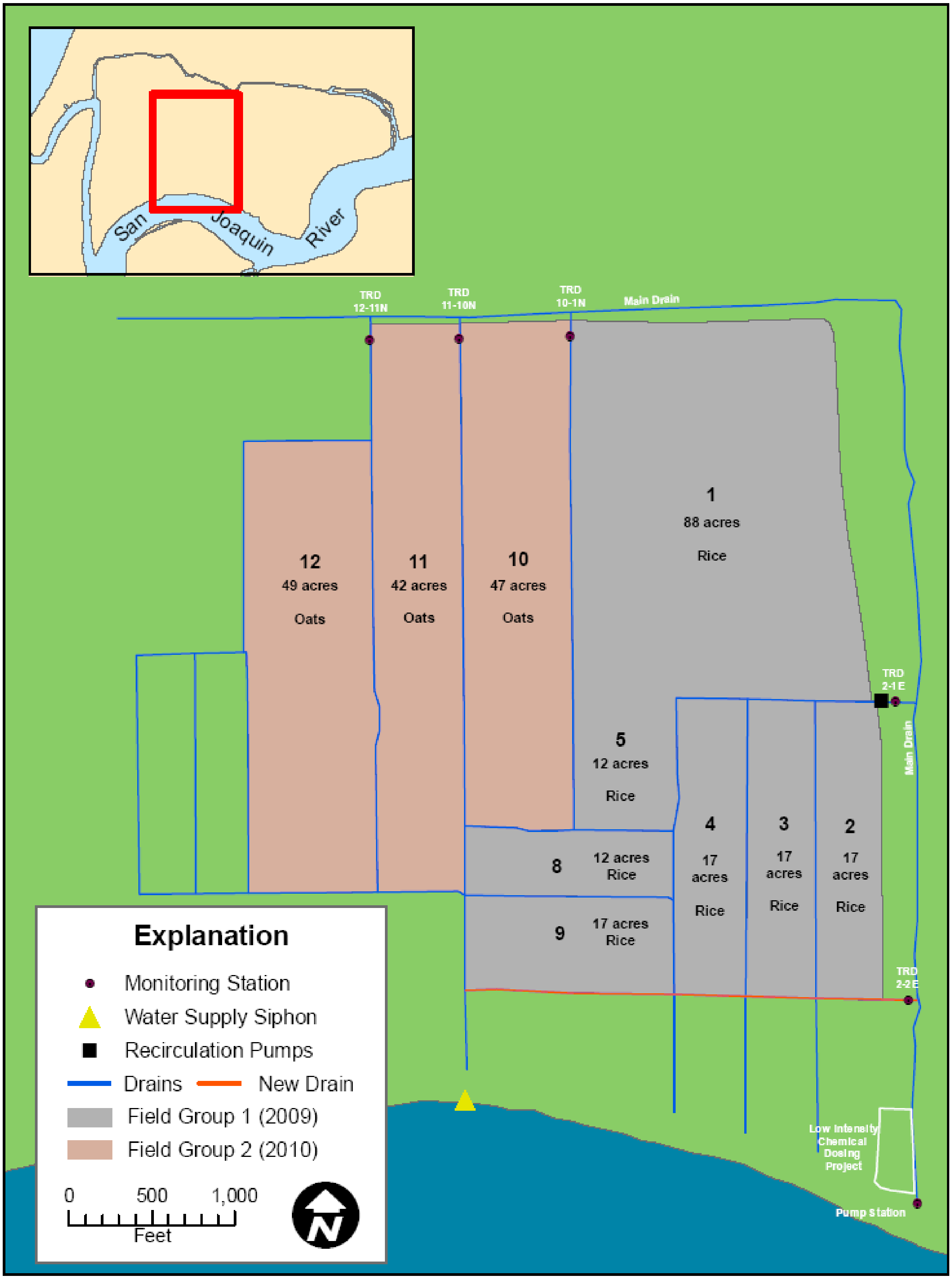

Figure 1. Twitchell rice growing area.

2.3 Key Environmental Issues

Increasing rice acreage in the Delta raises regulatory water-quality concerns about the potential for large loads of dissolved organic carbon (DOC) and disinfection byproducts (DBPs) in the drinking water supply for millions of Californians. Previous research on established rice fields provided direction for implementation of management practices that reduce deleterious aqueous exports of DOC, nitrogen and DBPs but more investigation is required to quantify how loads of these constituents will change with time. Pesticides and mercury also are potential deleterious exports that have not been investigated in Delta rice fields. Mercury also presents a biological and human health concern if it accumulates in the food chain and fish. Higher greenhouse gas emissions relative to current land uses (methane and nitrous oxides) may also be problematic if large areas are converted to rice. Increased rice acreage also raises concerns about mosquito breeding and vector control.

2.4 Conceptual Model

The original scope of work for research included five topical headings: water quality (which includes biological effects), subsidence, carbon dynamics, agronomy and economics. Figure 2 shows the conceptual model for the primary interacting processes affecting water-quality constituents of concern and greenhouse gas emissions. Initial flooding of oxidized organic soils mobilizes dissolved organic carbon (DOC) which can flow via the subsurface to drainage ditches and diffuse into surface water for discharge to surface drains. Previous research indicates that inflow and surface and subsurface outflow restriction limits DOC and dissolved nitrogen exports from rice fields without detrimental effects on yields. These two drainage sources currently mingle on Delta islands where they are discharged to Delta channels. A portion of the DOC forms disinfection byproducts (DPB's) such has trihalomethanes (THMs) during treatment for drinking water.

Pesticides (primarily herbicides) are generally applied prior to flooding. Depending on their chemical and physical properties, these compounds can adsorb to the soil organic fraction or dissolve in surface or groundwater and discharge to drains. Dissolved organic carbon can enhance the solubility and aqueous mobility of some pesticides. Figure 2 illustrates that aqueous methyl mercury concentrations are affected by carbon cycling, sulfate concentrations and oxidation-reduction (redox) status. Fertilization, crop productivity, and redox status will affect the extent to which rice paddies will release methane and nitrous oxides.

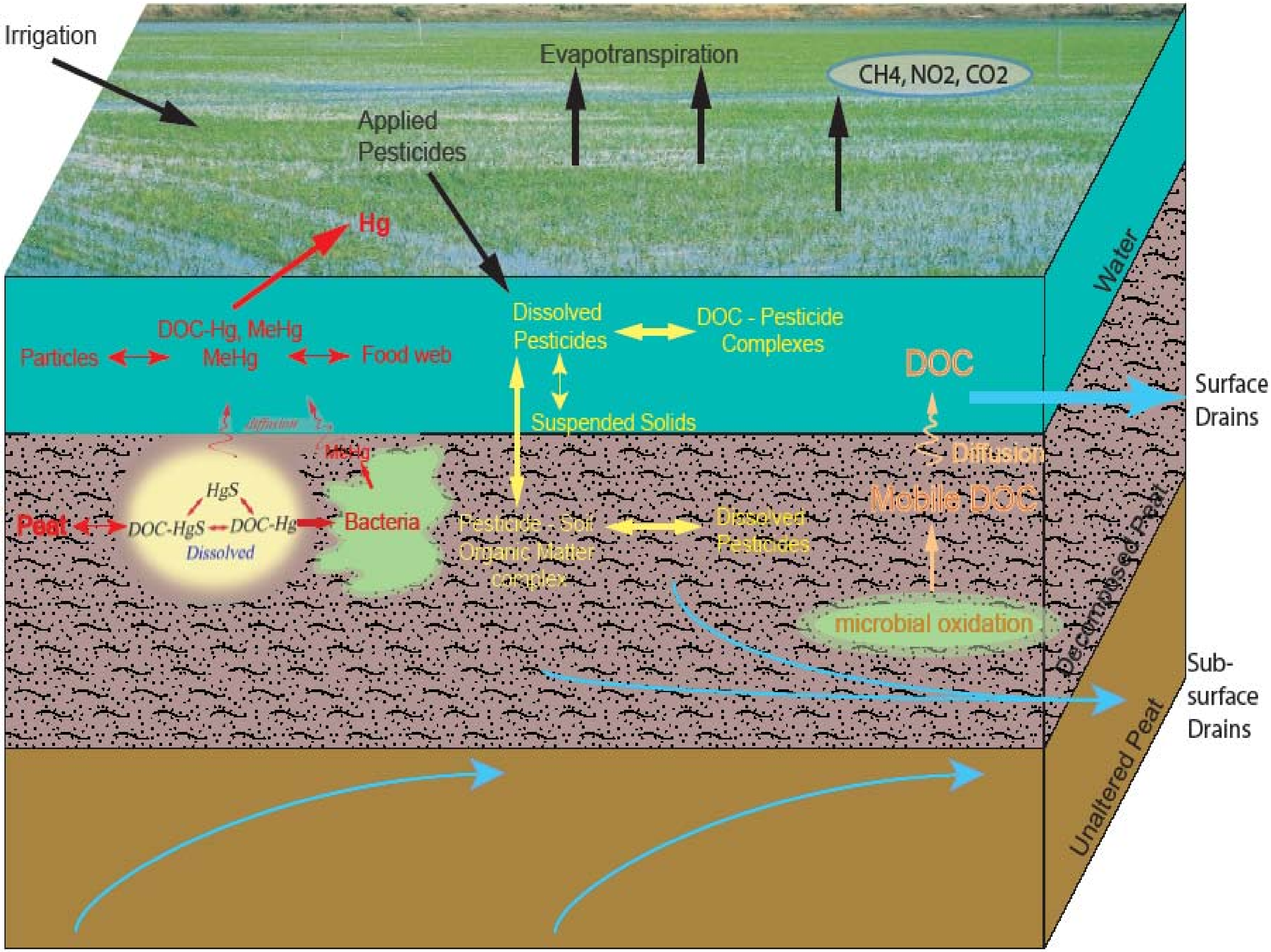

Figure 2. Conceptual model for processes affecting key constituents of concern in Delta rice field.

2.5 Project Team

Brian Brock is the project manager for DWR. A consortium of public and private organizations (Reclamation District 1601, HydroFocus, Inc., UC Davis, UC Berkeley, UC Extension Service, US Geological Survey, Bachand and Associates) proposed to the Department of Water Resources (DWR) to conduct research and plant rice on a farm-scale demonstration rice field on Twitchell Island in the western Delta. Louis Casale, experienced Delta Rice Farmer and the firm Gornto Ditching were contracted to prepare the fields and plant rice.

2.6 Scope of Work and Key Objectives

The original scope of work outlined an extensive data collection effort during 3 rice-growing seasons beginning in fall 2008. Project funding was reduced substantially in early 2009. This reduced the level of data collection efforts and analysis. A key project outcome for the originally proposed work was to define practices for optimizing rice production and mitigating deleterious exports that will be transferable to other Delta rice growing areas. An integrated understanding of processes through field-based data collection and analysis is essential for transferability to other rice growing areas. The current level of effort will provide a basis for future large-scale rice production that will help delineate ways to optimize production, reduce deleterious exports and future data collection and monitoring.

To answer the essential questions related to rice production, the original scope proposed to conduct the work at different scales of observation that included laboratory experiments, in-situ mesocosms, experimental cells of several acres, and a demonstration project farm field of about 300 acres. It was proposed that DOC transport and exports, processes affecting pesticide concentrations and loads in drainage waters, and aspects of MeHg cycling would be addressed at the field scale. Also, subsidence measurements and greenhouse gas measurements would occur at the farm-field scale using chambers and micro-meteorological methods. The following summarizes the key proposed objectives for the current level of effort.

- Implement rice farming on Twitchell Island under the direction and supervision of experienced researchers.
- Document practices for growing rice.
- Evaluate potential water-quality concerns and processes affecting water quality;
    - DOC, DBPs, MeHg and pesticides are the primary constituents of concern.
- Measure land-surface elevation changes in rice and adjacent fields and relate these measurements to carbon budget dynamics;

- Use field carbon and biomass measurements to help understand processes affecting carbon pools and fluxes;
- Measure greenhouse gas fluxes and;
- Disseminate results.

The project was awarded to RD1601 on May 22, 2008 and Project Funding Agreement between DWR and the Reclamation District was developed shortly thereafter. The following sections provide a summary of progress through October 2009.

3.0 Project Activities

3.1 Rice growing and related activities

Figure 3 shows the time line of field activities and the following sections provide additional information.

3.1.1 Surveying and field leveling

Prior to September 2008, surveying and field design occurred. Fields were surveyed by Aaron Beaver using all terrain vehicle mounted Global Position System measurements relative to a stable benchmark on Twitchell Island. Elevations were accurate to about 0.10 foot. Elevations measurements were spaced 100 to 200 feet apart. Using the elevation measurements, maps were generated and cut and fill volumes were estimated. From late September through November, fields were leveled to allow for about 1 to 2% slopes. Approximately 53,000 cubic yards were moved less than 3 months.

3.1.2 Water supply infrastructure planning, installation and flooding dates.

Key Delta threatened species (Chinook Salmon, Delta Smelt, Longfin Smelt, Splittail) are present in the channel during April and May when rice is typically flooded and water budget calculations demonstrated that irrigation for rice would result in additional water diversion relative to corn. To avoid additional withdrawals during this key period, irrigation water for flooding was withdrawn primarily from the Twitchell Island main drain.

Planning, design and purchase of materials for water supply infrastructure began in October 2009. Bryan Brock, Bachand and Associates and Bruce Gornto estimated pipe sizes based on expected water demand. Water delivery pipe installation began in mid January and was complete by mid February (Figure 3). Figure 4 shows the 2009 water supply infrastructure for rice. The predominant source of water was the main drain and rice drainage water via pumps north east of Field 2 (Figure 4). There was also water supplied from the siphon which was rehabilitated for this project (Figure 1).

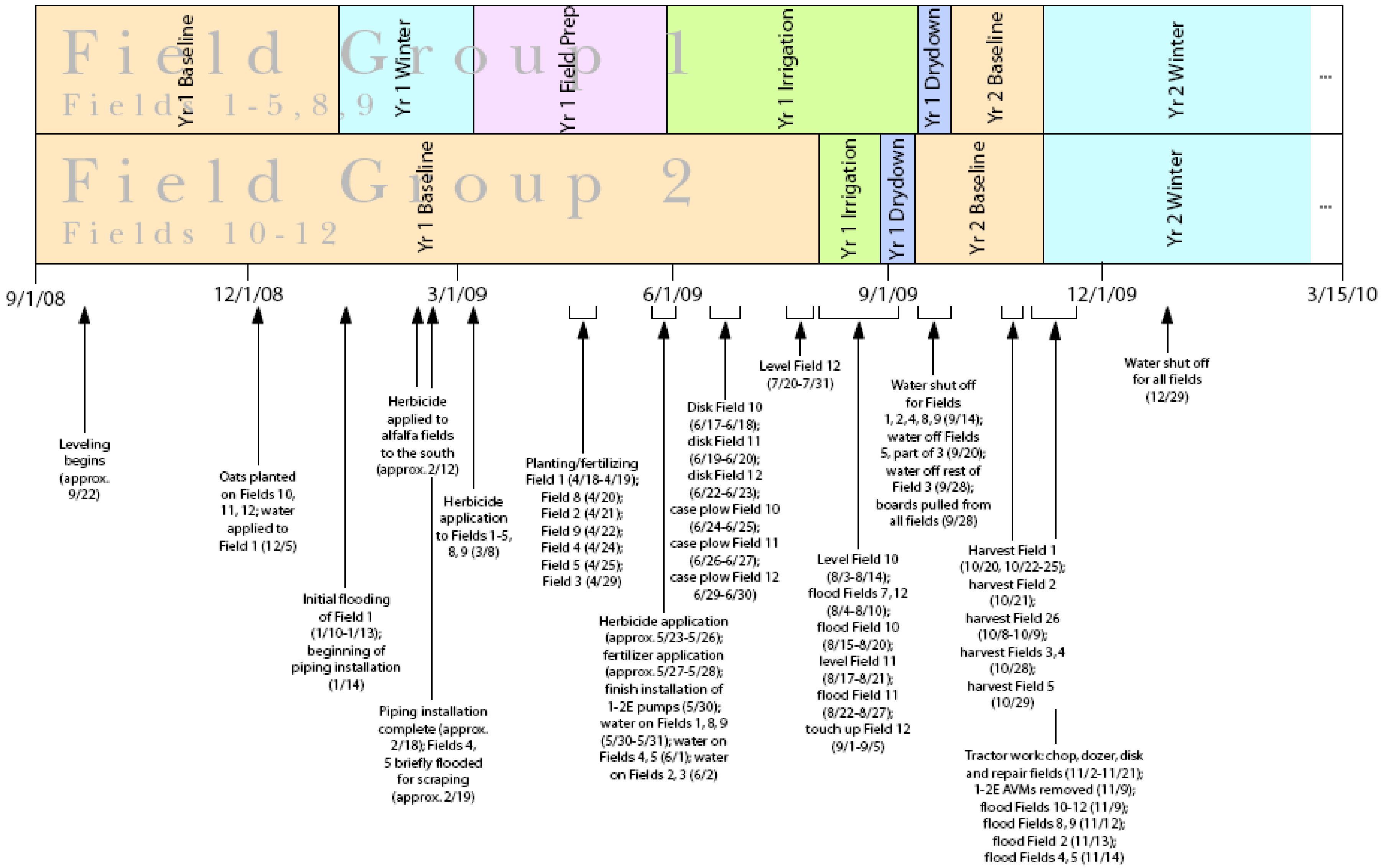

Figure 3. Timeline for Twitchell rice growing and data collection.

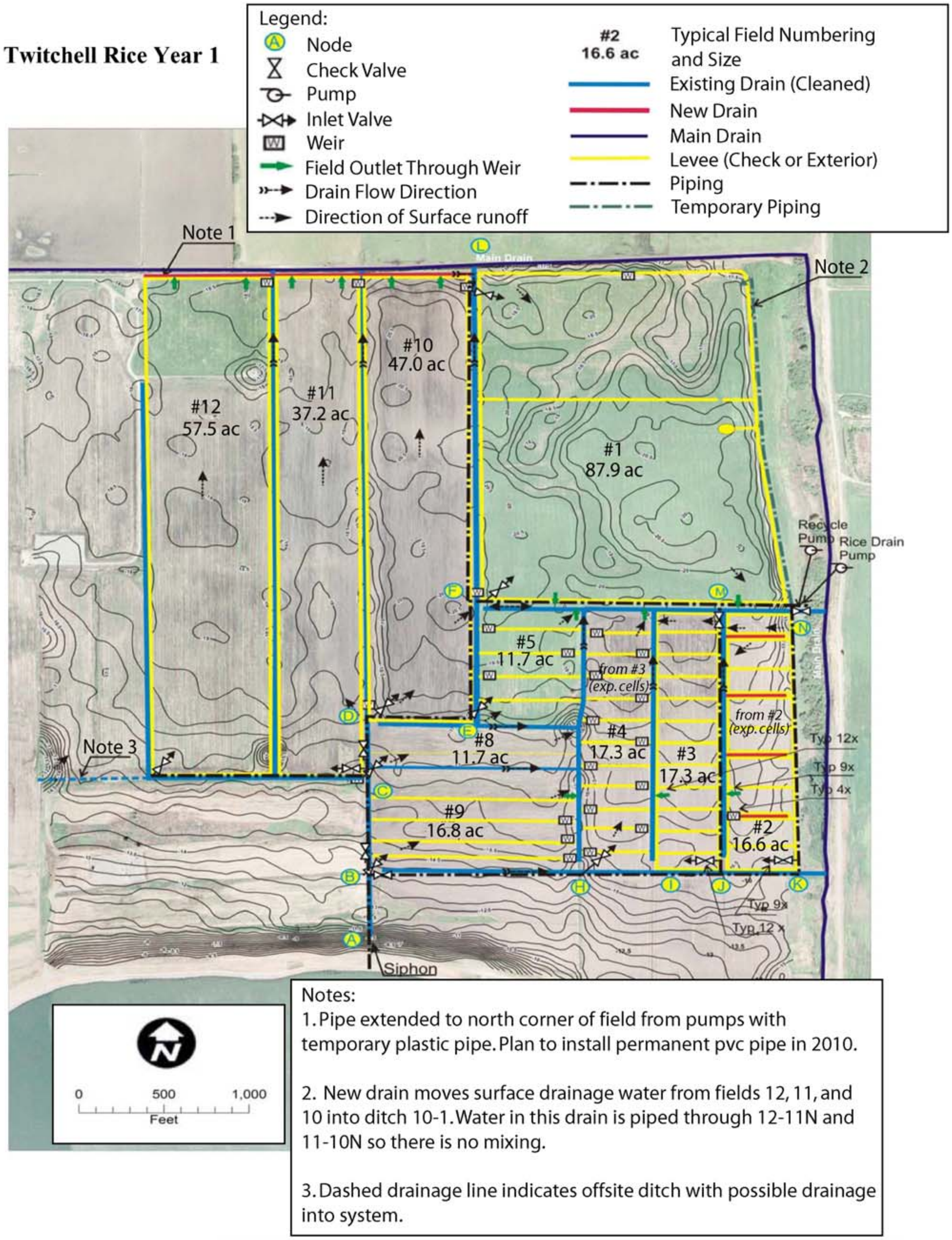

Figure 4. Water delivery and drainage system.

Flooding began on May 30, 2009 and continued through September 14th when water supply was shut off. The pumps together applied about 8 cubic feet per second. About 1650 ac-ft were pumped onto the rice fields during the irrigation season. An estimated 25% was diverted to Fields 10, 11 and 12 for second year rice conversions and a small volume of water was siphoned from the San Joaquin River.

3.1.3 Field preparation: ditch work and drainage.

All existing drainage ditches were cleared of vegetation and deepened. New drainage ditches were excavated as shown on Figure 1. Over 19,000 linear feet of drainage ditches were cleaned and over 1,200 linear feet of new ditches were constructed.

3.1.4 Planting

The rice variety M104 was planted on April 19th at the rate of150 pounds of seed per acre. Other varieties for testing were planted in Field 3. The results of this variety trial are discussed below.

3.1.5 Pesticide/herbicide/fertilization application

Glyphosate (Roundup) was applied to the fields for controlling weeds prior to planting in early March. Two herbicides (bispyribac sodium and pendimethalin) were applied to the fields prior to flooding during May 25-26, 2009. Aqua ammonia fertilizer was injected at seeding on April 19th.

3.1.6 CEQA documentation

On May 28, 2008, Reclamation District 1601 filed a notice of categorical exemption with the County Clerk of Sacramento based on general exemption CEQA statute 15061(b)(3). The project was justified as exempt because it involves the conversion of one agricultural use to another.

3.1.7 Habitat mitigation

Wetlands, brush and trees were removed during the rice field preparation process. A 2.5-acre mitigation area was established on the southeastern area of Twitchell Island (Figure 1) where 1 acre of trees (3:1 replacement) and brush (2:1 replacement) and 0.5 acre of wetlands (1:1 replacement) were established in spring 2009.

3.1.8 Rice Harvest

Rice was harvested in mid-October by a contractor (Bouldin Farms) and sold to Pacific International Rice Mills, Inc. in Woodland, CA. Overall, production was low relative to the Sacramento Valley and Delta rice growing areas. The average yield was about 25 hundred weight (cwt) per acre (Table 1). Typical yields for the Delta and Sacramento Valley are 80 to 100 cwt per acre.

Table 1. Rice yields

Field	Acres	Dry Weight (cwt)	cwt/acre
1	84.24	2063	24.5
2	14.79	1276	86.3
4	17.09	764	44.7
5	11.43	287	25.2
8	13.88	924	66.6
9	15.38	477	21

Low rice yields were attributed to 1) unacceptable rice due to high moisture (October rains delayed harvest and also caused high grain moisture), 2) grain consumption by birds, 3) uneven water distribution, and 4) grain head shattering due to wind.

3.2 Research and data collection results

Research and data collection activities were reduced substantially due to reduction of available funding. In early 2009, the project team developed a list of high priority tasks and associated costs. The total allocation for research and data collection activities was $376,180.

3.2.1 Quality Assurance Project Plan and Field Sampling Plan progress

A Quality Assurance Project Plan provides detailed descriptions for data collection, sampling and analysis and was first developed in fall 2008 and almost completed prior to the January 2009 bond freeze.

3.2.2 Hydrologic Monitoring

At the monitoring stations shown in Figure 1, Bachand and Associates measured drain flow with acoustic velocity meters (AVM) installed in pipes within drainage ditches. AVMs were visited monthly and checked with handheld Marsh-McBirney and Sontec flow meters. All drain flow was a mixture of surface and subsurface flow. Flow and monitoring began during fall 2008. However, the drainage ditches that drained fields planted to corn and oats (TRD 11-212 and TRD 10-11) collected primarily subsurface flow. HydroFocus installed a McCrometer in-line propeller flow meter coupled to a data recorder to measure total island drain flow at the island pump station (TMD-PS). Irrigation water was delivered from two recirculation pumps that extracted water from near the main drain and the siphon shown in Figure 1. The pumps near the main drain pulled water from the main drain to the east and from the main rice drainage ditch to the west.

Table 2 shows the measured water volumes at the monitoring stations shown in Figure 1 and the siphon. The siphon and the two pumps applied a total of 1,796 acre feet of water to 180 acres of rice (or 9.98 feet). Crop evapotranspiration (ET) during this time

(May-September) was 3.2 feet[4]. The large amount of water applied relative to ET indicates large volumes of lateral seepage into the rice drains.

Table 2. Volumes measured at monitoring stations shown in Figure 1.

Month	Large Pump	Siphon	Small Pump	TMD-PS	TRD 10-1 N	TRD 11-10 N	TRD 12-11 N	TRD 2-1 E	TRD 2-2 E
	Ac-Ft								
October					0.0	0.0	0.0		6.8
November					0.0	4.4	0.0		13.0
December					0.0	-1.5	-0.1	-2.7	
January				438.6	1.7	18.8	0.1	16.4	11.0
February				756.9	18.9	20.3	10.9	36.5	15.5
March				646.0	2.3	20.8	14.5	2.1	16.7
April				467.7	0.5	12.9	0.4	-1.7	10.7
May	24.1		7.9	461.8	2.6	11.7	0.3	-16.3	5.7
June	361.9		118.0	504.9	22.9	13.0	1.2	115.1	11.5
July	358.1		99.5	549.3	54.7	13.6	0.9	70.1	9.8
August	349.7	111.1	121.5	664.7	12.4	20.2	6.9	93.8	9.3
September	151.4	0.0	92.4	749.8	8.4	18.8	7.3	105.3	
Total	1245.23	111.09	439.28	2930.52	101.04	77.26	16.65	367.94	36.32

[4] We estimated crop ET by multiplying reference ET from the DWR California Irrigation Management System station on Twitchell Island by crop coefficients for rice which ranged from 1.2 during early season to 0.80 during late season.

We used the values in Table 2 to estimate per area drain flow to assess drainage volumes for rice relative to drained agricultural crops. For comparison, we estimated the per acre drainage from the area apparently contributing to TRD 11-12[5]. We also assumed that the drain flow at TRD 1-10, 1-2 and 2-2 was contributed approximately by 180 acres of rice. Table 2 shows per area drain flows based on these assumptions. The data in Table 3 illustrate the differences between drained agriculture and rice.

The average drain flow for TRD 12-11 N of 0.0023 acre ft/acre-day is similar to values reported by Deverel and others[6] which ranged from 0.001 to 0.0033 acre feet/acre-day for drained agricultural areas on eastern Twitchell Island. In contrast, average drain flow for the rice fields is substantially greater at 0.01 acre feet/acre-day. Also, values for the sum of TRD 10-1, 1-2 and 2-2 prior to flooding during October to April are consistent with the TRD 12-11 N values and those reported by Deverel and others[7] for drained agricultural areas on eastern Twitchell Island. The Twtichell main drain pump station per acre flows are about 2 times larger than those for TRD 11-12 and those reported by Deverel and others and about 50% of the estimated rice drain flows (Table 3).

The assumptions underlying the calculated values shown in Table 3 contain uncertainty. For example, TRD 10-11 is probably influenced by drainage from the rice fields. However, the comparison is valid for demonstrating the difference in drainage volumes between rice and drained crops.

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[5] We assumed that the drain collected groundwater from the area extending from half-way between TRD 10-11 to half way between TRD 11-12 and the drainage ditch west of TRD 11-12. This area is 42 acres.
[6] Deverel, S.J., Leighton, D.A. and Finlay, M.A., 2007, Processes Affecting Agricultural Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 2. http://repositories.edlib.org/jmie/sfews/vol5iss2/art2
[7] ibid

Table 3. Per acre drain flow for rice fields and contributing area to TRD12-11.

	TRD 12-11 N	Rice (sum of TRD 10-1, 1-2 and 2-2)	Entire island (TMD-PS)
	acre feet/acre-day	acre-ft/acre-day	acre-ft/acre-day
October	0.000014	0.001213	
November	0.000001	0.002413	
December	-0.000039	-0.000492	
January	0.000076	0.005208	0.004024
February	0.007502	0.014061	0.007689
March	0.008968	0.003772	0.005927
April	0.000241	0.001769	0.004434
May	0.000191	-0.001431	0.004237
June	0.000799	0.027677	0.004787
July	0.000540	0.024116	0.005040
August	0.004273	0.020708	0.006098
September	0.004684	0.021056	0.007108
Average	**0.002271**	**0.010006**	**0.00548**

3.2.3 Water Quality

The primary water quality concerns are dissolved organic carbon (DOC) and methyl mercury (MeHg). The following sections describe results of concentration measurements and load calculations for DOC, mercury and pesticides in drain water. Results of fish mercury levels are also discussed.

3.2.3.1 DOC Concentrations and Loads

Figure 5 shows that DOC concentrations are generally higher in the rice drains (2-2E, 2-1E and 1-10N) relative to the corn/oats drains (12-11N, 11-10N). Figure 6 shows that during winter, concentrations increased similarly in all drains. However, when rice fields were flooded during May through August, DOC increased in the rice drains but USGS personnel measured consistently lower DOC concentrations in the corn/oat field. These trends are consistent with previous studies of DOC concentrations and loads on Twitchell Island; high DOC concentrations result from flushing of DOC from the shallow, oxidized soil layer on Twitchell during wet periods[8]. DOC accumulates due to oxidation of the organic soils primarily during summer and fall and is flushed from the soils to drainage ditches during winter rains. Flooding for rice cultivation also flushes DOC from the organic soils.

[8] Fujii, R., A.J. Ranalli, G.R. Aiken, and B.A. Bergamaschi, 1998, Dissolved organic carbon concentrations and compositions, and trihalomethane formation potentials in waters from agricultural peat soils, Sacramento-San Joaquin Delta, California: Implications for drinking water quality. US Geol. Survey Water Resour. Investigations Rep. 98-4147.; Deverel, S.J., Leighton, D.A. and Finlay, M.A., 2007, Processes Affecting Agricultrual Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 2.

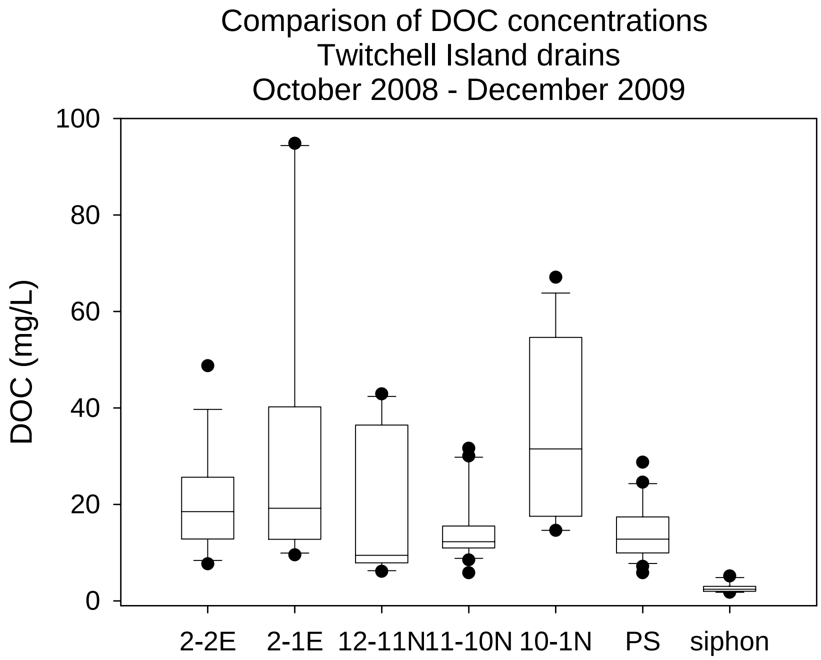

Figure 5. Box plot of drain-water DOC concentrations (mg/L). Rectangles represent the inner quartile range or 75% of the data and the horizontal line in the rectangle is the median. Lines extending above and below the rectangle represent 90 percent of the values. Dots represent values beyond the 90th percentile. PS represents the main drain pump station (TMD-PS).

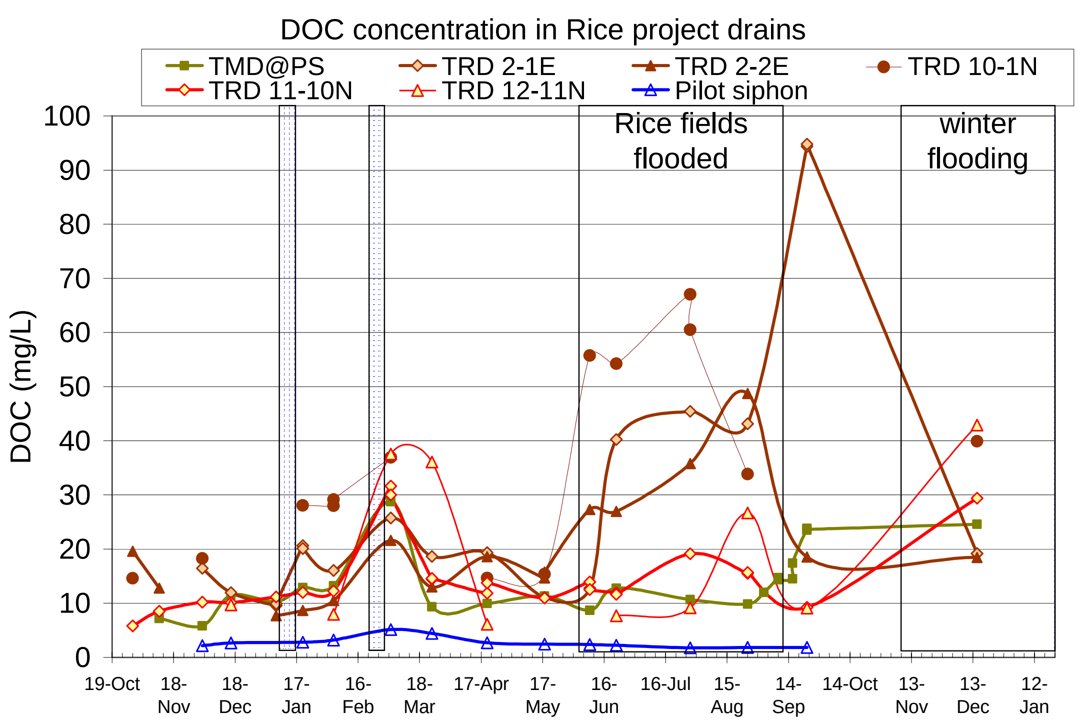

Figure 6. Dissolved organic carbon concentrations in drains. Blue areas indicate flooding of rice fields.

Per acre DOC loads were calculated for rice and corn/oats fields (Figure 1). The corn/oats drains (TRD 12-11N and 11-10N, Figure 1) , and rice drains (TRD 10-1N, 2-1E, 1-1E, Figure 1) during non-flooded conditions, exported similar amounts per acre of DOC compared to values previously reported for drains in corn fields and for the entire island[9] (Table 4). The rice fields exported much greater amounts of DOC during the irrigation period than the corn/oats drains but were similar to exports from the impounded wetlands on Twitchell Island[10]. Previous work demonstrated that DOC loads can be reduced by maintaining high water levels in the drains[11].

[9] Deverel, S.J., Leighton, D.A. and Finlay, M.A., 2007, Processes Affecting Agricultrual Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 2.

[10] Fleck, J.A., Fram, M.S., and Fujii, R., 2007, Organic Carbon and Disinfection Byproduct Precursor Loads from Constructed Non-Tidal Wetland in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 1.; Burow, K.R., Constantz, J., and Fujii, R., 2005, Using heat as a tracer to estimate dissolved organic carbon flux beneath a restored wetland. Ground Water 43(4): 545–556.; Deverel, S.J., Leighton, D.A. and Finlay, M.A., 2007, Processes Affecting Agricultrual Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 2.

[11] Bachand & Associates, Hydrofocus, Inc., University of California, Davis, US Geological Survey, Ducks Unlimited, and Contra Costa Water District, 2006, Reducing Non-Point DOC and Nitrogen Exports from Rice Fields: A Pilot Study and Quantitative Survey to Determine the Effects of Different Hydrologic Management Practices. SWRCB Agreement No. 03-165-555-0.; Final Report to State Water Resources Control Board

Table 4. DOC loads from Twitchell Island drains.

Management	Dry period DOC loads (g/acre-day)	Wet Period DOC loads (g/acre-day)
Entire Island[12]	May-Nov, Avg = 73 Range = 18 - 161	Dec-Apr, Avg = 576 Range = 78 – 1,253
Entire Island[13]	May-Nov, Avg = 80	Dec-Apr, Avg = 249
Corn fields[14]	May-Nov Range = 8 – 41	Dec-Apr Range = 56 – 174
Impounded Wetlands[15]	NA	Avg = 1,038 Range = 499 to 1,486 Range = 809 – 2,833
Corn/Oats Rice Entire Island[16]	Dry Period Avg = 66 Non-irrigated Avg = 63 Dry period Avg = 57	Wet Period Avg = 115 Irrigated = 1,518 Wet Period Avg = 109

Table 5 shows the daily DOC load in kg/day entering the rice field from the recirculation pumps (see Figure 1) was greater by over two fold than the daily load from the rice drains. The measurement from the rice drain was upstream of the recirculation pumps so that exported load was recycled back onto the rice fields with the water from the rice drain.[17]

[12] Templin, W.E. and Cherry, D.E., 1997, Drainage-return, surface-water withdrawal, and land-use data for the Sacramento-San Joaquin Delta, with emphasis on Twitchell Island, California. USGS Open-File Report 97-350.; DWR-MWQI

[13] Deverel, S.J., Leighton, D.A. and Finlay, M.A., 2007, Processes Affecting Agricultrual Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 2.

[14] ibid

[15] Fleck, J.A., Fram, M.S., and Fujii, R., 2007, Organic Carbon and Disinfection Byproduct Precursor Loads from Constructed Non-Tidal Wetland in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 1.; Burow, K.R., Constantz, J., and Fujii, R., 2005, Using heat as a tracer to estimate dissolved organic carbon flux beneath a restored wetland. Ground Water 43(4): 545–556.; Heim, WA, Deverel, SJ, Stephenson, M, 2009, Farmed Islands and Monomethylmercury in the Sacramento-San Joaquin Delta Final Report submitted to the Central Valley Regional Water Quality Control Board.

[16] This study

[17] Recirculation pumps drew water from the main drain and the projects rice drain. Water volumes from the rice drains made up 15 – 40% of the water being pumped (Table 2).

Table 5. Comparison of DOC loads for early, mid and late season for rice source water and drains.

Irrigation Period	Rice Pumps / Source Water	Siphon	Rice Drain
	water (cu meters)		
Early	19005	0	4253
Mid	19495	4658	3533
Late	17236	1485	4291
	DOC (kg/d)		
Early	298	ND	140
Mid	309	ND	152
Late	ND[18]	ND	ND

3.2.3.2 Mercury Concentrations and Loads

USGS and Bachand and Associates personnel collected drain-water samples for analysis of methyl mercury from six locations in the Twitchell Island Rice Project area from October 2008 through September 2009 (Figure 1). Samples were collected biweekly to monthly, with more frequent sampling corresponding to flooding and draining. All samples were collected using ultraclean (clean-hands/dirty-hands) techniques.[19]

Concentrations of MeHg in unfiltered drain water samples ranged from 0.1 to 1.9 nanograms per liter (ng/L) and were elevated in all drains relative to the nearby San Joaquin River water where previously reported concentrations ranged from 0.05 – 0.25 ng/L. The USGS measured MeHg mean concentrations significantly higher in rice drains TRD 10-1N, 2-2E relative to the corn/oats drains (TRD 12-11 and 11-10) (Figure 7; $p<0.0035$). MeHg Concentrations in the primary rice drain (2-1E) were not significantly higher than the corn/oats drains (11-10N and 12-11N) but Figure 7 shows elevated concentrations in 2-1E relative to the corn/oat drains (Figure 7; $p>0.2$). Concentrations at the pump station were lower than the rice drain concentrations but not significantly different from 2-1E or the corn/oats drains. Similar trends were observed for MeHg particulate and dissolved concentrations.

[18] ND indicates that concentrations were not determined.

[19] Samples were collected in 2 – 2 L PETE bottles and placed on wet ice in coolers immediately for transport to the USGS Lab for processing. Sample processing included the filtration of well-mixed samples for analysis of particulate and dissolved mercury species. Lab analyses of total mercury (THg) and methylmercury (MeHg) were conducted at the Wisconsin Mercury Research Lab (WiMRL) in Middleton, WI.

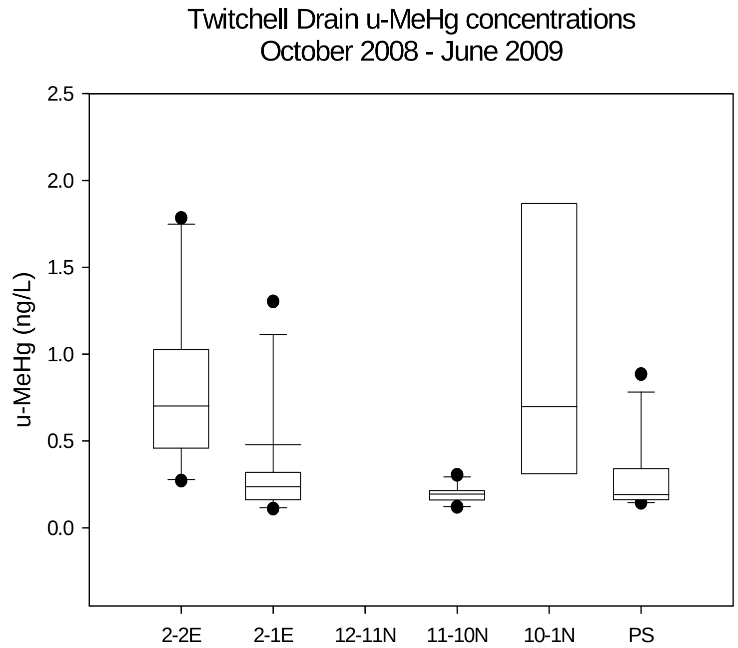

Figure 7. Box plots for methyl mercury (MeHg) concentrations in unfiltered drain samples at TRD sites and the Twitchell Island main drain pump station (PS). Rectangles represent 75% of the data and the horizontal line in the rectangle is the median. Lines extending above and below the rectangle represent 90 percent of the values. Dots represent values beyond the 90^{th} percentile.

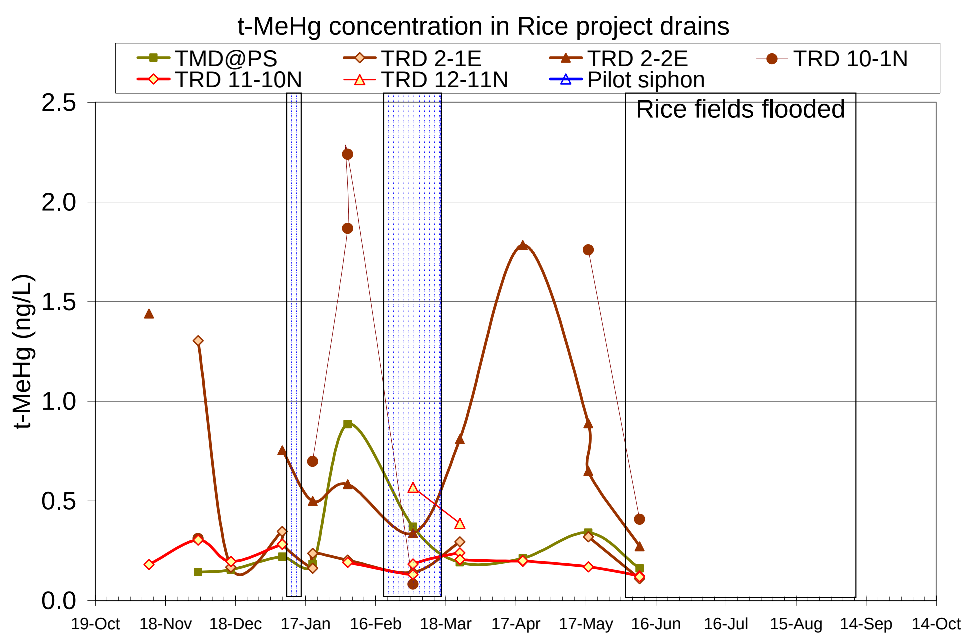

Figure 8. Temporal variability in methyl mercury (MeHg) concentrations in unfiltered drain samples.

Figure 8 shows the highest MeHg concentrations occurred during the non-flooded conditions in the rice fields. The lowest concentrations occurred shortly after field inundation from intentional flooding or periods of increased rainfall. These trends were observed only in the rice fields suggesting rice conversion activities played a role increasing MeHg concentrations.

MeHg loads were calculated for the wet and dry periods using two to four months of data where results were available for all drains. Loads from the rice drains were two to three times greater than the corn/oats drains and the island averages for both periods. The corn/oats drains were similar in magnitude to bogs and fens of northern climates and results from a study in managed tidal wetlands of Grizzly Island in the nearby Suisun Marsh Complex.

The areal loading from the rice fields were also in the range of bogs and fens but were in the upper end of the range. The areal loads from the rice drains are approximately one-half to one-third of the loads from Brown's Island, a natural tidal wetland located about 5 miles west of Twitchell Island, and only 10-20% of the loads measured from impounded wetlands in the southeast corner of Twitchell Island. However, there is a substantial MeHg load onto the rice fields from the recycled water and siphon that was not accounted for in Table 6. The per acre loads from the rice drains are likely to increase when the irrigation period is included in the analysis. However, because drainwater is recycled, there was no net export of MeHg from the rice fields.

Table 6. Comparison of MeHg loads in Twitchell Island drains and other systems

Management Area	Wet period u-MeHg loads (µg/A-day)	Dry Period u-MeHg loads (µg/A-day)
Twitchell Island[20]		
Entire Island Avg	3.3 (Jan-Mar)	1.2 (Apr-Jun)
Corn/oats	3.5 (Jan-Mar)	1.2 (Apr-Jun)
Rice	8.6 (Jan-Mar, June)	3.2 (Apr-May)
Twitchell Island[21]		
Impounded wetlands	31.2 – 58.7	NA
Twitchell Island[22]		
Corn	1.8 – 26.3 (Oct-Apr)	ND
Impounded wetlands	5.7 – 56.7	NA
Bouldin Island		
Tomatoes	3.2 – 9.7	ND
Rice	-0.4 – +0.2	ND
Other island estimates		
Entire island avg	-1.6 – +2.4	ND
Brown's Island[23]		
Tidal wetland	17.8 – 28.7	NA
Grizzly Island[24]		
Managed tidal wetland	2.1	NA
Bogs and Fens in WI, MN, NY, Sweden and Ontario, Canada[25]	0.6 – 6.1	NA

[20] Values from this study (results to date)
[21] Sassone, E.R., Bonnema, A, Stephenon, M, Hein, WA, Newman, A, Fleck, J, Coale, K, 2008, Task 5.3a Methylmercury Loading Studies in Delta Wetlands: Twitchell Island *in* Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries: An Integrated Mass Balance Assessment Approach. CALFED Mercury Project Final Report. September 15, 2008.
[22] Heim, W.A., Deverel, S., Ingrum, T., Piekarski, W., and Stephenson, M., 2009, Assessment of Methylmercury Contributions from Sacramento-San Joaquin Delta Farmed Islands. Report submitted to Chris Foe and the Central Valley Regional Water Quality Control Board.
[23] Fleck, J.A., Fram, M.S., and Fujii, R., 2007, Organic Carbon and Disinfection Byproduct Precursor Loads from Constructed Non-Tidal Wetland in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 1.
[24] Stephenson, M, Bonnema, A, Hein, W, Coale, K, 2008, Task 5.3a Methylmercury Loading Studies in Delta Wetlands: Grizzly Island *in* Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries: An Integrated Mass Balance Assessment Approach. CALFED Mercury Project Final Report. September 15, 2008.
[25] Krabbenhoft, D. P., Benoit, J. M., Babiarz, C. L., Hurley, J. P., & Andren, A. W., 1995, Mercury cycling in the Allequash Creek Watershed, northern Wisconsin. *Water, Air and Soil Pollution* 80: 425–433.; Jeremiason, JD, Engstrom, DR, Swain, EB, Nater, EA, Johnson, BM, Almendiner, JE, Monson, BA, & Kolka, RK, 2006, Sulfate Addition Increases Methylmercury Production in an Experimental Wetland. Environmental Science & Technology

These data provide evidence for the mechanism of wet-dry cycles causing production DOC and MeHg. DOC is produced by oxidation of the organic matter in the peat soils of Twitchell Island where it is preserved until it is physically flushed out of the soils via advective transport[26]. DOC loads can be reduced relatively easily by reducing drain flows by maintaining high water levels in drains. In contrast, MeHg is produced as a result of sulfate, iron and possibly manganese reduction pathways that require substrate supply of reactive Hg and bioavailable organic matter[27]. The temporal trend of MeHg concentrations in the drains on Twitchell Island suggest that MeHg concentrations lag behind DOC concentrations due to the time required to establish pathways that generate MeHg. In essence, DOC is produced during the unflooded (dry) season and is immediately available for transport once flooding occurs whereas MeHg is produced only after the flooding occurs, thus delaying the build-up and export of MeHg relative to DOC.

3.2.3.3 Mercury in Fish

In order to evaluate potential changes in methylmercury availability and bioaccumulation in cultivated rice fields in the Delta, USGS personnel sampled 96 wild Western mosquitofish (*Gambusia affinis*; hereafter mosquitofish) from three locations in the main drain (near TRD 11-10 N and 2-1E and TMD-PS) every two months from 2/16/2008 to 10/19/2009. During each sampling event, USGS personnel captured mosquitofish using beach seines or dip nets.

USGS personnel analyzed only individuals with a standard length between 22 and 39 mm. Upon sampling, fish were immediately placed in labeled polyethylene bags and held on ice until their return to the laboratory (within 6 hrs) where they were stored at -20°C. Prior to total mercury (THg) analysis, each fish was dried at 50°C to a constant mass, and homogenized to a fine powder using a mortar and pestle. THg was determined in each individual fish at the USGS-Davis Field Station Environmental Mercury Lab following EPA method 7473, using an integrated sequence of thermal decomposition and amalgamation followed by atomic absorption spectroscopy.

40(12): 3800-3806.; Driscoll, CT, Holsapple, J, Schofield, CL, and Munson, R, 1998, The chemistry and transport of mercury in a small wetland in the Adirondack region of New York, USA. Biogeochemistry 40(2): 137-146.; Lee, Y and Iverfeldt, A, 1991, Measurement of methylmercury and mercury in run-off, lake and rain waters. Water, Air and Soil Pollution 56(1): 309-321.; St Louis, VL, Rudd, JWM, Kelly, CA, & Barrie, LA, 1995, Wet deposition of methylmercury in northwestern Ontario compared to other geographic locations. Water Air Soil Poll. 80: 405-414.

[26] Deverel, S.J., Leighton, D.A. and Finlay, M.A., 2007, Processes Affecting Agricultrual Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 2.; Fleck, J.A., Fram, M.S., and Fujii, R., 2007, Organic Carbon and Disinfection Byproduct Precursor Loads from Constructed Non-Tidal Wetland in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 1.

[27] Compeau, GC, and Bartha, R, 1985, Sulfate-Reducing Bacteria: Principal Methylators of Mercury in Anoxic Estuarine Sediment. Appl Environ Microbiol. 50(2): 498-502.; Gilmour, CC, Riedel, GS, Ederington, MC, Bell, JT, Gill, GA, and Stordal, MC, 1998, Methylmercury concentrations and production rates across a trophic gradient in the northern Everglades. Biogeochemistry 40(2): 327-345.; Marvin-DiPasquale, M, and Cox, MH, 2007, Legacy Mercury in Alviso Slough, South San Francisco Bay, California: Concentration, Speciation and Mobility U.S. Geological Survey, Open-File Report 2007-1240.

USGS personnel sampled and analyzed a total of 96 mosquitofish for THg concentrations during December 2008 and March, April, June, August and October 2009. Across all sites and dates, the geometric mean (± standard error) mercury concentration in mosquitofish was 0.062 ± 0.002 µg/g wet weight, which is more than twice the value (0.03 µg/g wet weight) designated by the Central Valley Regional Water Quality Control Board mercury TMDL for protection of wildlife health (Figure 9). Additionally, 97% of fish sampled exceeded the TMDL threshold.

Total mercury concentrations in mosquitofish did not differ among sites ($F_{2,81}$ = 2.13, P = 0.12), but increased with length ($F_{1,81}$ = 4.02, P = 0.048) and differed among sampling dates ($F_{5,81}$ = 4.92, P = 0.001). Mercury concentrations were highest for samples collected during December 2008 and March 2009 and lowest for samples collected during the April and June 2009. Because the mosquito fish were collected from the drainage canals, Hg concentrations are not necessarily reflective of the influence of mercury bioaccumulation within rice fields, which is expected to be much higher[28].

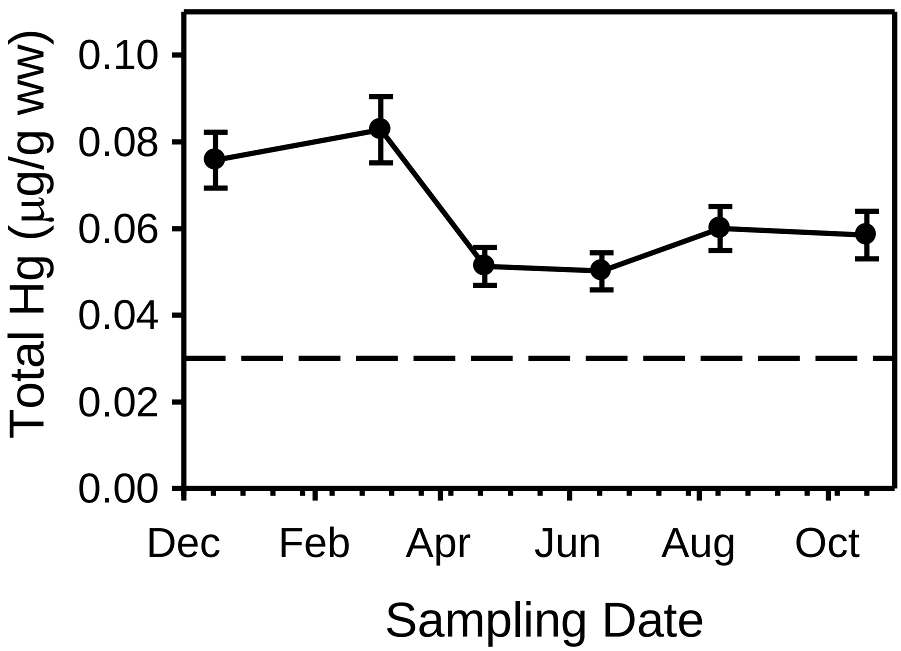

Figure 9. Total mercury concentrations (least square means ± standard errors; µg/g wet weight) in mosquitofish from Twitchell Island rice field outlets. Dashed line represents Central Valley Regional Water Quality Control Board TMDL threshold for protecting wildlife health (0.03 µg/g wet weight).

3.2.3.4 Pesticides

USGS personnel collected soil samples on October 29, 2008 from the fields after leveling and before flooding to quantify residual pesticides concentrations from previous activities in the area. Samples were analyzed using microwave extraction and

[28] Ackerman, JT, and Eagles-Smith, CA, 2010, Agricultural wetlands as potential hotspots for mercury bioaccumulation: experimental evidence using caged fish. Environmental Science and Technology 44: 1451-1457.

carbon/alumina cleanup and quantified via GC/MS. Table 7 shows the detected compounds. For comparison, legacy pesticides and degradation products DDT, DDE and DDD were measured at levels close to or exceeding EPA Region 9 risk based screening levels[29]. Measured levels of carbofuran, pendimethalin and permethrin were well below EPA screening levels[30].

Table 7. Results of Twitchell Island soil pesticide analysis after field leveling prior to winter flooding. Concentrations are in ng/g dry weight.

	% Organic Carbon	Carbofuran	Pendimethalin	p p'-DDE	P p'-DDD	p p'-DDT	Permethrin
Field 1	7.4	1.3	0.6	3.7	1.5	4.9	0.0
Field 2	14.7	3.5	nd	37	8.7	55	3.4
Field 2(rep)		4.2	nd	41	8.8	55	2.6
Field 3	20.7	1.1	0.5	33	6.5	29	5.4

Two herbicides (bispyribac sodium and pendimethalin) were applied to the fields prior to rice planting and flooding during May 25-26, 2009. USGS personnel sampled drain water on June 6, 15 and 30, 2009. Bispyribac sodium was analyzed via high performance liquid chromatography while concentrations of pendimethalin and other herbicides were analyzed via gas chromatograph/mass spectrometry (GC/MS). Pesticide and DOC concentrations are shown in Table 8. Bispyribac sodium and Pendimethalin concentrations decreased with time (Table 8). All concentrations were well below aquatic life levels of concern.

Table 8. Results of Twitchell Island water analysis of pre-plant herbicides.

Sample Location	Date	DOC (mg/L)	Bispyribac Sodium (ng/L)	Pendimethalin (ng/L)
Field 1 Recycle	6/4/2009	42	1430	2487
Water (TRD 2-1E)	6/15/2009	85	590	1825
	6/30/2009	31	141	511
Southern Drainage	6/4/2009	27	140	767
Ditch @ Field Rd	6/15/2009	27	80	515
(TRD 2-2E)	6/30/2009	29	30	229
Treatment Field (Field 3)	6/4/2009	2.5	nd	129
Main Drain	6/15/2009	26	nd	52
Pumping Station	6/30/2009	11	nd	47

3.2.4 Subsidence

HydroFocus personnel constructed two extensometers, one each in the Twitchell Island rice and corn fields to monitor small-scale variations in land surface elevation. At both

[29] See http://www.epa.gov/region9/superfund/prg/. Carcinogenic screening levels are 7.2, 5.1 and 7.0 mg/kg for DDD, DDE and DDT, respectively.
[30] Screening levels were 62,000, 25,000 and 31,000 mg/kg for carbonfuran, pendmethalin and permithrin, respectively.

locations, land-surface elevation was measured relative to the extensometer structure which was anchored below the peat so land-surface elevation variations reflected processes occurring in the peat.

In the rice field, a steel base support pipe was driven to refusal into the mineral layer underlying the peat soil. A modified sedimentation-erosion table (SET)[31] was inserted into a grooved stainless steel core in the base support pipe which ensured instrument stationarity and replacement to the exact same position after movement to accommodate field operations (Figure 10). The SET arm extended horizontally about one meter and was adjusted to level. A metal rod with a 5-inch-diamter metal disk that that rested on the ground freely moved vertically in the hole on a metal plate at the end of the arm (Figure 10). HydroFocus personnel fastened a Macro Sensors GHSI 750 linear variable differential transformer (LVDT) to the rod above the plate (Figure 10). The piston arm rested on the plate so that the sensor body would move with the rod and the piston arm would remain stationary. A Campbell CR510 data logger recorded LVDT measurements every 15 minutes.

In the corn field, HydroFocus constructed an extensometer similar to the one described in Deverel and Rojstaczer[32]. Specifically, three metal pipes were driven to refusal into the mineral layer below the peat. Three lengths of angle-iron were welded onto the pipes and to each other to form a level horizontal equilateral triangle. Then a Macro Sensors HSI 750 LVDT was fastened vertically to one of the triangle sides, with its piston arm resting on a ¼-inch-thick aluminum plate on the ground. A Campbell CR510 data logger recorded LVDT measurements every 15 minutes.

[31] Boumans, R.M.J., and Day, J.W.J., 1993, High precision measurements of sediment elevation in shallow coastal areas using a Sedimentation-Erosion Table: *Estuaries* 16, no. 2, p. 375-380.
[32] Deverel, S.J., Rojstaczer, S., 1996, Subsidence of agricultural lands in the Sacramento-San Joaquin Delta, California: Role of aqueous and gaseous carbon fluxes. *Water Resources Research*, 32(8): 2359-2367.

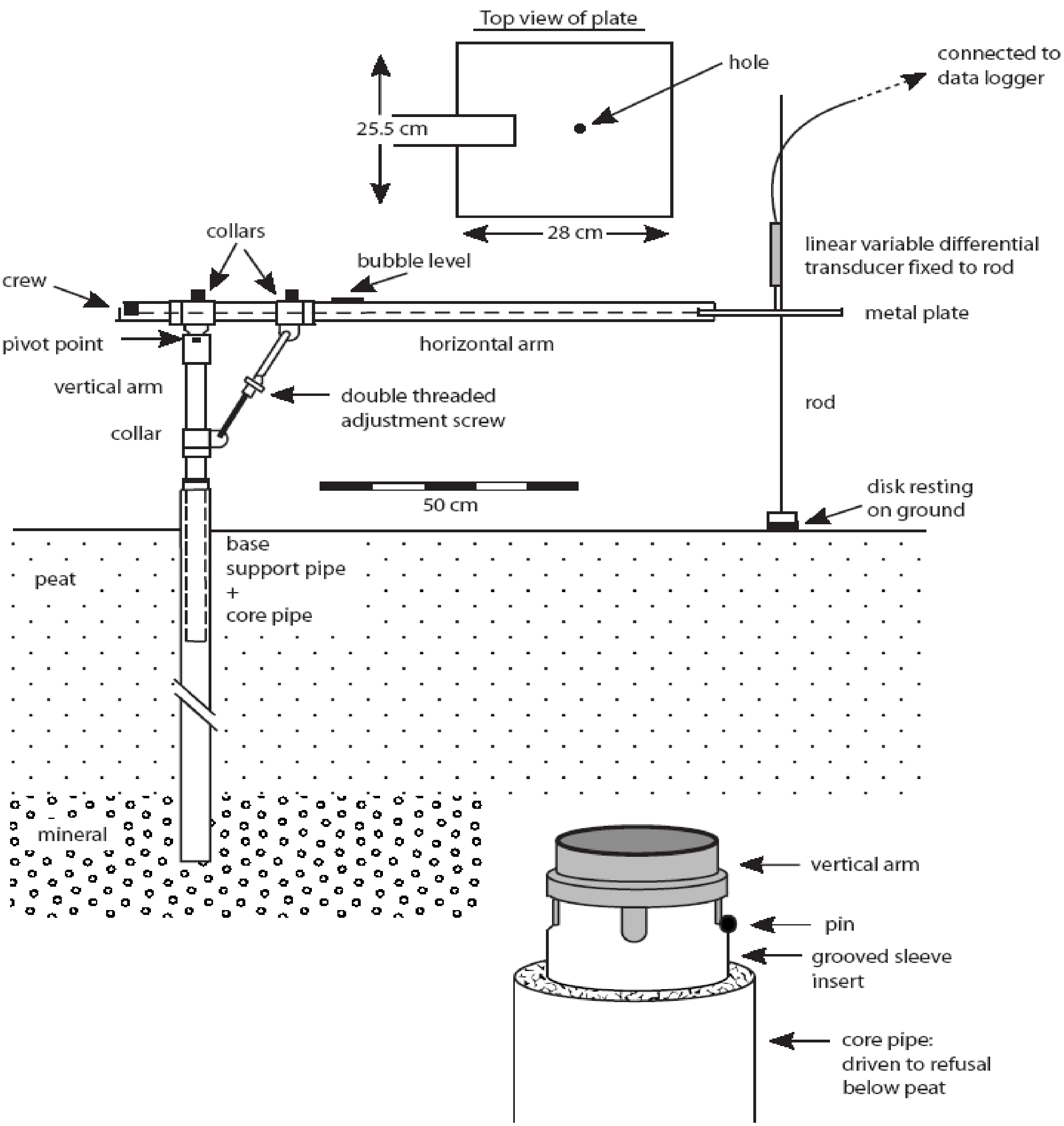

Figure 10. Extensometer in rice field.

Concurrent with land surface elevation measurements, groundwater levels were monitored in nearby two-inch observation wells. In each well, an In-Situ Mini Troll pressure transducer measured and logged the height of the overlying water column every 15 minutes. HydroFocus personnel also manually measured depth-to-water measurements with a Durham Geo Slope Indicator electric water level sounder. For each site using land surface and groundwater level data, we calculated inelastic subsidence and accretion as the difference between the land surface levels on dates where water levels were equal.

Groundwater and land surface levels decreased in the rice field from late winter through spring (Figure 11). From late May through mid-September, the field was flooded and groundwater levels rose and remained steady for most of the season, and then decreased when the field was drained for harvest. Land-surface elevation generally followed groundwater levels although it increased more gradually and continually when the field was flooded. We estimated 4.0 mm (0.16 in) of inelastic subsidence during a 95-day period from 3/2/09 to soon after flooding (6/5/09). The extensometer measured 19.9 mm (0.78 in) of accretion during a 121-day period from early in the flooding (5/31/09) to soon after draining (9/29/09) (Figure 11).

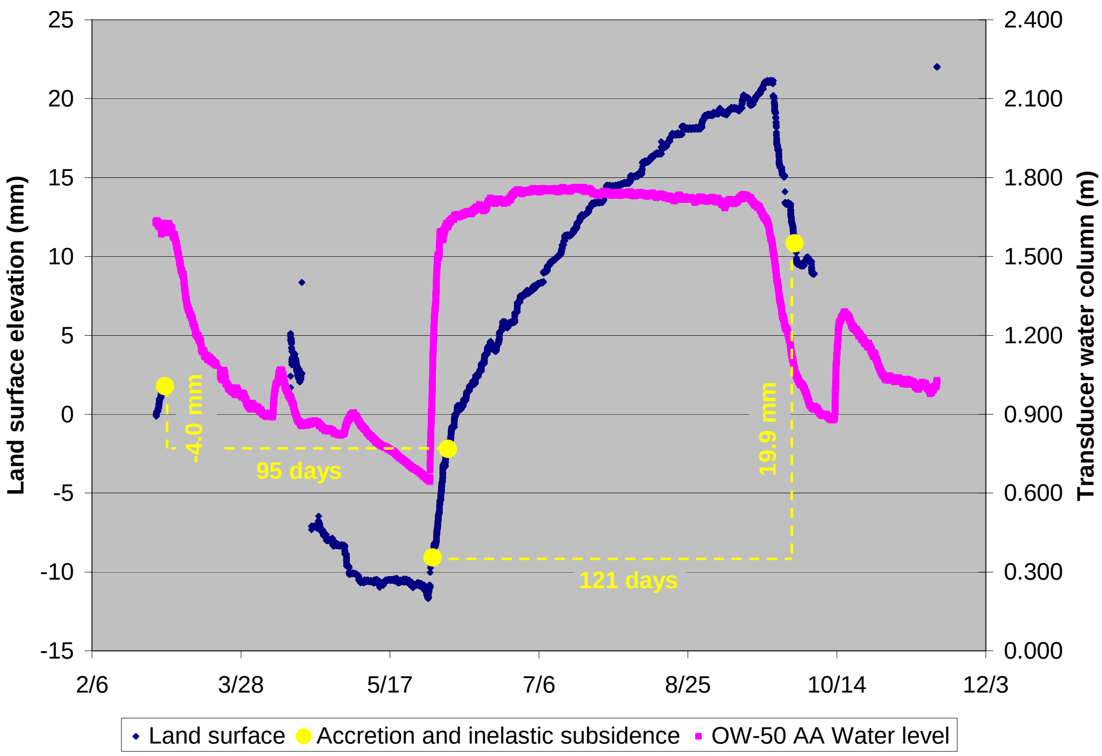

Figure 11. Land-surface elevation and groundwater levels at rice field extensometer. Yellow text and dotted lines represent elevation changes between dates and time where equal groundwater levels were measured.

At the corn extensometer, groundwater and land surface levels decreased from mid-August and early July, respectively (Figure 12). Groundwater levels remained mostly steady from mid- to late September, and then began to rise in October. At that time, the rate of decrease in land surface elevations slowed and elevations subsequently remained relatively constant. During and immediately after a rainstorm in mid-October, groundwater levels and land surface increased. Afterward, the groundwater levels continued to rise and land surface remained relatively constant. We estimated 7.3 mm (0.3 inches) of inelastic subsidence during a 63-day period from mid-summer (8/12/09) to after the October rainstorm (10/14/09) when groundwater levels were equal (Figure 12). Using methods described in Deverel and Rojstaczer and soil and CO_2 flux data provided by Will Horwath and Yacov Assa at UCD, we estimated 1.00 mm of inelastic subsidence during this period. Previous estimates are generally higher and explain a larger portion of the inelastic subsidence[33]. These extensometer results indicate that rice stops or greatly limits oxidative subsidence.

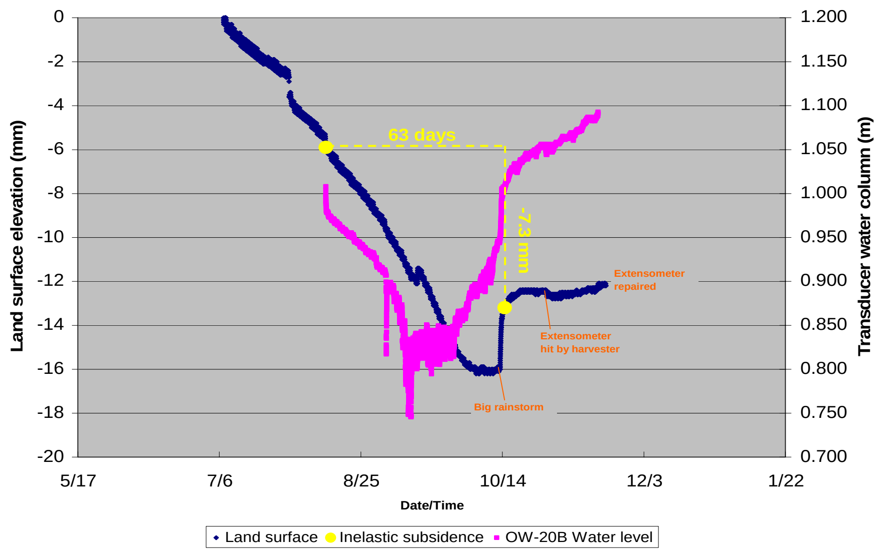

Figure 12. Land-surface elevation and groundwater levels at corn field extensometer. Yellow text and dotted lines represent elevation changes between dates and time where equal groundwater levels were measured.

3.2.5 Gas Flux Measurements

The University of California, Berkeley Biometeorology Lab (UCBBL) under the direction of Professor Dennis Baldocchi made eddy covariance measurements of water vapor, carbon dioxide (CO_2) and methane (CH_4) exchange over the Twitchell Island rice field. In a parallel study, UCBBL is measuring the same paramters on Sherman Island over a degraded peatland pasture infested with pepperweed. A standard set of eddy covariance instrumentation and associated suite of meteorological and soil instrumentation was installed in the rice field during April 2009. UCBBL measured greenhouse gas fluxes, and associated environmental variables on a quasi-continuous basis throughout the growing season.

Greenhouse gas fluxes were measured with the eddy covariance method[34]; all sensors were sampled at 10 Hz and covariances were computed for 30 minute durations to ensure measurement of all fluctuations across the spectrum of turbulence. Wind velocity was measured with a Gill Windmaster Pro sonic anemometer, which was positioned at 3 m above the ground. Next to the anemometer was an open-path infrared spectrometer (LICOR 7500) for measuring CO_2 and water vapor. Methane was measured with an off-axis tunable diode laser spectrometer.

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[33] Deverel, S. J. and Leighton, David A., 2009, Historic, recent and future subsidence in the Sacramento-San Joaquin Delta, in press, San Francisco Estuary and Watershed Science and Deverel and Rojstaczer (1996) (see previous footnote).
[34] Baldocchi, DD, 2003, Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystems: past, present and future. Global Change Biol 9:479-492.

In addition to the flux measurements, UCBBL monitored an array of environmental variables crucial for interpreting the greenhouse gas fluxes; incoming solar and net radiation, air temperature, relative humidity, soil temperature, water table depth and temperature, wind direction, wind speed and soil heat flux. These sensors were sampled once every second and were reported as 30 minute averages. Changes in the status of the vegetation were monitored with periodic measurements of leaf area index and high resolution spectral reflectance. Regular assessment of canopy structure and phenology was provided via regular pictures from a web camera; we extracted digital signals from the camera in the red, green and blue channels and constructed a vegetation index to monitor phenology.

UCBBL compared our rice greenhouse gas flux measurements with data from the peatland pasture. Figure 13 shows the mean diurnal pattern constructed from fluxes made during the growing season. Rice uses more than twice the volume of water during the day relative to the Sherman pasture, and it is an active source of water vapor at night due to the warm and flooded paddy. However, based on ET measurements described above, rice water consumption is about 3.2 feet during the growing season about 37.5 % greater than the 2 feet[35] required by corn in the Delta.

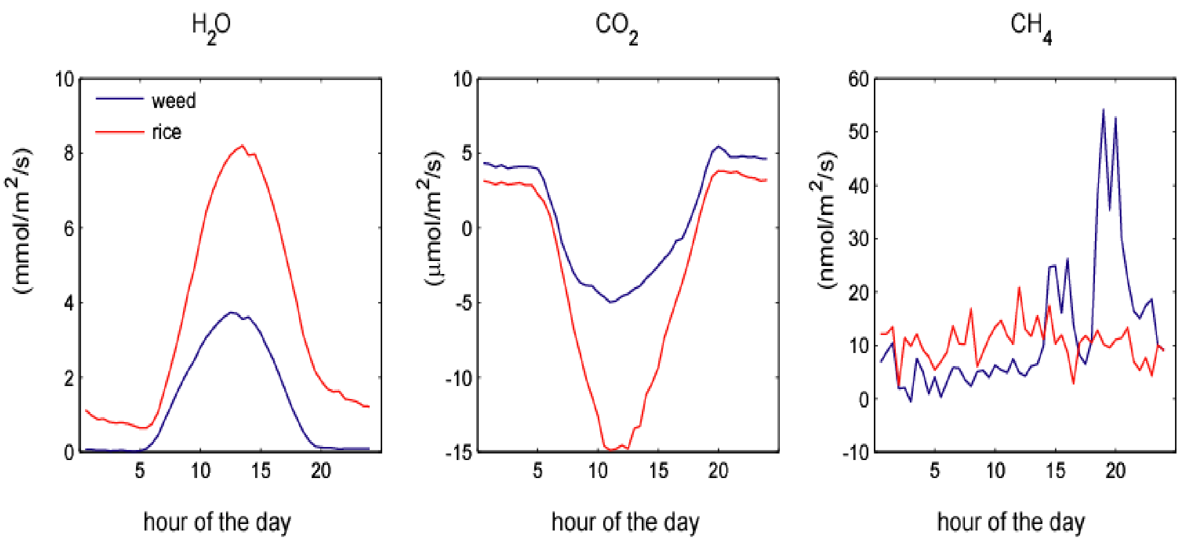

Figure 13. Carbon dioxide (CO_2), methane (CH_4) and water fluxes for the Twitchell Island rice field and Sherman Island (weed)

The rice takes up carbon at about 3 times the rate of the pasture during midday. Moreover, the flooded nature of the rice paddy inhibits nocturnal respiration, compared to the aerated pasture. Methane fluxes from the rice are about double those from the aerated pasture. The rice paddy is a strong sink of carbon removing over 600 g C m^{-2} (grams carbon per square meter) from the atmosphere compared to the pasture, which

[35] G. J. Hoffman 1, E. V. Maas 1, T. L. Prichard 2, and J. L. Meyer, 1983, Salt Tolerance of Corn in the Sacramento-San Joaquin Delta of California, Irrig Sci (1983) 4:31-44 reported an average of 2.04 feet for corn on Terminous Tract.

is a source of carbon dioxide (178 g C m^{-2}). The rice produces twice as much CH_4 relative to the pasture (3,080 mg C m^{-2}). These preliminary results using eddy covariance measurements indicate that rice growing on organic soils in the Delta is a sink for carbon dioxide and a weak source of methane.

University of California Davis (UCD) personnel under the direction of Professor Will Horwath measured emissions of nitrous oxide (N_2O), CO_2 and CH_4 from corn and rice on Twitchell Island from April to October every one to three weeks. Static flux chambers with a diameter of 25 cm and a length 9 cm for the corn and lengths of 9, 29, 59 and 99 cm for the rice (depending on plant growth) were used to measure GHG fluxes. For each flux measurement the chamber was placed on top of the permanent ring and 24 milliliters of gas was extracted with a syringe from within the chambers at fixed intervals for a fixed period of time. Before each gas extraction from the chamber, a fan inside the chamber was turned on for 1 minute to mix the air inside the chamber. All gas samples were analyzed on a Shimadzu 2014 (GHG edition) gas chromatograph.

Rice plant samples were taken at 47, 80, 95, 132 days after seeding (DAS) and at harvest (170 DAS). Root samples were taken at each plant sampling date except for at harvest. Soil samples from 0-5 cm and 5-15 cm were taken for inorganic nitrogen analysis and total carbon and nitrogen. Corn plant samples were taken at harvest for total biomass, carbon and nitrogen determination. Soil samples were collected before the corn was planted and post-harvest for total carbon and nitrogen determination.

There were significant differences between crops with respect to total soil carbon and nitrogen between pre-planting and post-harvest and between the rice and corn. The reduction in soil carbon to 15 cm was more pronounced in the cornfield than in the rice field. The rice had significantly higher final biomass than the corn. As a result more rice carbon was incorporated into soil following harvest than for corn.

Figure 14 shows the CH_4 flux by date for rice and corn. The largest rice CH_4 fluxes occurred after early August. UCD chamber CH_4 fluxes were of similar magnitude as those measured by the UCBBL Eddy Covariance methods.

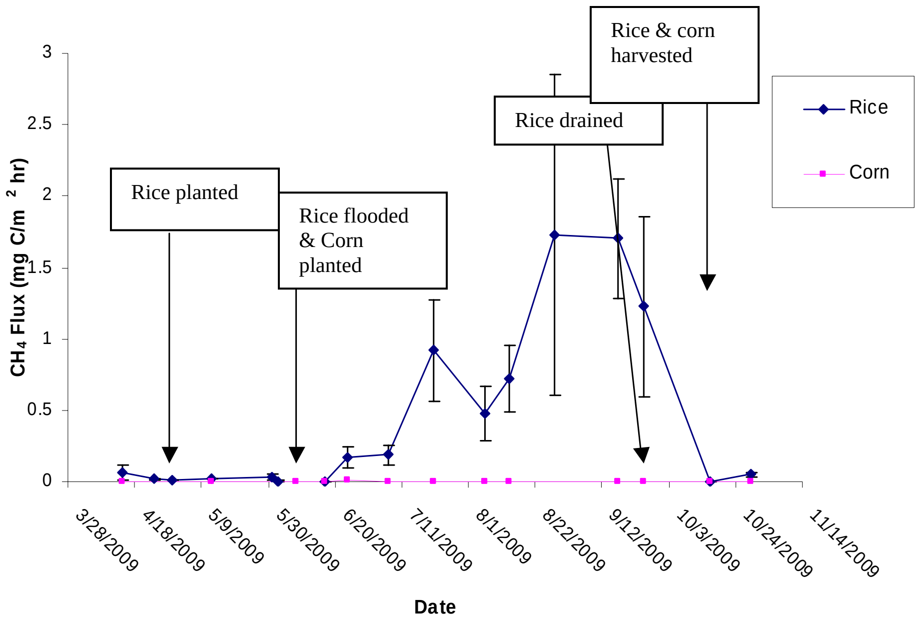

Figure 14. Methane (CH_4) fluxes from corn and rice fields during 2009.

CO_2 emissions (Figure 15) were lower for rice relative to corn until June 24th when they increased after anthesis and then declined. N_2O fluxes (Figure 16) were higher in rice relative to corn during the first month and a half until the rice field was permanently flooded. During the growing season, N_2O fluxes from the corn and rice fields were close to zero. During mid October there was a large N_2O flux measured in the corn field. The soil carbon decrease from before planting to after harvest was significantly higher for the corn compared to rice, and total residue biomass carbon was lower in the corn field. The results from the carbon pre plant vs. post harvest soil analysis and the UCBBL results demonstrate that there was overall higher amount of carbon lost in corn.

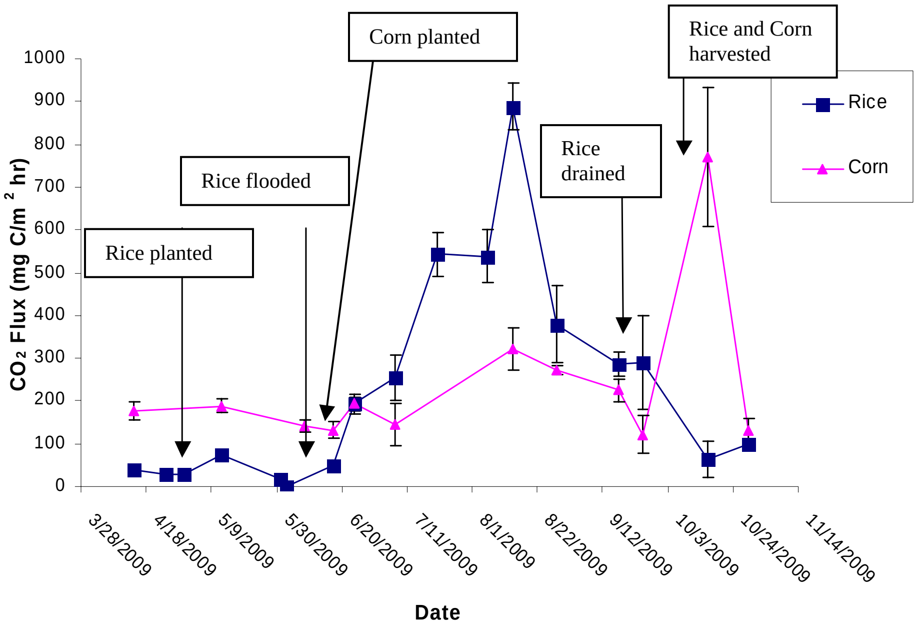

Figure 15. CO_2 fluxes from the rice and corn (values for rice represent chamber deployment over plants while for the corn, the chamber was placed over ground between rows)

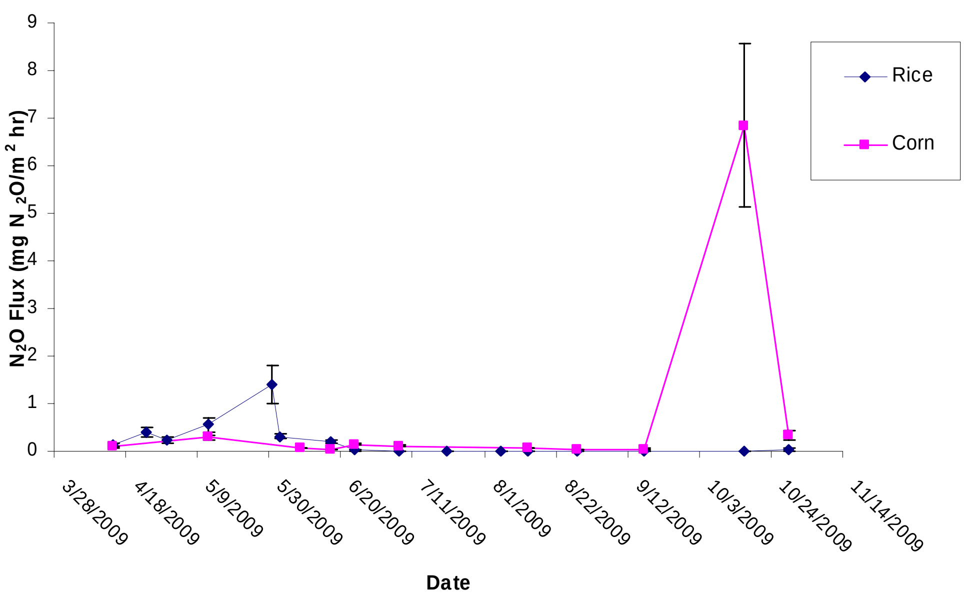

Figure 16. N_2O fluxes from rice and corn during 2009

3.2.6 Agronomy

Poor stand establishment, delayed harvest due to direct/dry seeding, and particularly cold temperature induced sterility or "blanking" can affect rice productivity in the Delta. Rice breeders at the California Rice Experiment Station (RES) have developed varieties for cold tolerance. UC Davis Agronomy and Cooperative Extension (UCDACE) evaluated the productivity of these new varieties on Twitchell Island to determine their potential for commercial productivity under the coldest and windiest of Delta conditions. Two variety experiments were conducted—one in large plots to evaluate the commercially available varieties with the best known cold tolerance and one small plot test to evaluate new advanced line cultivars for their potential to tolerate cold temperatures.

The varieties Calmochi-101, M-104, M-202 and M-206 were drill-seeded to a depth of 1.5 in on April 29th into one acre plots in Field 3 (Figure 1) replicated three times using the farmer's drill seeder. In the small plot test, 12 advanced lines and 6 commercial varieties (including the four tested in large plots) were drill seeded on April 27th, with a small plot research drill seeder in 5 x 30 ft plots. All plots were harvested on October 27th with a small plot research combine. Grain moisture was measured at harvest and all yield data was corrected to 14% grain moisture days to 50% heading and percent lodging were measured for all varieties in both the large and small plots. Plant height was measured from the soil surface to the tip of the panicle in the small plot test.

Table 9 shows the results of the large plot test. The leading variety was Calmochi-101 followed by M-206, M-104 and M-202. The Calmochi-101 yield was significantly greater than the all other varieties. Blanking in M-206 and M-104 was estimated at 10-15% and 5-10% respectively, but M-104 also had additional shattering losses estimated at 10-15% due to 15-20 mph wind speeds. M-202, one of the original cold tolerant Calrose type varieties for the Valley Home/Escalon area had blanking levels of 40%. This accounted for its poor yield performance and clearly demonstrated the severity of plant response to cold air temperatures with traditional California varieties.

Table 9. Twitchell island large plot variety trial results.

Variety	Grain Type	Grain Yield at 14% Moisture lbs/acre		Grain Moisture at Harvest (%)		Days to 50% Heading	
Calmochi-101	S	9890	(1)	15.0	(4)	110	(1)
M-206	M	7450	(2)	18.9	(2)	121	(3)
M-104	M	6440	(3)	17.0	(3)	111	(2)
M-202	M	3870	(4)	19.7	(1)	125	(4)
MEAN		6910		17.7		117	
CV		14		4.4		1.2	
LSD (.05)		1760		1.4		3	

S = short; M = medium; L = long.
Numbers in parentheses indicate relative rank in column.

The commercial varieties in the small plot tests were similar in ranking to the large plot test with Calmochi-101 ranking at the top followed by M-206, M-104 and M-202. The other two commercial varieties, S-102 and L-206 were intermediate between M-202 and the top three ranking varieties. In the cold environment on Twitchell Island, the average time to 50% heading for these varieties was 115 days after planting, fully 10 days later than the average days to heading for intermediate to late maturing varieties in Sacramento Valley tests, again demonstrating the challenges of growing rice in this environment.

4.0 Summary and Conclusions

We initially hypothesized that rice cultivation in the Delta will stop subsidence. However, increasing rice acreage in the Delta raises water-quality concerns due to the potential for increased loads of drinking water constituents of concern (DOC and DBPs), pesticides and methyl mercury in Delta channels. Mercury also presents a biological and human health concern if it accumulates to greater degree in the food chain in rice fields. Higher greenhouse gas emissions (methane and nitrous oxides) relative to current land uses may also be problematic. Quantification of the subsidence mitigation potential for rice is also required.

Reclamation District 1601 and DWR began preparation for planting rice on 180 acres on Twitchell Island in summer 2008. Rice was planted in April 2009. Starting in fall 2008, in cooperation with Reclamation District 1601 and DWR, representatives from UC Davis, UC Berkeley, US Geological Survey, Phillip Bachand and Associates and HydroFocus, Inc. collected and analyzed data to assess water and air quality, mercury in biota, alternate rice varieties and factors affecting yields and subsidence mitigation in rice. The following summarizes the key conclusions.

- Results of hydrologic monitoring showed that the average per acre drain flow for the rice fields was over 4 fold larger than for adjacent drains in corn and oat fields. There was substantial lateral seepage from rice fields to adjacent fields. The previous study on Delta rice feasibility suggested high water levels in the drains to minimize the export of water as subsurface water from rice fields. This approach would be expected to minimize drain discharges and reduce loads of DOC and MeHg from subsurface flows.

- Consistent with previous studies, high drain-water DOC concentrations associated with rice are the result of flushing of DOC generated during oxidation in shallow soils.

- Rice drain DOC loads (uncorrected for drain water reuse) during the irrigation season were over 13 times the loads for corn and oat fields. Non-irrigation season rice loads were comparable with corn and oat fields. Per acre MeHg loads from the rice drains were two to three times greater than the corn/oats drains and the island averages for both irrigated and non-irrigated periods.

- Average MeHg concentrations were significantly higher in rice drainage ditches relative to the corn/oats drainage ditches.

- Drain water was recycled back onto the rice fields during the irrigation season and any water deficit was made up with pumping water from the Twitchell Main Drain. For those reasons, the Twitchell rice fields were a net sink for DOC and probably a net sink for MeHg. This approach can be used here to minimize exports of DOC and MeHg.

- The highest MeHg concentrations occurred during non-flooded periods in the rice drains. The lowest concentrations occurred shortly after field inundation from intentional flooding or periods of increased rainfall.

- DOC and MeHg data provide evidence for the mechanism of wet-dry cycles causing production DOC and MeHg. DOC is produced by oxidation of the organic matter in the peat soils where it is preserved until it is physically flushed out of the soils.

- In contrast, MeHg is produced as a result of sulfate, iron and possibly manganese reduction pathways that require substrate supply of reactive Hg and bioavailable organic material. The temporal trend of MeHg concentrations in the drains on Twitchell Island suggest that MeHg concentrations lag behind DOC concentrations due to the time required to establish pathways that generate MeHg. Therefore, DOC is produced during the unflooded (dry) season and is immediately available for transport once flooding occurs whereas MeHg is produced only after the flooding occurs, thus delaying the build-up and export of MeHg relative to DOC.

- Two herbicides were applied to the rice fields prior to planting; bispyribac sodium and pendimethalin. Concentrations of these herbicides in rice drain water within a week after flooding were below levels of aquatic life concern and concentrations decreased during two additional sampling events.

- Rice and corn extensometer data indicate that rice will stop subsidence. The rice extensometer measured 19.9 mm (0.78 in) of accretion during a 121-day period from early in the flooding (5/31/09) to soon after draining (9/29/09). The corn extensometer measured 7.3 mm (0.3 inches) of inelastic subsidence during a 63-day period from mid-August to mid-October.

- Eddy covariance measurements for rice on Twitchell and pasture on Sherman demonstrated that rice uses more than twice the amount of water during the day relative to the Sherman pasture, and it is an active source of water vapor at night. However, based on ET measurements on Twitchell, rice water consumption is about 3.2 feet during the growing season or about 37 % greater than the 2 feet required by corn.

- Preliminary results using eddy covariance measurements indicate that rice growing on organic soils in the Delta is a significant sink for carbon dioxide and a weak source of methane.

    - Rice takes up carbon at 3 times the rate of the Sherman pasture during midday and removes over 600 g C m^{-2} (grams carbon per square meter) from the atmosphere compared to the pasture, which is a source of carbon dioxide (178 g C m^{-2}).
    - Methane fluxes in rice were greater than the Sherman pasture.

- UCD chamber flux measurements generally agreed with the eddy-covariance results. In addition, chamber flux results showed that nitrous oxide fluxes occurred prior to flooding of the rice fields. Larger fluxes were measured in the corn field after harvest. Methane fluxes were larger in rice than corn, but overall the methane emissions were very low.

- Rice was harvested in mid-October. Overall, production was low relative to the Sacramento Valley and Delta rice growing areas. The average yield was about 25 hundred weight (cwt) per acre. Typical yields for the Delta and Sacramento Valley are 80 to 100 cwt per acre. High moisture, shattering, blanking, water distribution non-uniformity and bird consumption appear to be the primary reasons for low yields.

- Yields in the rice variety trials were generally consistent with typical yields for the Delta and Sacramento Valley. Results of the trials among commercial medium grain varieties demonstrated that yields for M206 were greater than M104 and M202. Cold induced sterility or blanking in M-206 and M-104 was about 10-15% and 5-10% respectively, but M-104 also had additional grain head shattering losses of about 10-15% due to 15-20 mph winds.