Annual Progress Report for Twitchell Rice Project, 2011
February 13, 2013

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1.0 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 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 implies stopping or greatly reducing subsidence on delta organic soils. Environmental viability translates to no net addition of deleterious exports to the water supply or negative effects on biota.

1.1 Background

Agriculture 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 which require an aerated root zone cause subsidence by exposing organic soils to oxygen. Because subsidence is a key factor affecting water supply and biological resources, there is a need to stop and reverse its effects. Agricultural practices that stop subsidence are therefore highly desirable. Rice farming can potentially stop or greatly reduce the loss of soil from the delta.

Carbon loss due to soil organic-matter oxidation is the primary cause of subsidence[10]. The original impetus for investigating rice as a subsidence mitigation land use came from Miller and others[11]. They demonstrated that wetlands which were flooded from early spring through midsummer resulted in no net carbon loss. Rice growers use a similar water management practice, flooding rice fields during the warmest months when soil oxidation rates are highest, thus indicating that rice is a viable crop for stopping subsidence.

In the past, cool night temperatures precluded delta rice cultivation. However, within the last 20 years, development of new rice varieties tolerant of low air and water temperatures resulted in delta rice production with yields comparable to the Sacramento Valley. Available data indicates the combination of in-season and off-season flooding and addition of rice residues will stop or greatly reduce oxidative soil loss.

Heightened recent interest in subsidence mitigation prompted further investigation into rice production on State-owned Twitchell Island. Rice is successfully grown on over 3,000 acres on central and eastern delta islands. However, further assessment is required before wide-spread rice farming can be implemented in the western delta because lower air and water

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[10] 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.
[11] 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.

temperatures and higher soil and water salinity and wind speeds may affect production. Also, possible deleterious water- and air-quality effects require consideration. To assess rice as a subsidence mitigation strategy, in 2008, 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.

1.2 Project Location

One hundred and eighty acres were planted to rice in spring 2009 and an additional 130 acres were planted in 2010. In 2011, an additional 12 acres were planted to rice for a total of 322 acres. Figure 1 shows the field location and areas planted to rice in 2009 and 2010.

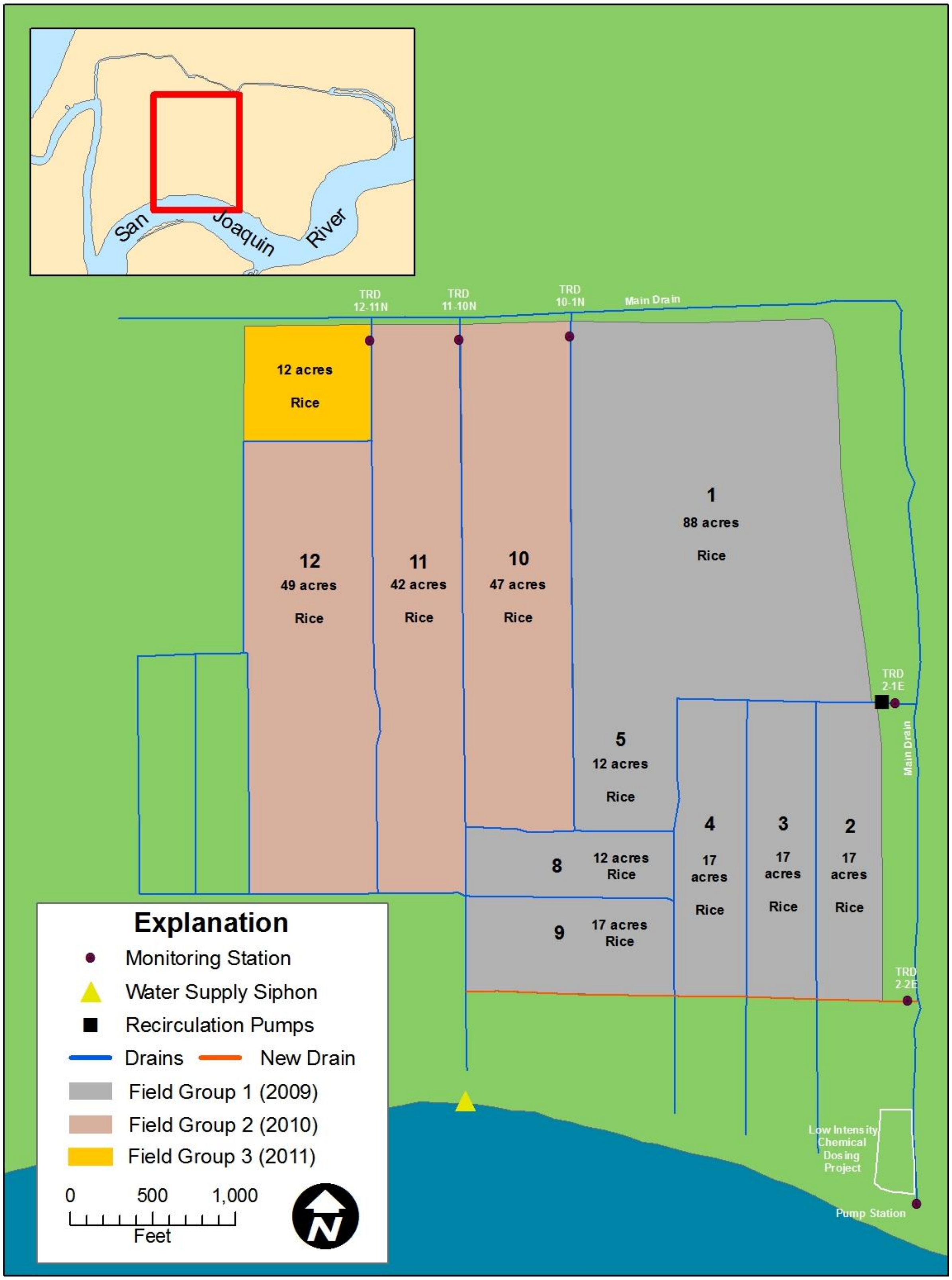

Figure 1. Twitchell rice growing area. Group 1 fields were converted to rice in 2009. Group 2 fields were converted to rice in 2010.

1.3 Key Environmental Issues

Increasing rice acreage in the delta raises 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 in established rice fields provided direction for implementation of management practices that reduce deleterious aqueous exports of DOC, nitrogen and DBPs but more investigation was required to quantify how loads of these constituents will change with time. Pesticides and mercury also are potential deleterious exports that had not been investigated in delta rice fields. Mercury presents a biological and human health concern if it accumulates in the food chain and fish. Higher greenhouse (methane and nitrous oxides) gas emissions relative to current land uses may also be problematic if large areas are converted to rice. Increased rice acreage also raises concerns about mosquito breeding and vector control and increased water use.

1.4 Conceptual Model

The original scope of work included five topical areas: water quality (including biological effects), subsidence, carbon dynamics, agronomy and economics. Figure 2 shows the original 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 move to drainage ditches and diffuse into surface water for discharge to surface drains. Previous research indicated that inflow and surface and subsurface outflow restriction limits DOC and dissolved nitrogen exports from rice fields without detrimental effects on yields. Surface and subsurface 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 as 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 MeHg 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.

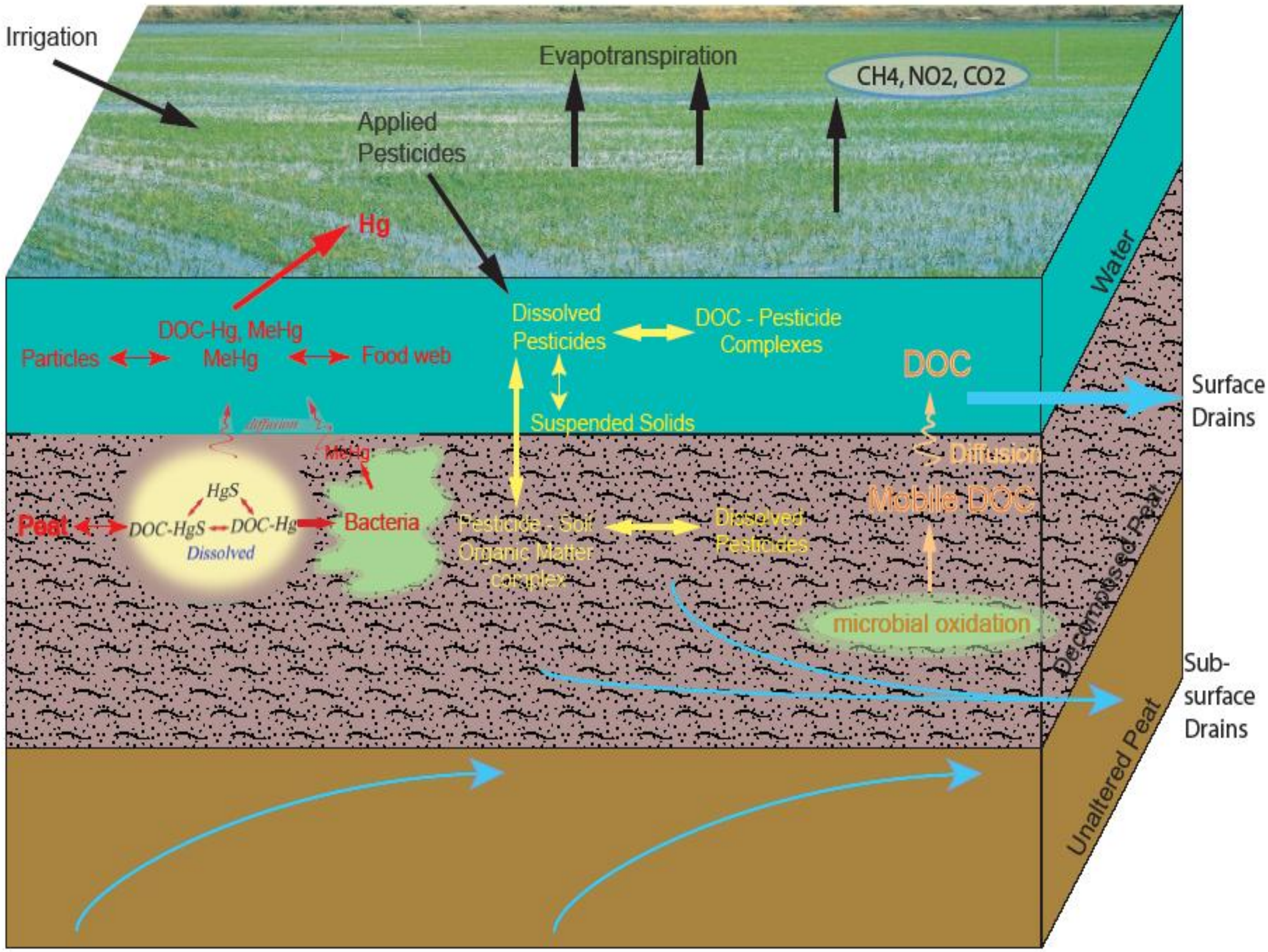

Figure 2. Conceptual model for processes affecting key constituents of concern in delta rice field.

1.5 Project Team

Brian Brock is the project manager for DWR. Reclamation District 1601, HydroFocus, Inc., UC Davis, UC Berkeley, UC Extension Service, US Geological Survey, and 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. Gornto Ditching was contracted to prepare the fields and plant rice.

1.6 Scope of Work and Key Objectives

The original scope of work outlined an extensive data collection effort during three rice-growing seasons beginning in fall 2008. Project funding was reduced substantially in early 2009 which reduced the level of data collection efforts and analysis. A key project outcome is 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 optimize production, reduce deleterious exports and identify 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 and greenhouse gas measurements would occur at the farm-field scale using chambers and micro-meteorological methods. Agronomic evaluation of varieties and management practices has been conducted by UC Davis. The following summarizes key 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 and subsidence;
- Measure greenhouse gas fluxes;
- Conduct variety trials and evaluate alternate crop management practices 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 provides a summary of progress through December 2011.

2.0 Project Activities

2.1 Rice growing and related activities

Figure 3 shows the time line of field activities for 2011 and the following sections provide additional information. Previous annual reports provided time lines for 2009 and 2010.

2.1.1 Surveying and field leveling

Prior to September 2008, surveying and field design occurred. Fields were surveyed by Aaron Beaver using an 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 1 to 2% slopes. Approximately 53,000 cubic yards were moved in less than 3 months.

2.1.2 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, we withdrew irrigation water for flooding primarily from the Twitchell Island main drain.

Figure 4 illustrates water management practices and infrastructure. The rice system includes the rice fields and infrastructure to recycle drain water. Water for irrigation and winter flooding was pumped from the island main drain (Twitchell Main Drain) and the rice drain (TRD 2-1E shown on Figure 1) and, siphoned from the San Joaquin River ($Q_{SI,main\ drain}$, Q_{RR}, $Q_{SI,siphon}$). Q_{RO} (Figure 4) represents rice field drainage outflow. A portion of this outflow is recycled (Q_{RR}). The net rice system drain flow, Q_{SO}, is the rice field drain flow minus inflow from recycled drainage water.

Planning, design and purchase of materials for water supply infrastructure began in October 2008. 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 2008 (Figure 3). During 2009, 180 acres were planted to rice (Figure 1). Approximately 130 additional acres were planted to rice during 2010, increasing the total rice area to 310 acres. Acreage was increased slightly in 2011 with the addition of the 12 acre northern section of Field 12, just south of the main rice drain. Total 2011 rice acreage was 322 acres. Weirs not blocked at drain 2-1 and so water levels in the ditch system were kept relatively low throughout the year. Figure 5 shows the direction of flow during the irrigation season. Table 1 gives details on the location and water management at each monitoring location. Weirs controlling flow to and from drains 12-11, 11-12 and 10-1 were blocked so that drain water flowed toward the 2-1 drain where pumps recycled the water back onto the fields.

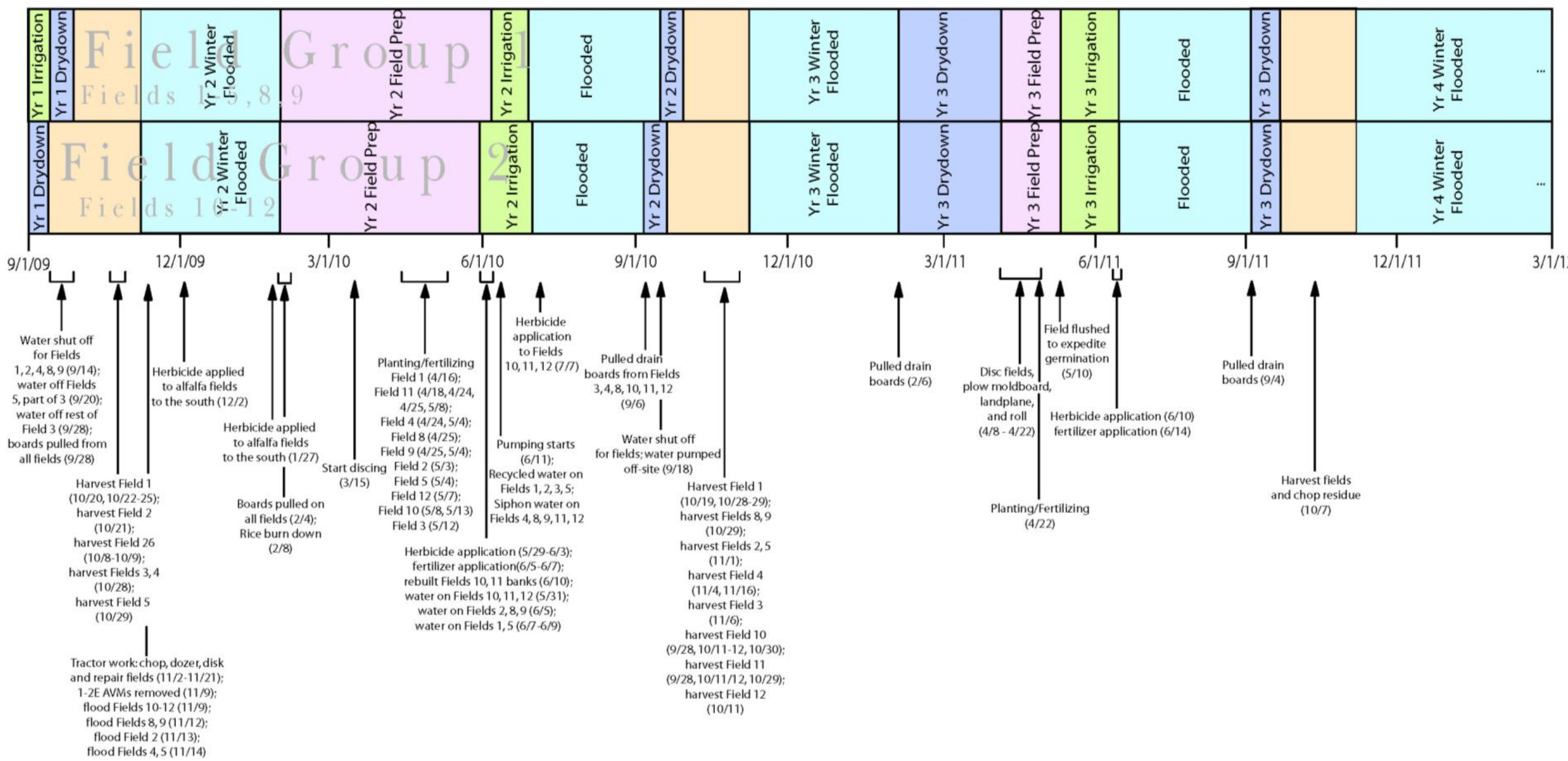

Figure 3. 2011 timeline for Twitchell rice growing and data collection.

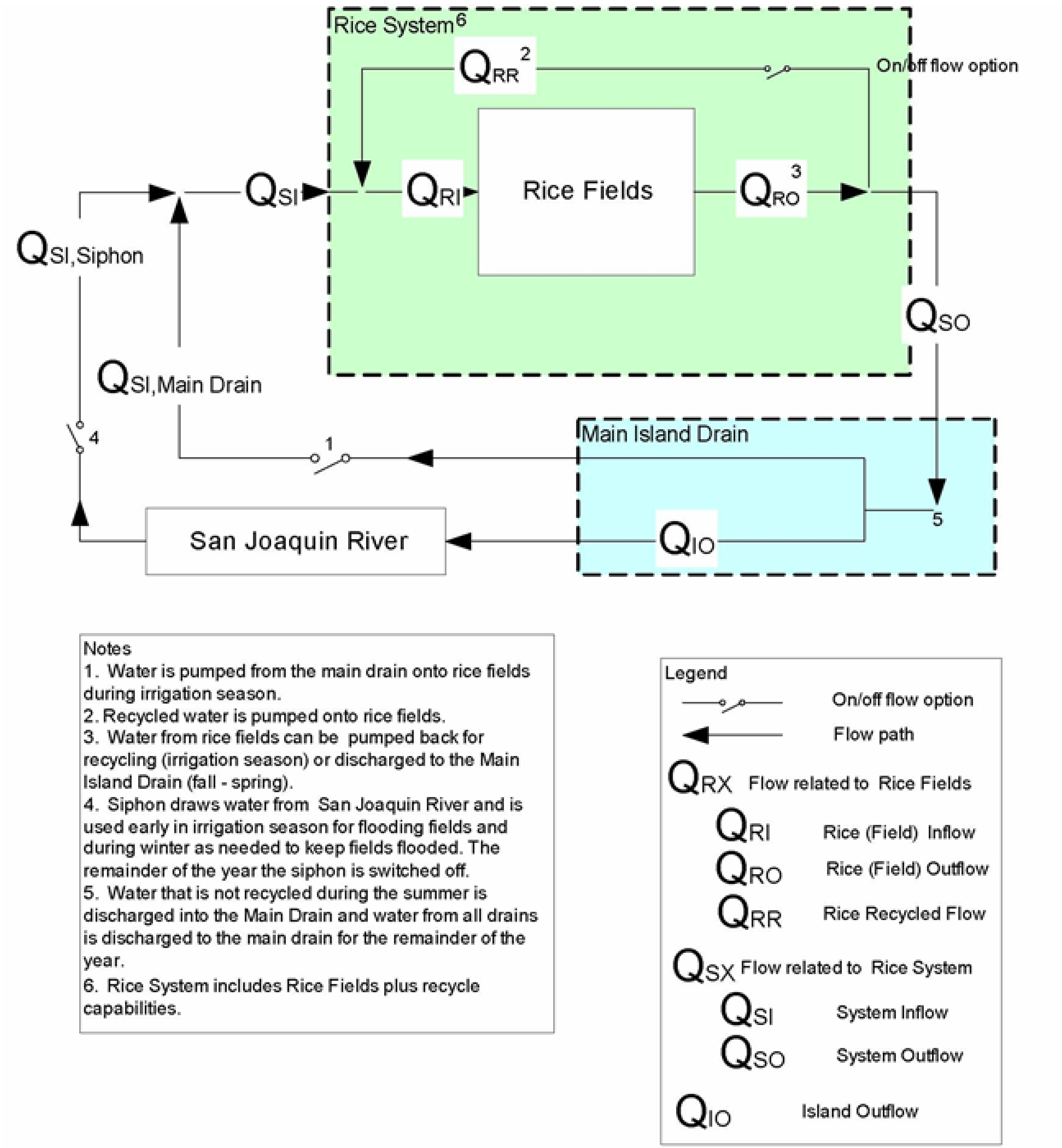

Figure 4. Diagrammatic representation of rice system water management.

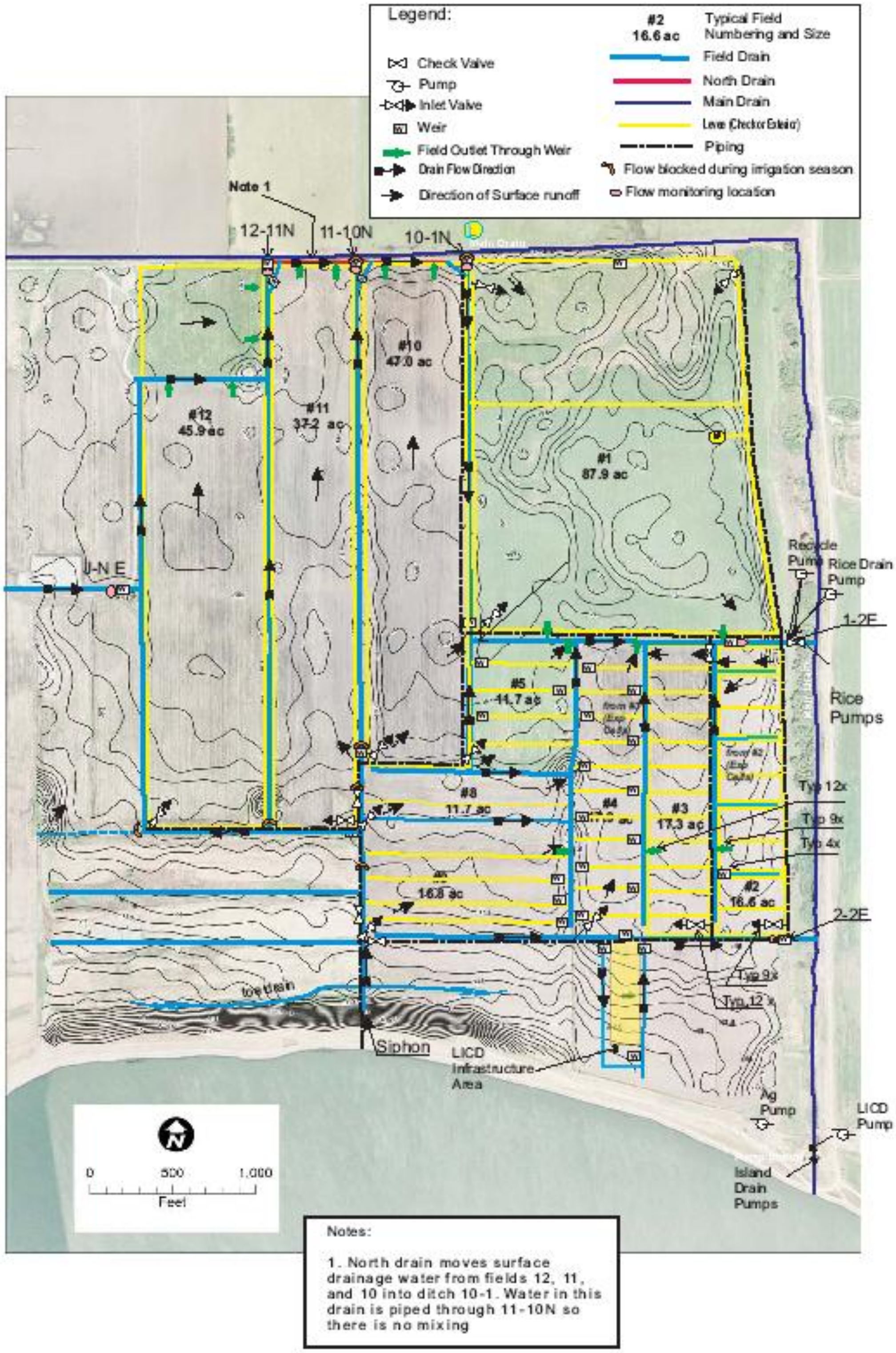

Figure 5. Water delivery and drainage system.

As detailed in Figure 5, the predominant sources of water during the irrigation season were the main drain and rice drainage water via pumps northeast of Field 2. Early in the irrigation season, water was also siphoned from the San Joaquin River (Figure 1). During winter, the siphon provided most of the water for flooding the rice fields. Initial flooding began in November 2010, with San Joaquin River water and continued through early February 2011 (Figure 3). During the irrigation season, pumps applied about 4 to 8 cubic feet per second. About 1,270 ac-feet were pumped onto the 322 acres of rice during the irrigation season or about 4 acre-feet/acre.

Table 1. Water Management and Monitoring in 2011.

Location	Description	irrigation season operations	Winter/drainage operations
TRD 2-1 E	Drainage ditch between Field 1 and 2, 3, 4, and 5 to the south. Collects seepage and surface water from these fields and fields 8, 9, 10, and 11. Flow monitoring instruments are in pipes downstream of weirs and upstream of pumps.	Main rice-system drainage ditch. Weir was not blocked this year, resulting in lower drain levels than last year Drain discharges to the pumps for recycling; and extra water drains to the main island drain..	Weir was not blocked in the winter and drain discharged into the main island drain.
TRD 2-2 E	Drainage ditch parallel to southern edge of Field 2. It is a subsurface drain for Field 2.	Drain water levels varied to maintain water levels low enough for growing alfalfa in fields south of rice fields. Discharges to main island drain at harvest.	Higher flows in this ditch may be due to high subsurface flow from areas south of the rice fields and possibly seepage from the San Joaquin River. The ditch received significant off-site flow in May 2011 and so flow and water quality monitoring were discontinued.
TRD 10-1 N	Drainage ditch located between Fields 10 and 1. A drain north of fields 10 and 11 (North Drain, see Figure 5), carries surface water from these fields to 10-1, south of the flow monitoring location. Instrumentation measures water exchange between this ditch and the Twitchell Main Drain.	This drain does not discharge to the main drain during the rice growing season. It receives water from the Main Drain and fields 1 and 10. Water moves south to TRD 2-1 for recycling. .	Discharged to the Twitchell Main Drain during winter.
TRD 11-10 N	Drainage ditch between fields 11 and 10.	Flow was blocked during spring field preparation and irrigation season.	Discharged to the Twitchell Main Drain during winter. TRD 11-10 may have carried some off-site flow from the south drain

TRD 12-11 N	Drainage ditch between fields 12 and 11 collects subsurface flow from fields 11 and 12 and surface flow from field 12, adjacent fields and South Drain. Flow from South Drain stopped in May 2011 when flow was blocked. In December 2010, a new ditch was opened to western fields (TRD J-N E). Water from this ditch enters TRD 12-11 N.	Flow was blocked during spring field preparation and irrigation season.	Discharged to the Twitchell Main Drain during winter.
TRD J-N E	Ditch cut to drain fields west of the studied area.	Minimal flow measured during summer.	Winter flow not monitored but was probably significant.
Large Pump	30 HP pump located near SE corner of Field 1	Pumps water to rice fields from Main Drain and from drain 2-1.	Does not operate during winter
Small Pump	15 HP pump located near SE corner of Field 1	Pumps water to rice fields from the island Main Drain and from drain 2-1.	Does not operate during winter. Used to promote drainage of fields prior to field preparation
Siphon	San Joaquin River siphon.	Water from the siphon flows to rice irrigation system.	Used except to flush salts during spring,

2.1.3 Planting, Growing, Harvesting

The rice varieties M104 and Calmoche 101 were planted in 2011 at the rate of 100 pounds of seed per acre (Table 2). Other varieties for testing were planted in Field 3. Flooding began in late May to early June (Table 2). Water was drained from the fields in early to mid-September and harvest occurred primarily during October and November (Table 2, Figure 3). Harvested grain was sold to Sun West Foods. Overall, production was low relative to the Sacramento Valley and Delta rice growing areas. The average 2011 yield was about 51 hundred weight (cwt) per acre. Typical yields for the delta and Sacramento Valley are 80 to 100 cwt per acre. The average yields in 2009 and 2010 were 36 and 43.5 cwt per acre.

Table 2. Key events of the 2011 rice growing season.

Field	Planted	Flooding Started	Water Drained	Harvested
1	4/21-5/2	5/11/2011	8/29/2011	10/18, 10/21, 10.22, 10/26
2	5/5/2011	5/27/2011	9/14/2011	11/2
3	4/21-5/2	5/27/2011	9/14/2011	11/2
4	4/21-5/2	5/27/2011	8/30/2011	10/27, 10/28
5	4/21-5/2	5/27/2011	8/30/2011	10/21
8	4/21-5/2	5/27/2011	8/30/2011	10/18
9	4/21-5/2	5/27/2011	8/30/2011	10/18
10	4/21-5/2	5/27/2011	8/30/2011	9/30, 10/1, 10/3, 10/14
11	4/21-5/2	5/23/2011	8/30/2011	10/1, 10/15 - 10/17
12	4/21-5/2	5/23/2011	8/30/2011	10/19, 10/20

2.1.4 Pesticide/herbicide/fertilization application

Table 3 shows chemical applications. Application dates for Fields 10, 11, and 12 were different from the other rice fields because these three fields were flooded earlier than the remaining fields.

Table 3. Chemical applications on and near rice fields in 2011.

Date	Fertilizer or Herbicide	Mixture Details
4/21-4/27	11-52-0 fertilizer drilled in with seed	100 lb/acre N
5/11/2011	Prowl, Regiment, Sandea, syl tec	1000 gal water; 9-4oz bags of Regiment; 25 gal Prowl; 2.5 gal SYL TAL; 25 gal UN 32; 40 oz Sandea
6/3-6/10	30-0-20 fertilizer	200 lb/acre N
6/10/2011	Weed Spray	

2.1.5 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 from CEQA statute 15061(b)(3). The project was justified as exempt due to conversion of one agricultural use to another.

2.1.6 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.

3.0 Results

3.1 Hydrologic Monitoring

At the monitoring stations shown in Figure 5, Bachand and Associates measured drain flow with acoustic velocity meters (AVM) installed in pipes in 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 monitoring began during fall 2008. However, in 2009 ditches that drained fields planted to corn and oats (TRD 12-11 and TRD 11-10) collected primarily subsurface flow. During 2010 and 2011, these fields designated as Group 2 were planted to rice.

Table 4 shows the measured flows at the monitoring stations shown in Figure 1 and the siphon. The siphon and the two pumps applied a total of 2,396 acre feet of water to 322 acres of rice (7.4 acre-feet/acre). The University of California Berkeley Biometeorology Lab estimated that the rice evapotranspired 1.096 m (3.6 feet) of water from September 20, 2010 to September 19, 2011. The large volume of water applied relative to ET indicates substantial lateral seepage. About 2,692 acre feet of drain water flowed from rice fields.

Table 4. Monthly flows for monitoring stations in 2010-2011 (acre-feet).

Year	Month	Inflows				Outflows				
		Large Pump	Siphon	Small Pump	TRD J-N[4]	TRD 10-1 N	TRD 11-10 N	TRD 12-11 N	TRD 2-1 E	TRD 2-2 E[3]
2010	Sept (1)	0.0	0.0	0.0	0.0	0.0	2.2	-0.1	34.3	1.9
2010	October	0.0	0.0	0.0	0.0	0.0	-14.6	0.8	36.7	6.5
2010	November	0.0	330.4	0.0	0.0	4.6	20.3	22.2	155.5	8.5
2010	December	0.0	334.4	0.0	38.0	10.3	70.4	64.6	383.4	25.5
2011	January	0.0	187.1	0.0	38.0	3.9	66.0	58.1	291.1	20.8
2011	February	0.0	47.5	0.0	21.3	-0.2	35.1	33.3	166.1	18.2
2011	March	0.0	0.0	0.0	1.9	-0.9	4.3	17.3	109.8	29.0
2011	April	0.0	0.0	0.0	0.0	0.0	-7.2	-2.2	59.3	8.8
2011	May	12.9	165.4	2.6	0.0	-0.4	4.6	-0.3	91.3	6.7
2011	June	70.8	294.7	20.4	-0.3	5.5	35.4	8.7	120.3	5.4
2011	July	188.2	241.1	55.3	-0.5	4.3	33.4	7.6	220.7	9.7
2011	August	290.0	58.4	51.8	0.0	0.1	52.7	12.1	233.6	8.7
2011	Sept (2)	36.9	0.0	8.2	0.6	-1.1	-7.4	-0.6	92.8	4.3
Total		598.8	1,659.0	138.3	99.1	26.2	295.1	221.6	1,994.7	153.9

1 September 20-30, 2010

2 September 1-19, 2011

3 Monitoring of Flows at 2-2 was discontinued in May 2011 because 2-2 ditch was opened to off-site flow. Starting in May, flows were estimated as equal to flows measured in 2010.

4 Flows at TRD J-N were estimated for December through March. Ditch was cut through to Twitchell in December and flow from west was occurring, though it was not measured. Off-site flow was estimated based on observations of 12-11 flow.

5 Prior to May 2011, flow from the toe ditch could flow through the rice field system. This flow is not included here but is estimated to be approximately 0.65 ac-ft/day.

6 Pump flow shown here is water into the rice system only. Water volumes pumped out of the system are not included. All water flowing out at 2-1 (recycled or pumped off) is measured with flow meters at TRD 2-1 E.

7 A small diversion of flow to the LICD project was made between 7/1/2011 and 9/19/2011. The diversion, totalling 40 ac-ft, is not included in large pump flow volumes because this water was not pumped back onto rice fields.

Most inflows and outflows from the rice fields occurred during late fall and winter (winter flooding) and summer (irrigation) (Table 4). However, the use of recycled water reduced the volumes of outflows from the rice system to the Twitchell Main Drain during the irrigation season; most of the rice drain water was captured by recycling pumps at TRD 2-1E and reapplied to the fields.

Table 5 shows outflows from the rice fields and the rice system. The average daily per acre drain flows for the rice fields and system were 0.021 and 0.017 acre-feet/day from the from the rice fields and rice system, respectively. Deverel and others[12] reported

[12] 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

0.001 to 0.0033 acre feet/acre-day for drained agricultural areas on eastern Twitchell Island during the growing season.

Table 5. Per acre drain flow for rice fields.

	Exports, acre-ft/acre-day	
	Rice Fields	**Rice System**
October-10	0.0009	0.0009
November-10	0.0198	0.0198
December-10	0.0535	0.0535
January-11	0.0421	0.0421
February-11	0.0260	0.0258
March-11	0.0140	0.0140
April-11	0.0041	0.0041
May-11	0.0082	0.0079
June-11	0.0161	0.0111
July-11	0.0256	0.0111
August-11	0.0288	0.0066
September-11	0.0124	0.0036
Average	**0.0209**	**0.0167**

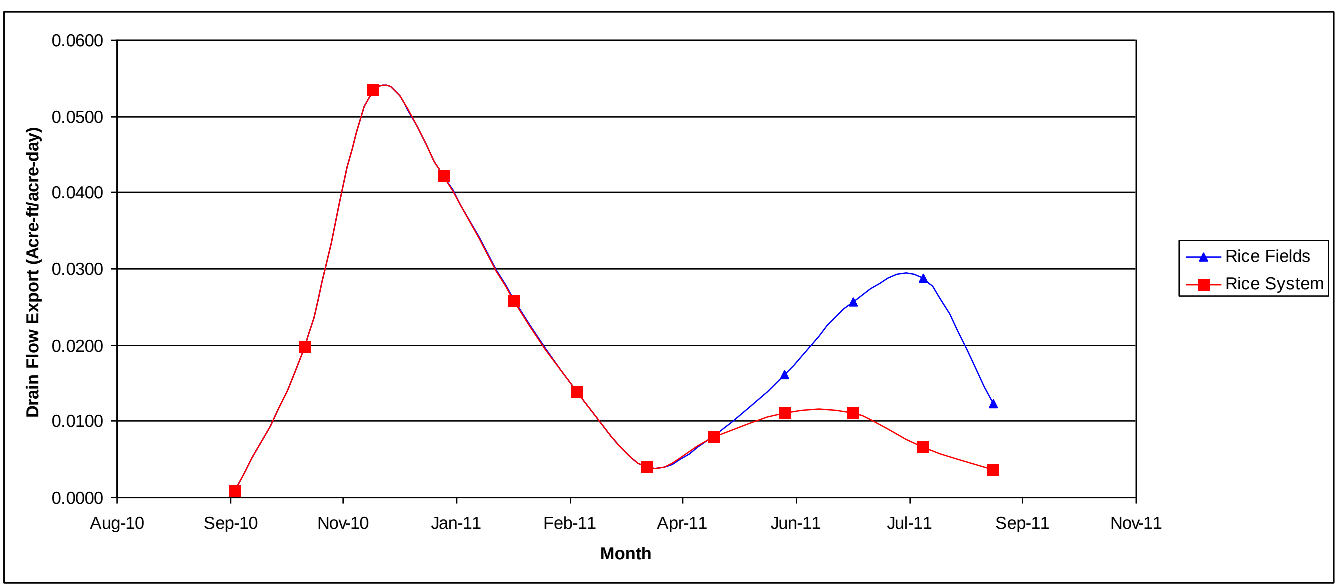

Figure 6. Comparison of daily per acre drain flow for rice fields and the rice system.

Figure 6 shows daily drain flow in acre-feet/acre-day from rice fields, and the rice system. Drain flow from rice fields is recycled within the rice system (Figure 4). Flows were highest during the fall and winter. Outflow from the rice fields also increased during the summer, although water recycling kept rice system outflow during the summer relatively low. The rice system drain flow accounts for recycling of drain flow from the rice fields. In addition to recycled water, pumps drew water from the Twitchell Rice Drain, further reducing the total export of water from the island.

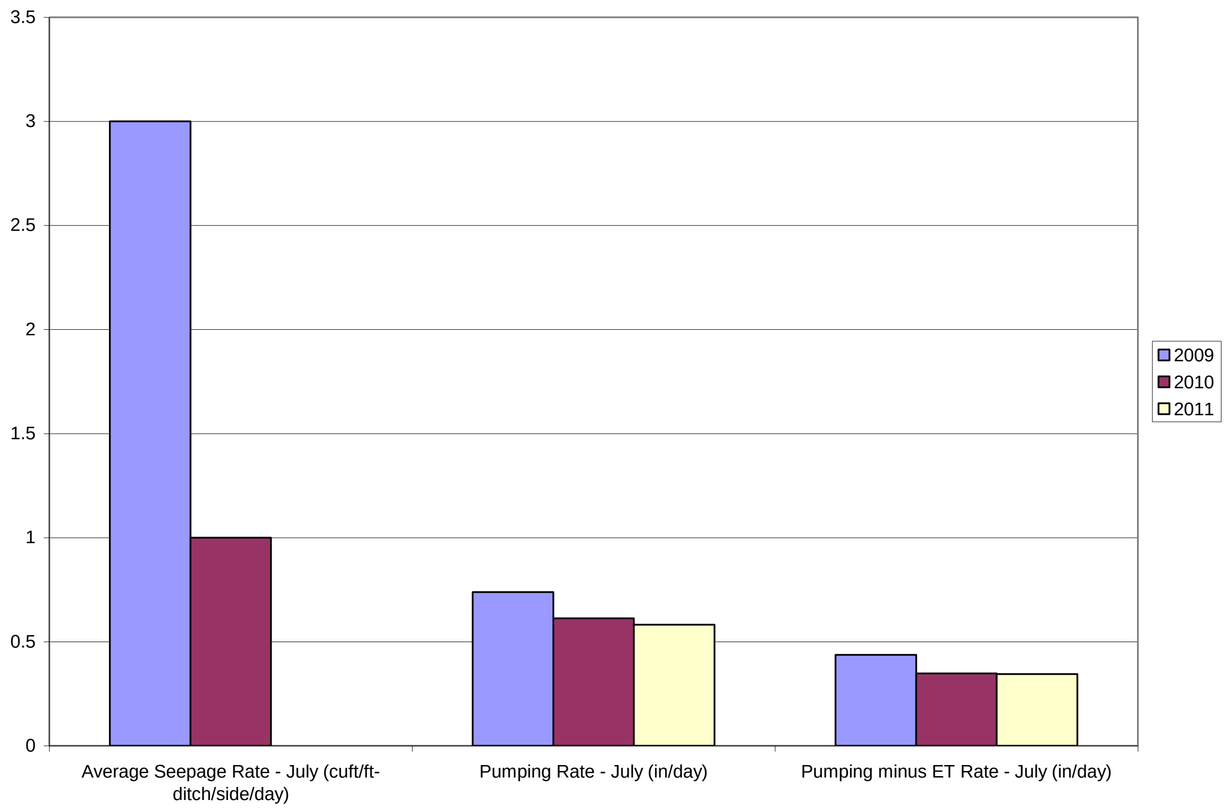

Figure 7. Estimated seepage and pumping rates for July 2009, 2010, and 2011. Rates are shown for July because it is a period of relatively steady-state conditions (as opposed to flooding or drainage).

Figure 7 compares seepage and pumping rates in 2009, 2010, and 2011. Seepage rates were not measured in 2011. In each of the 3 years of this project, water levels have been managed differently and this affected seepage rates. In 2009, the most seepage occurred as field water levels were kept high and ditch levels were kept low. In 2010, both field and ditch water levels were kept high while in 2011, both field and ditch water levels were kept low. The higher gradient between field and ditch maintained in 2009 may be responsible for the higher pumping and seepage rates. By keeping both water levels high in 2010, seepage losses were reduced.

3.1.1 Water Quality

United States Geological Survey and Bachand and Associates personnel measured field parameters (temperature, pH, dissolved oxygen, oxidation/reduction potential and electrical conductivity) and collected drain-water samples for determination of DOC, MeHg, nutrients and isotopes of oxygen and hydrogen from six locations shown in Figure 5 in the Twitchell Island Rice Project area from October 2008 through September 2011. The following sections present field parameter data, concentration measurements and load calculations for DOC, total dissolved nitrogen, and mercury and water-isotope data. Loads were calculated for each day that water samples were analyzed.

Concentration and load estimates during winter 2011 may have been affected by drain water from other fields. Between December 2010 and May 2011, a drainage ditch was excavated to the rice fields from the west. The fields to the west were leveled in preparation for rice cultivation in 2012. Significant drain flow onto the rice fields likely occurred between December 2010 and March 2011.

3.1.1.1 Field Parameters

3.1.1.1.1 Temperature

Figure 8 shows a strong seasonal trend in drain-water temperature. Drains 11-10 and 2-2 are dominated by subsurface flows whereas other drains have mixed contribution of surface rice drainage and subsurface seepage. The data in Figure 8 shows a similar pattern to the soil temperature data collected by UC Davis (Figure 37).

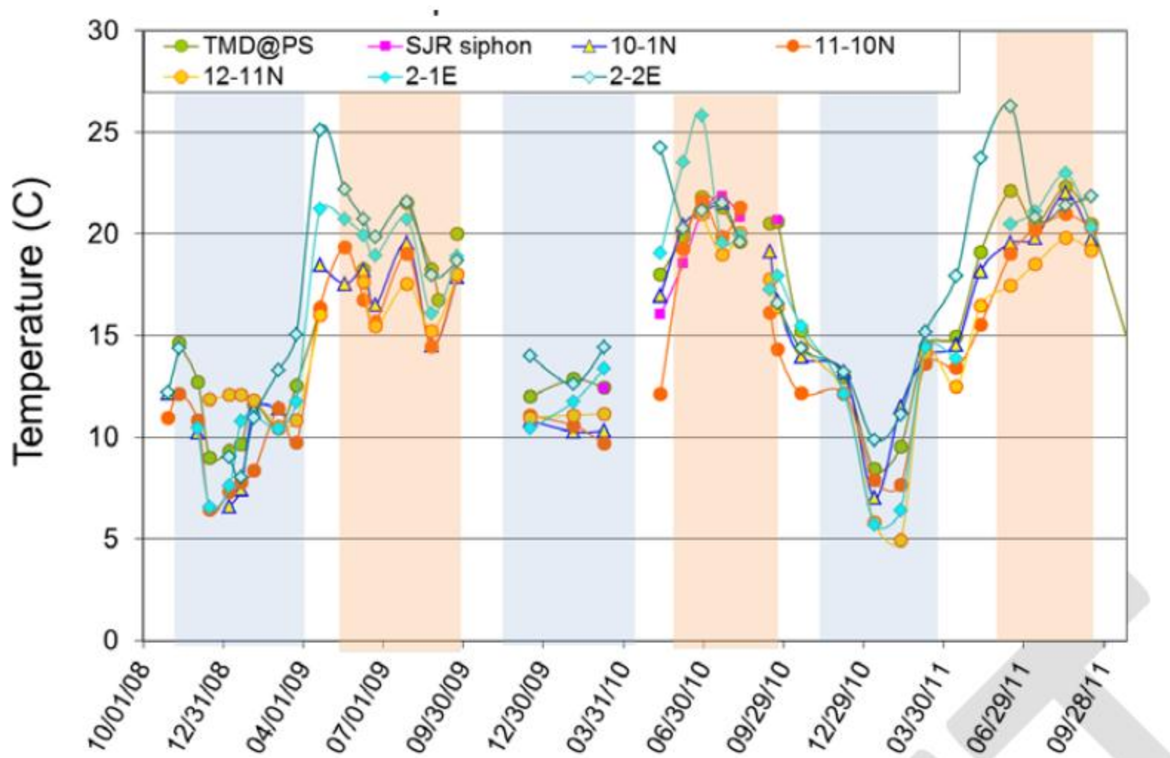

Figure 8. Time series of water temperature in the Twitchell Island ditches over the course of the study October 2008 through September 2011.

3.1.1.1.2 pH

The temporal variation of drain-water pH (Figure 9) shows variability between 6 and 7 with a suggestion of higher values in winter than summer possibly associated with use of San Joaquin River water for flooding. Island drainage water is which has a lower pH than San Joaquin River water is used for irrigation during the spring, summer and fall. Lower pH values were observed in in the 2-2E ditch relative to the other ditches. Measured pH values in all ditches were lower than measured values for the incoming river water.

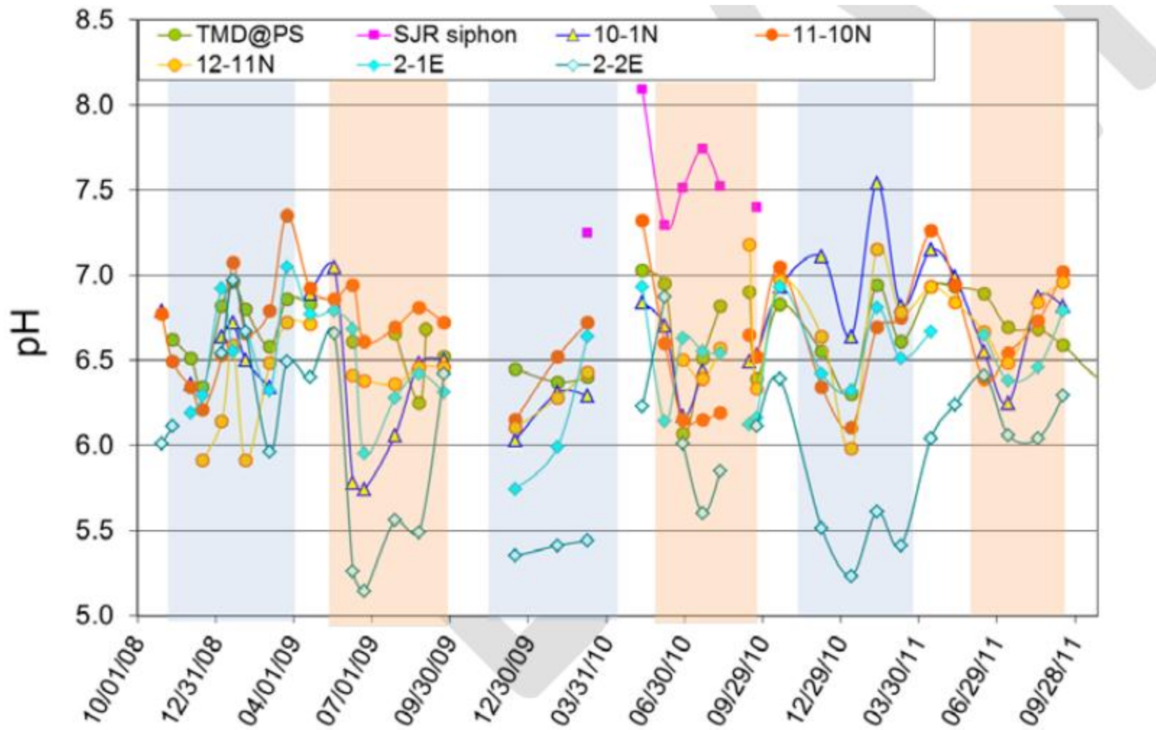

Figure 9. Time series of pH in the Twitchell Island ditches from October 2008 through September 2011.

3.1.1.1.3 Electrical Conductivity

Figure 10 shows that the electrical conductivity of drain water was highly variable ranging from less than 500 microSiemens/cm (uS/cm) to over 2,500 uS/cm both within and between ditches. Except for Ditch 12-11N which had the highest conductivity, values for the drains varied from less than 500 to about 1,800 uS/cm. Overall, the lowest values were measured during summer 2011. The conductivity of drainage water on Twitchell Island and other Delta islands is affected by evaporation of shallow groundwater and oxidation of organic soils[13].

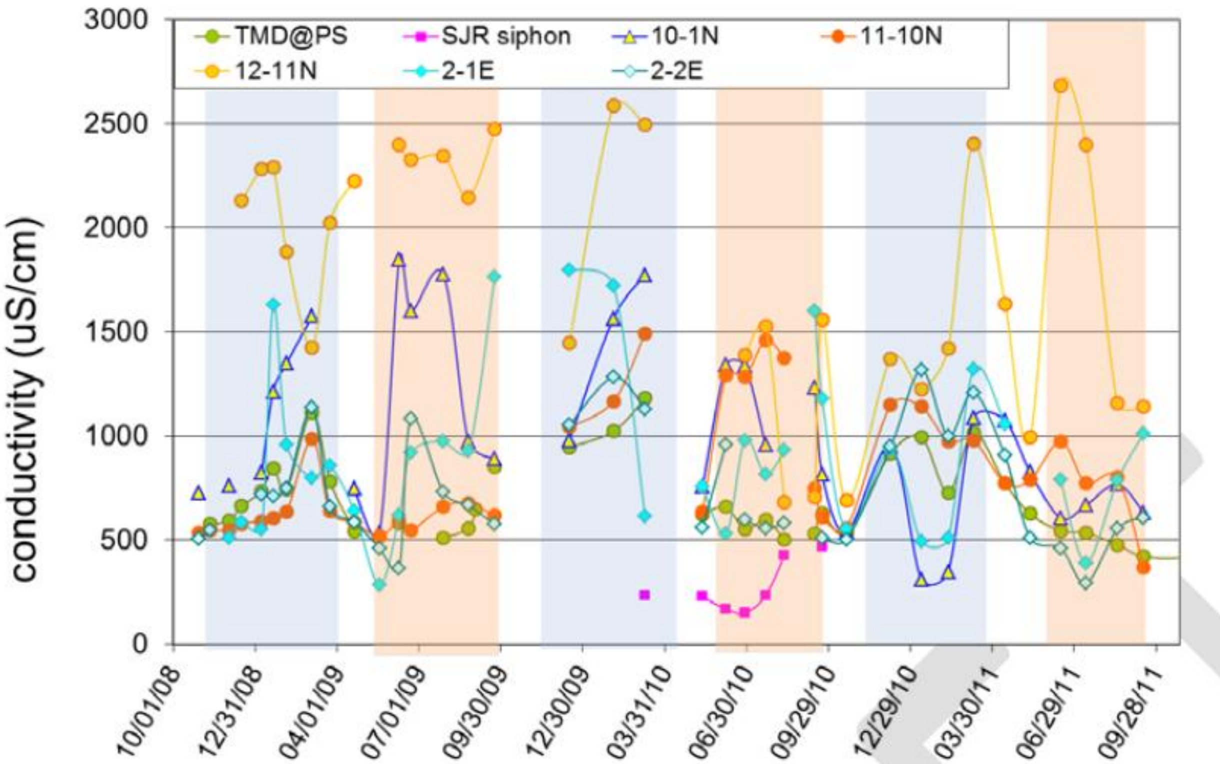

Figure 10. Electrical conductivity of drain water.

3.1.1.1.4 Dissolved Oxygen

Dissolved oxygen was highly variable in the drains (Figure 11) ranging from 0 to over 10 mg/L. General trends suggest that DO remained relatively stable or increased during winter flooding whereas DO decreased during summer flooding and the lowest values were measured during summer 2011.

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[13] 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

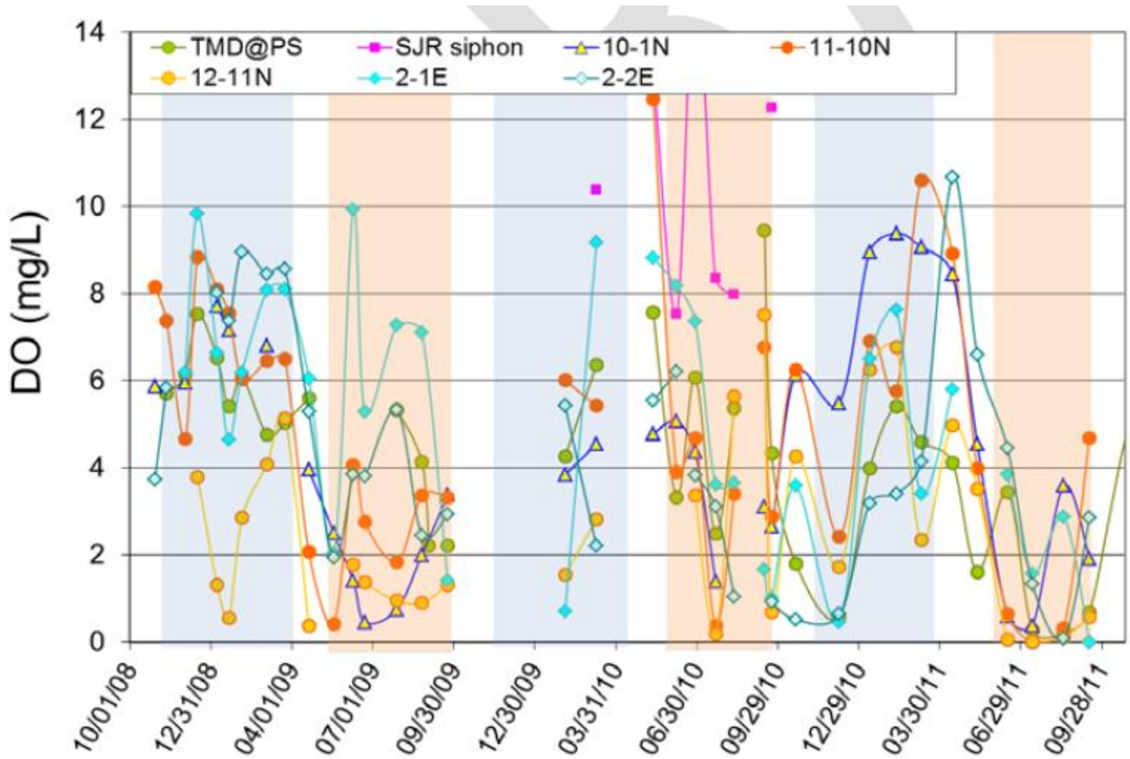

Figure 11. Dissolved oxygen in drains.

3.1.1.1.5 Oxidation/Reduction Potential

Oxidation-reduction potential (ORP) is a qualitative indicator of the capacity of the drainage water to oxidize or reduce redox-sensitive species such as iron, nitrogen, manganese and sulfate. We began measurement of ORP during January 2010. Figure 12 shows decreasing ORP values from summer 2010 through September 2011 which represents a generalized overall average ORP for iron and manganese reduction (0 to +200) towards that of sulfate reduction (-100 to -200).

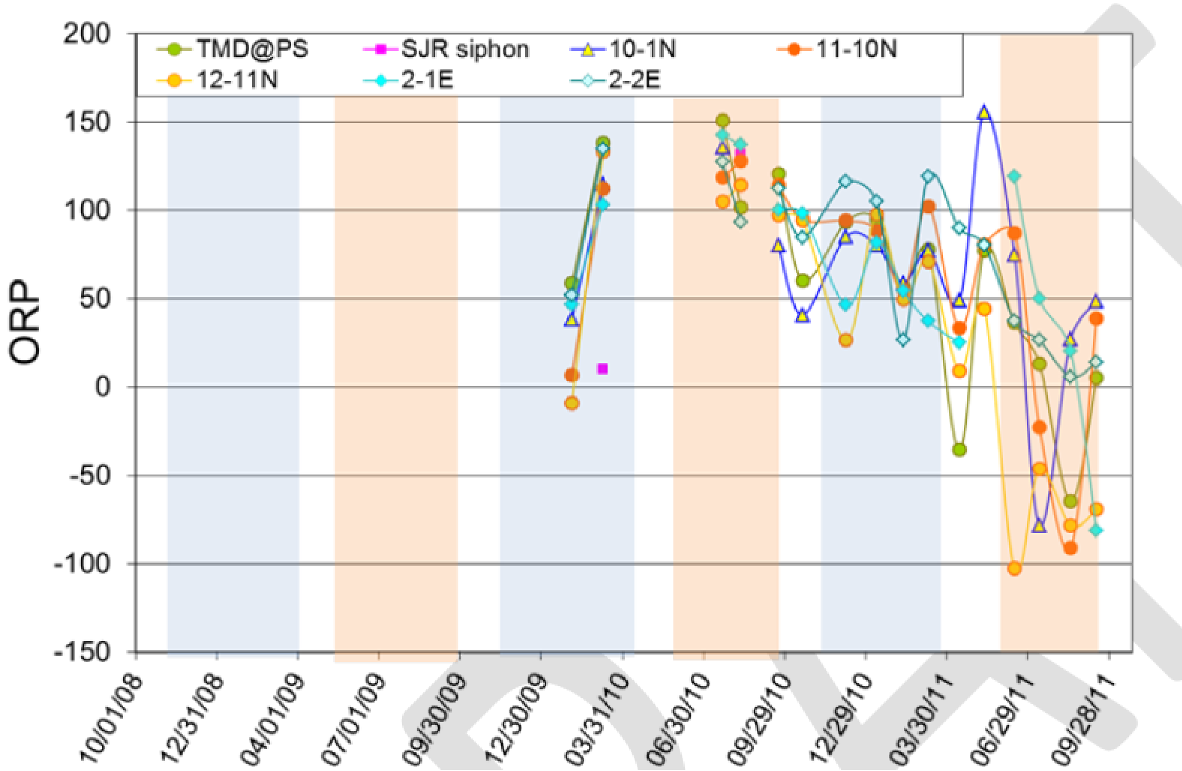

Figure 12. Oxidation-reduction potential in drains.

3.1.1.2 DOC Concentrations and Loads

Figure 13 shows DOC concentrations for six monitoring locations and San Joaquin River during 2009 to 2011. During 2009, DOC concentrations were higher in the rice drains (2-2E, 2-1E and 10-1N) relative to the corn/oats drains (12-11N, 11-10N). For 2009, 2010 and 2011, DOC concentrations in all rice drain samples were elevated relative to the San Joaquin River and the Twitchell Main Drain. Figure 13 shows increased DOC drain-water concentrations during periods of rice flooding. Analysis of Variance (ANOVA) on ranks (Dunns test) indicated statistically significant differences between seasons (winter vs. irrigation season) and group (group 1 includes field planted to rice in 2009 and group 2 includes planted to rice in 2010) ($p<0.001$) (Figure 1). Also, for Group 2, concentrations increased significantly from Year 1 (corn and oats) to Year 2 (rice). However, there was not a statistically significant difference between years for the Group 1 rice fields ($p<0.001$).

The observed spatial and temporal trends are generally consistent with previous studies of DOC concentrations and loads on Twitchell Island; high DOC concentrations resulted from flushing of DOC from the shallow, oxidized soil layer on Twitchell during wet periods[14]. For drained agriculture, DOC accumulates due to oxidation of the organic soils primarily during summer and fall and is flushed from the soils to drainage ditches by winter rains. DOC also accumulates during drained periods and flooding for rice cultivation flushes DOC from the organic soils. DOC loads from rice fields are shown in Table 6.

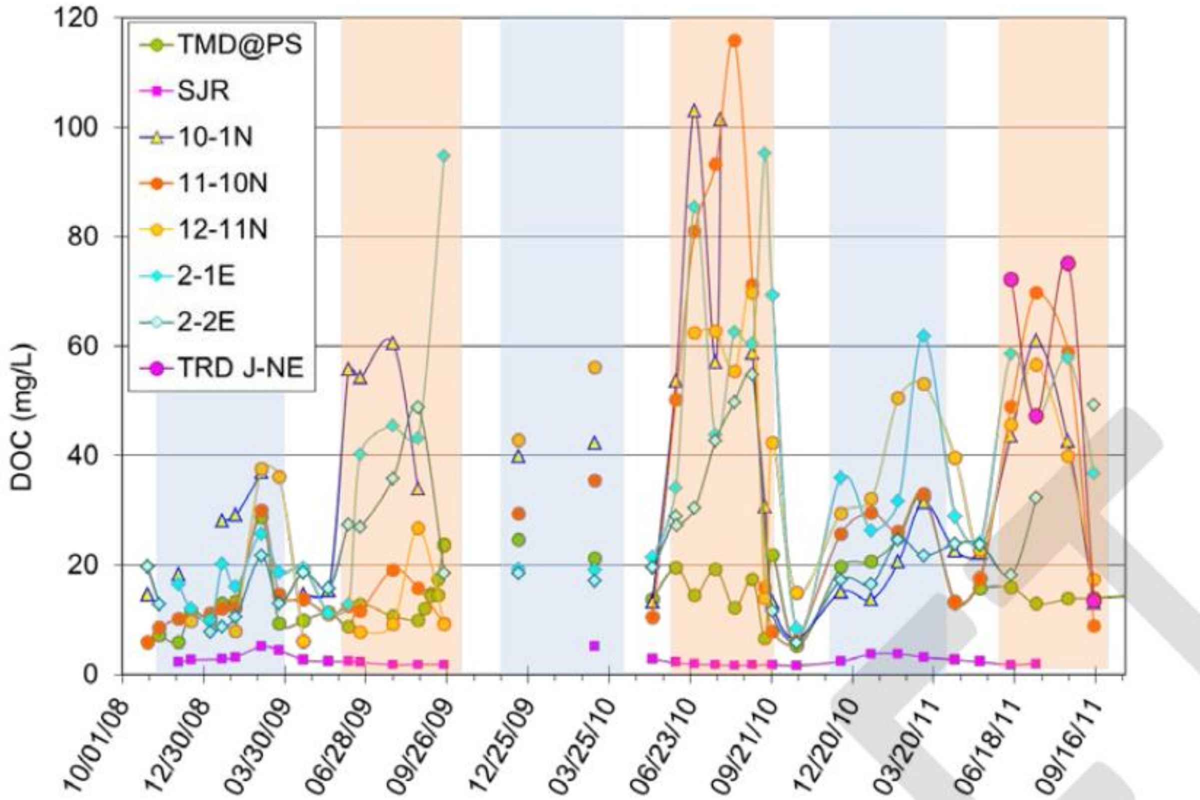

Figure 13. Dissolved organic carbon (DOC) concentrations in Twitchell Island drainage ditches from October 2008 through October 2011.

[14] 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.

Table 6 shows drain loads for DOC, TDN, and mercury exported from rice fields for 2010 and2011. During the irrigation season, rice field drain flow was reused for irrigation, resulting in exports from the rice systems that were lower than shown in Table 6. Winter export loads are likely high due to unmeasured flow from off-site.

There are a few values for comparison for areas within and outside the Delta for corn and similar crops within the Delta for mercury and DOC exports. Table 8 indicates that values for methyl mercury exports from typical Delta crops range from -1.6 to 57 micrograms/A-day. We are unaware of methyl mercury data for rice north of the Delta. Dissolved organic carbon loads for other crops besides rice in the Delta range from 8 – 174 g/acre-day. North of the Delta, reported agricultural loads (corn, alfalfa, tomatoes) ranged from 2 to 12 grams/A-day.[15]

Table 6. Constituent loads from rice fields for dissolved organic carbon (DOC), unfiltered methyl mercury (uMeHg) and unfiltered total mercury (uTHg). Irrigation includes the drainage period prior to harvest. (Winter loads are likely high due to unmeasured flow from off-site fields to the west.)

Constituent	Units	Loads											
		Fall			Winter			Spring			Irrigation		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
DOC	g/ac-day	**494**	*37*	*951*	**994**	*398*	*1466*	**131**	*29*	*550*	**1120**	*331*	*1605*
TDN		**67**	*4*	*130*	**98**	*31*	*155*	**25**	*16*	*33*	**158**	*141*	*177*
uMeHg	ug/ac-day	**3**	*3*	*4*	**55**	*4*	*133*	**1**	*1*	*2*	**8**	*6*	*12*
uTHg		**29**	*8*	*49*	**156**	*37*	*292*	**13**	*11*	*14*	**110**	*24*	*193*

Figure 14 shows the temporal variation in instantaneous DOC loads from December 2009 to September 2011. Figure 14 includes calculated import, export, and net export loads for the rice fields and export loads for the rice system. DOC field exports are highest during wet periods (irrigation and winter) but recycling of outflow water reduced the DOC export from the system during the irrigation season. The DOC field imports were higher during summer 2010 than summer 2011 because more recycled island drainage water was used in 2010 which has high DOC concentrations, as compared to water from the San Joaquin River.

[15] UC Davis, US Geological Survey and Bachand and Associates, 2010, Final Report, Quantifying loads and assessing management strategies for reducing drinking water constituents of concern in watersheds, submitted to State Water Resources Control Board, Agreement No. 04-173-555-0

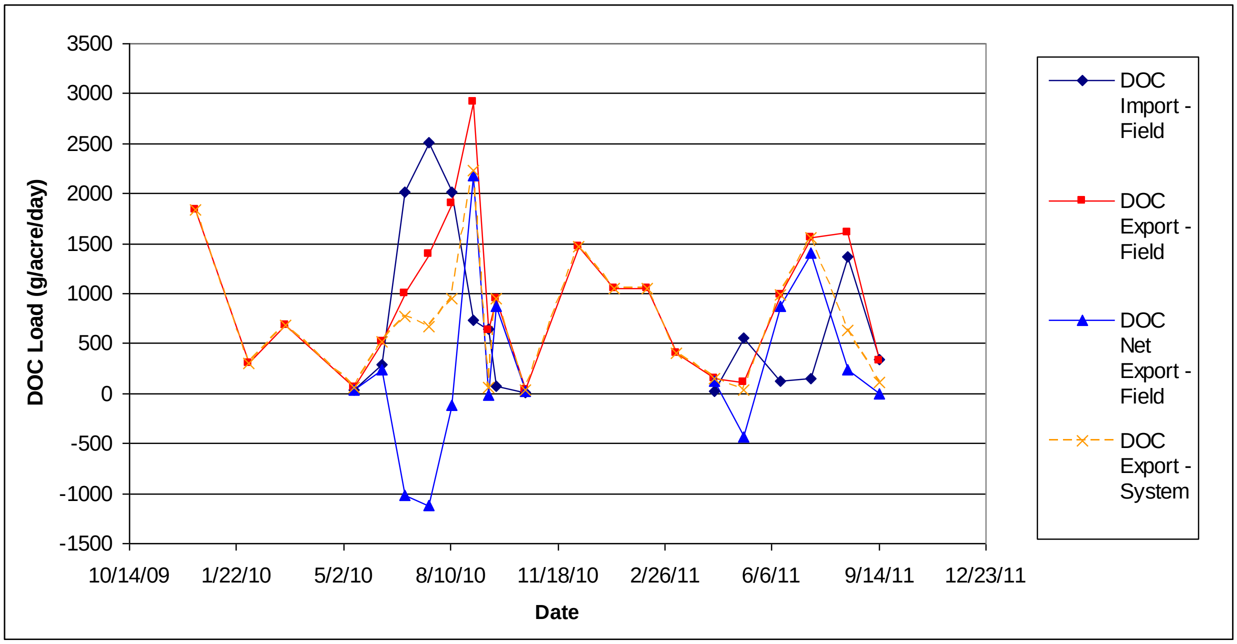

Figure 14. DOC loads from rice fields and system December 2009 to September 2011.

Average seasonal net field export loads were calculated for 2010 and 2011 (Figure 15) to investigate the seasonal tendency for gain or loss of constituents through the rice fields. Because of management differences, 2010 and 2011 irrigation seasons were considered separately. The spring and fall boxplots and numbers in Figure 15 are for both years. DOC loads increased more from the rice fields during fall (median= 451 g/acre/day) than during spring (median =32 g/acre/day). During the 2010 irrigation season, rice field DOC loads were highly variable and generally lower than the rice system DOC loads measured during the 2011 irrigation season (median = -66 and 552 g/acre/day for 2010 and 2011 respectively). The lower DOC loads during the 2010 irrigation season may be related to the higher DOC inflow concentrations. Because of the scatter in the load measurements and the small number of measurements, it is difficult to assess the statistical significance of the differences.

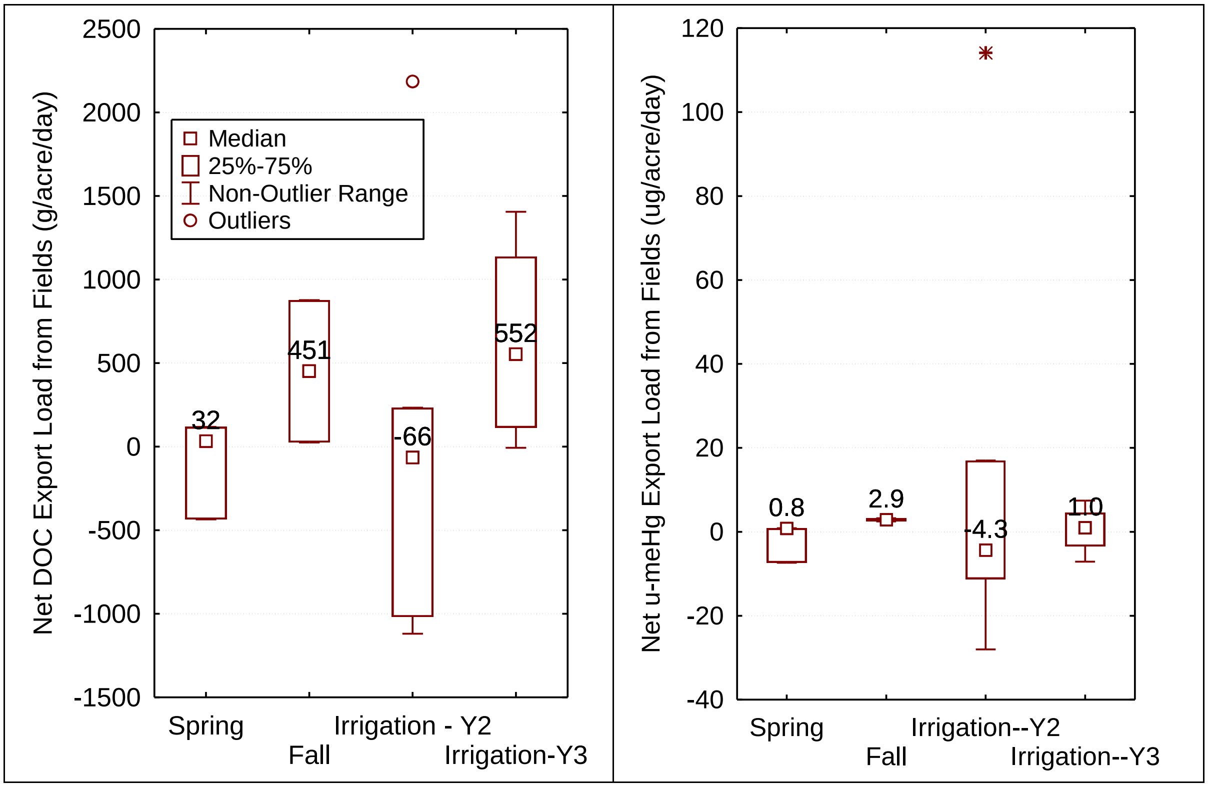

Figure 15. Boxplots showing net export loads of DOC and uMeHg for 2010 and 2011 (Y2 and Y3). Number of data points per category is as follows; spring (3), fall (2), irrigation 2010 (6) and irrigation 2011 (4). Numbers posted above median symbols are median values.

Table 7 shows DOC loads for different areas and land uses on Twitchell Island and the entire island. During non-flooded conditions in 2009 (corn/oats drain (TRD 12-11N and 11-10N, Figure 1) and in rice cultivation, DOC loads were similar to drain DOC loads previously reported for corn fields and the entire island[16] (Table 7). Rice field DOC loads were greater during irrigation than the corn/oats drains and were similar to DOC loads estimated for impounded wetlands on Twitchell Island[17].

During 2010 and 2011, rice field drain DOC loads during spring were comparable to late spring, summer and early fall DOC loads for the entire island reported in Table 7. Rice field winter and irrigation drain DOC loads were generally comparable to wetland drainage DOC loads. The rice field drain DOC loads shown in Table 7 were measured upstream of pumps which recirculate rice drain water during irrigation. Because the recirculated water contains high DOC and is not discharged, it is appropriate to compare the summer rice system load (total export load minus recycled load) to other locations. The rice system loads are lower than rice field loads but still tend to be above total island loads.

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[16] 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.

[17] 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 Agricultural Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science: 5(2) Article 2.

Table 7. DOC loads from Twitchell Island drains.

Land Use	Dry period DOC loads (g/acre-day)	Wet Period DOC loads (g/acre-day)
Entire Island[18]	May-Nov, Average = 73 Range = 18 – 161	Dec-Apr, Average = 576 Range = 78 – 1,253
Entire Island[19]	May-Nov, Average = 80	Dec-Apr, Average = 249
Corn fields[20]	May-Nov Range = 8 – 41	Dec-Apr Range = 56 – 174
Impounded Wetlands[21]	NA	Average = 1,038 Range = 499 to 1,486 Range = 809 – 2,833
2009 Rice Field	Average = 63	Average = 1,518
2010 Rice Fields	May 36*	Irrigation, June–Sep Average = 1393 (range = 519 to 2911) Winter, Dec-Mar; average = 937 (297 to 1835)
2010 Rice System**	Same as Field, above	Irrigation, June-Sep Average=863 (55 to 2227) Winter, same as Field, above

[18] 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

[19] 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.

[20] ibid

[21] 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.

2011 Rice Fields	Sept-Oct, Average=494 Apr-May, Average=131	June – Sep Average = 1120 (331 to1605)
2011 Rice System**	Same as Field, above	June – Sept Average=823 (112 to1555)

* One load measurement available for 2009-2010 dry period
**Rice Field exports to the main drain do not account for recycled water. Rice system exports are calculated as rice field exports minus recycled water.

3.1.1.3 Mercury Concentrations and Loads

United States Geological Survey and Bachand and Associates personnel collected drain-water samples for analysis of methyl mercury. Concentrations of MeHg in unfiltered drain water samples ranged from 0.1 to 13 nanograms per liter (ng/L) and were elevated in all drains relative to the nearby San Joaquin River where previously reported concentrations ranged from 0.05 – 0.25 ng/L (Fig 16). Elevated MeHg concentrations occurred under varying hydrologic conditions including both winter and summer flooded conditions and during spring drained conditions in 2009. The highest concentrations were always in fields that were converted or in transition between row cropping to rice. Within each year, the lowest MeHg concentrations occurred shortly after field inundation from intentional flooding or during drained conditions between flooding in summer and winter. The low concentrations reflect the contribution of river water used for irrigation. When irrigation water resulted in a higher water table, MeHg concentrations increased. The lowest irrigation-season MeHg concentrations were measured during 2011.

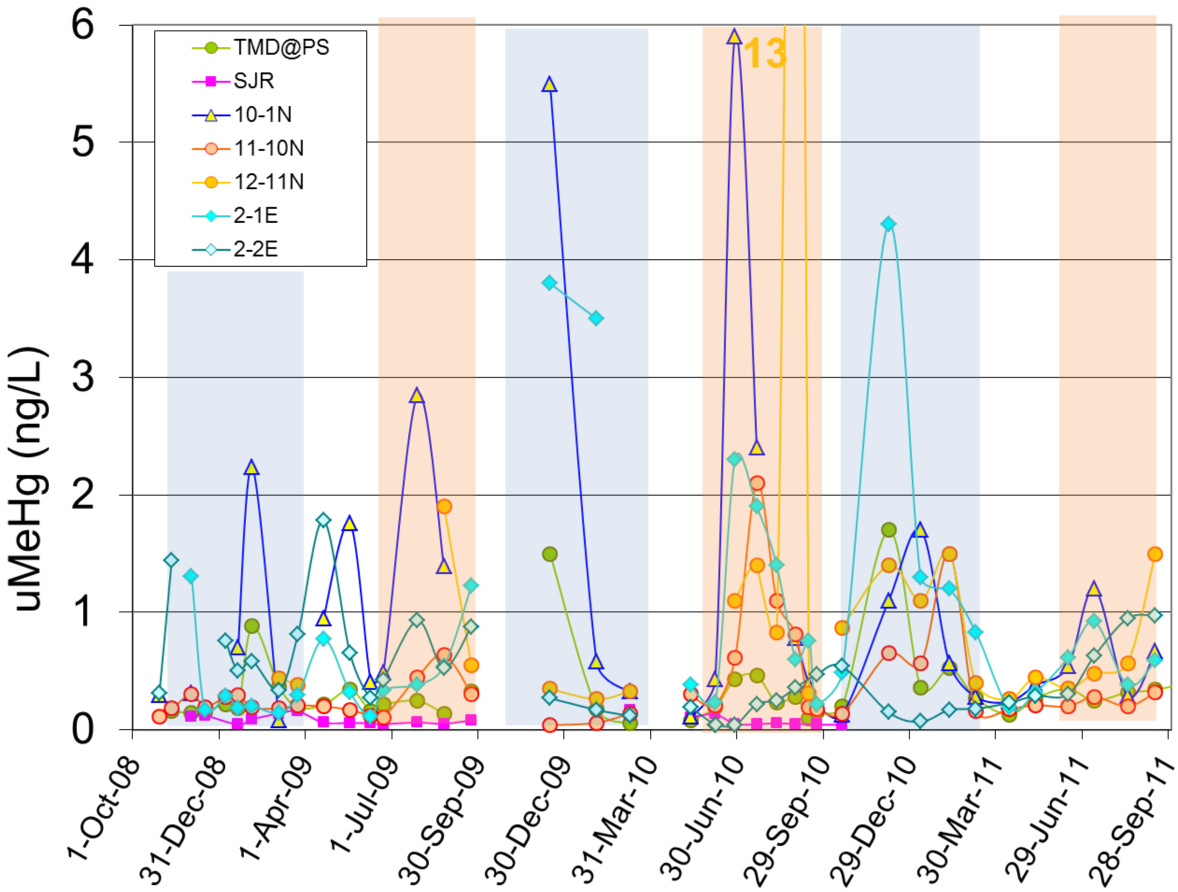

Figure 16. Unfiltered methyl mercury concentrations in drain and San Joaquin River water.

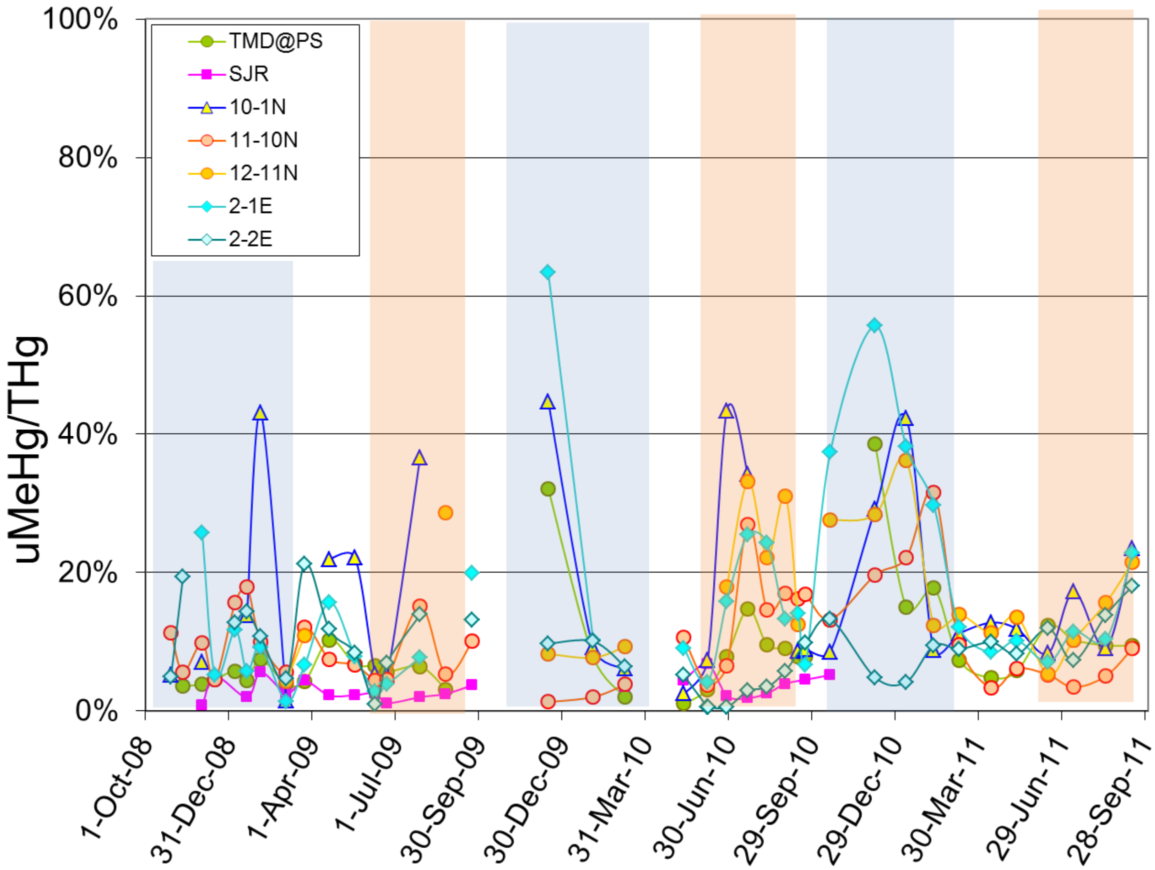

Figure 17. Percentage of methylmercury in total mercury in drain water samples October 2008 through September 2011.

The percentage of MeHg in total mercury (THg) in drain samples varied from 0.5% to 60% (Figure 17). Although variable, the MeHg/THg ratio was fairly consistent during flooded periods with peaks of 30-60% for both summer and winter. The average ratio was 10%. The relatively consistent trends in the ratio compared to concentrations likely reflect a consistent trend in seasonal methylation conditions independent of variations in partitioning and transport that contribute to variability in concentrations. The ratio remained consistently low throughout most of 2011 suggesting less methylation relative to previous years.

Statistical comparisons were conducted across several rice and row crop treatments including season, drain type, group and year - both independently and nested. The only difference observed in independent pooled comparisons was by drain type with row crop drains lower than rice and mixed drains and transitional drains in between (Figure 18; $p<0.05$, Dunn's). Although there was no significant difference between groups and years when pooled ($p=0.068$, Kruskall-Wallis), pairwise comparisons revealed that row crop and transitional drains (group1 year1) were lower than rice dominated drains (group2 year1, $p=0.006$; group 1 year3, $p=0.038$) agreeing with the analysis by type (Figure 19). For all analyses, the MeHg/THg ratio differences were less pronounced than concentrations but general trends are similar to concentration trends. Concentrations in row crop drains were similar to those of the island main drain (TMD-PS).

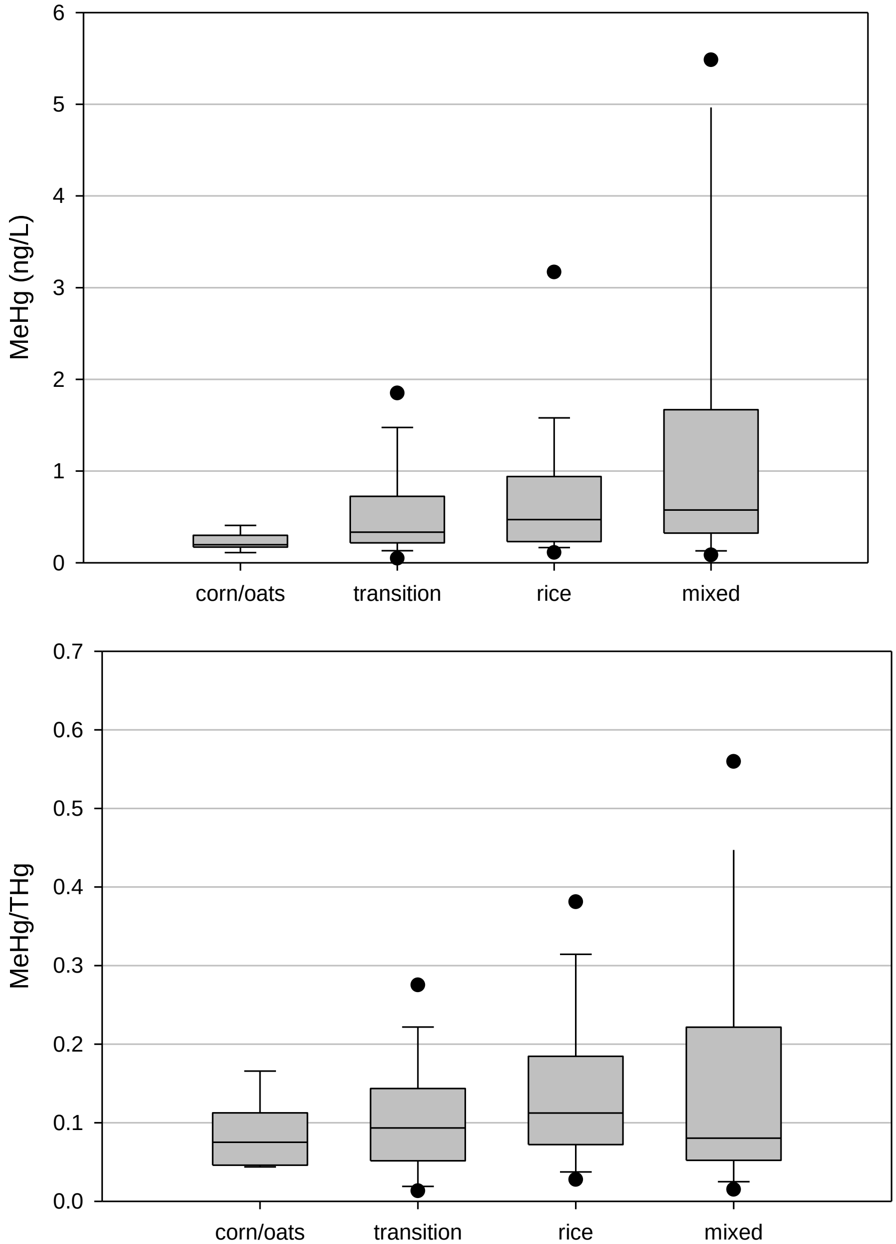

Figure 18. Boxplots showing the comparison of a) methylmercury concentrations and b) MeHg/THg ratios in Twitchell Island drainage water for four treatments.

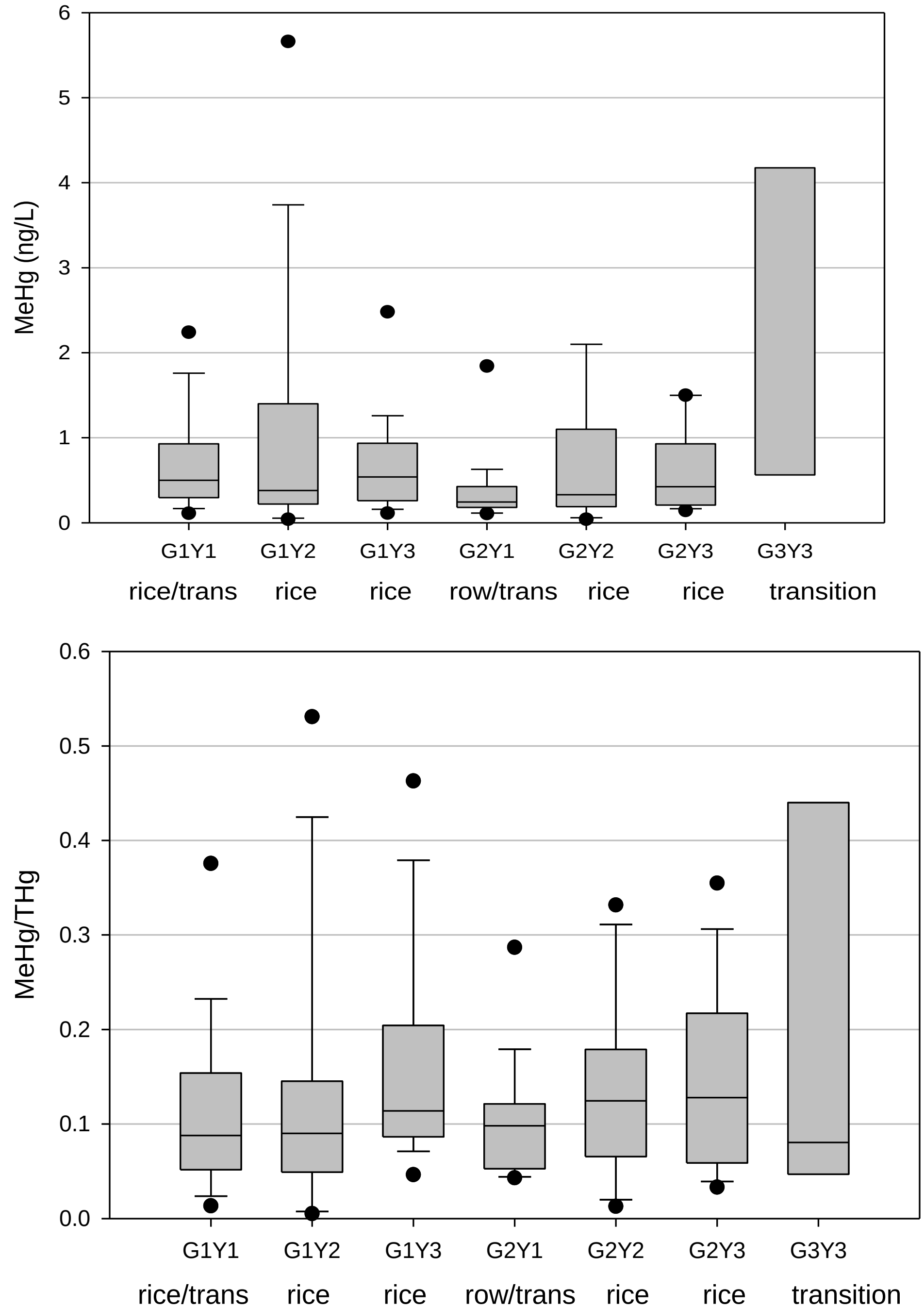

Figure 19. Boxplots showing comparison of a) MeHg concentrations and b) MeHg/THg ratios by group and year with dominant ditch type identified below the x-axis. G refers to the group and Y refers to year.

The effect of conversion to rice had a minor effect on the MeHg concentrations at the Main Drain Pump Station (TMD-PS) as only winter 2010 was greater than the historic winter data ($p=0.036$; Figure 18a). More notably, MeHg/THg ratios show an increasing trend with time for both summer and winter seasons (Figure 18b). The MeHg/THg ratios in this study could not be compared to previous years because THg was not measured in the previous studies[22]. Concentrations at the pump station may not increase markedly due to the reduced and controlled export of water from the rice production area; however, the notable increase in MeHg/THg suggests a possible change in the underlying processes that lead to MeHg at the island drain. As rice production increases its footprint on the island from approximately 5% in 2008 to about 17% in 2012, the ultimate effect of rice production may be better evaluated if monitoring is continued. For reference, the proposed methyl mercury standard for Delta surface water for prevention of accumulation of toxic levels in fish is 0.06 nanograms/L.

[22] 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.

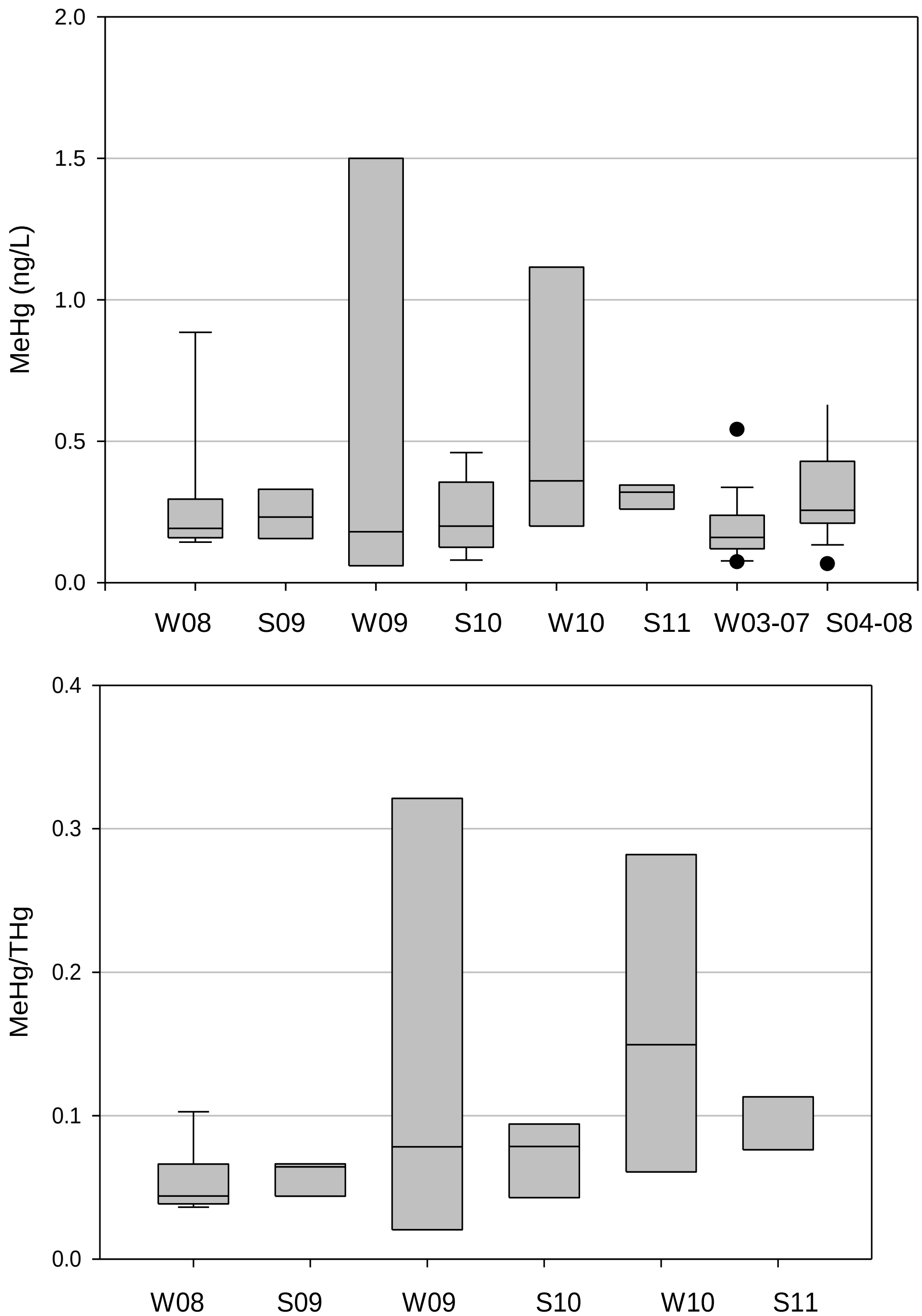

Figure 20. Boxplots showing the comparison between a) MeHg concentrations and b) MeHg/THg ratios at the Main Drain Pump Station (TMD-PS) on Twitchell Island for the summer and winter periods during the study and historic data from Foe (personal communication) and Heim et al. (2009). No historic data are available for THg following Year 1 conversion.

Rice field drain-water MeHg loads are shown in Table 6 and Figure 21. Figure 21 shows that despite fluctuations due to variable water- and land- management within and between years, measurement difficulty and gaps in MeHg concentrations, a similar pattern is evident during 2010 and 2011.

Figure 21 shows instantaneous uMeHg loads from December 2009 to September 2011 and includes import, export, and net export from the rice fields and exports from the rice system. The highest uMeHg exports occurred during winter and summer 2010. During both 2010 and 2011, winter loads were highest soon after flooding. Imports and exports during summer 2010 were higher than in summer 2011.

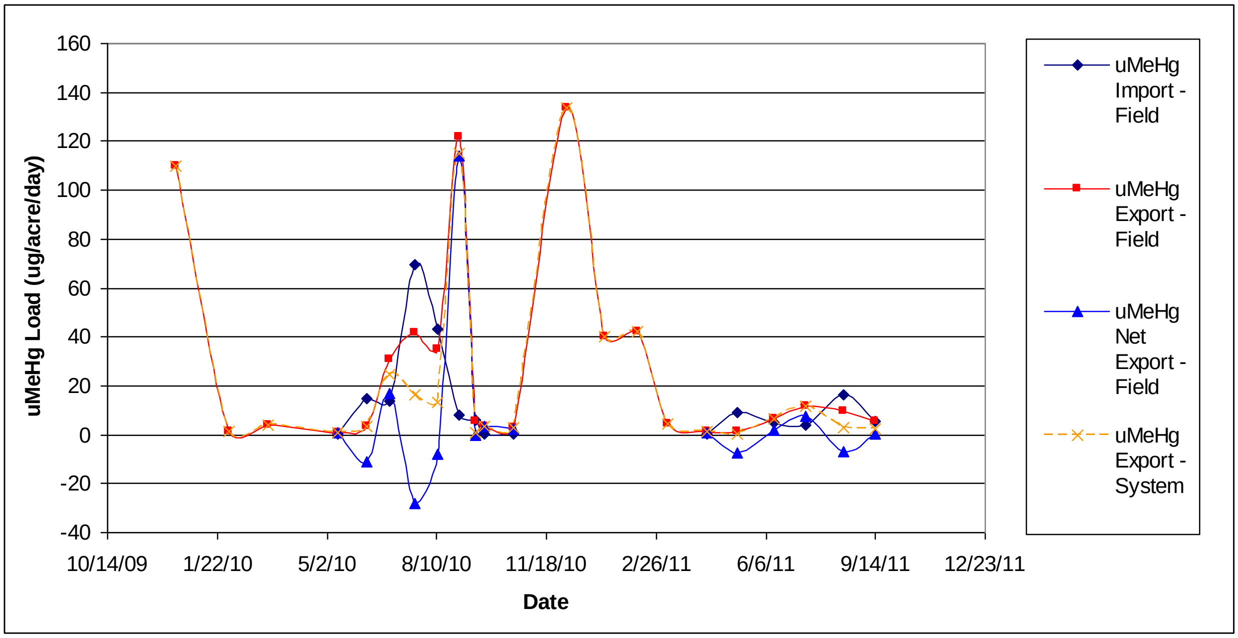

Figure 21. Unfiltered MeHg loads in rice drains (Dec 2009 to September 2011).

Using data for 2010 and 2011, seasonal net field export (export minus import) were calculated (Figures 15 and 21) to evaluate seasonal effects on MeHg loads. Because of management differences between 2010 and 2011 irrigation seasons, irrigation-season loads were plotted separately in Figure 15. During the 2010 irrigation season, the median MeHg rcie system load was -4.3 ug/acre/day. The highest net uMeHg export during the 2010 irrigation season was measured near the end of the flooded period (Figure 21). During the 2011 irrigation season and spring and fall of 2010 and 2011, rice system loads were less variable and the medians ranged from 0.8 to 2.9 ug/acre/day) Generally, the net MeHg loads per time period were similar. Because of the scatter in the load measurements and the small number of measurements, it is difficult to assess the statistical significance of the differences.

MeHg load data from all years are compared with other land uses in Table 8. Table 8 includes loads from corn/oats grown at Twitchell and 2008 - 2009 loads from the rice fields. In 2009, average uMeHg export loads from oat/corn fields for wet and dry periods were 3.5 and 1.2 ug/acre/day, respectively; similar to averages measured for the entire Twitchell Island and within the range observed previously for corn at Twitchell.

During the 2009 and 2011 irrigation seasons, average uMeHg loads exported from rice fields were very similar, 8.6 and 8.4 ug/acre/day, respectively. These loads were higher than the average 2009 non-irrigated period corn/oat drain-water load (1.2 ug/acre/day) and entire island drain-water load (1.2 ug/acre/day). The uMeHg loads are within the range reported previously for corn at Twitchell (1.8-26.3 ug/acre/day). The drain water loads 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 about 15-20% of the loads measured from impounded wetlands in the center of Twitchell Island. Spring export loads from 2009 and 2011 are similar to dry period measurements from the entire island.

The average uMeHg rice field export load measured during the 2010 irrigation season, 38 ug/acre/day was higher than the rice field loads during 2009 and 2011 and similar in magnitude to loads from the impounded wetlands at Twitchell. Some management practices that could account for the higher 2010 irrigation season loads are higher water levels, more recycled water use and different field preparation methods.

The load exported from the rice field is reduced by the load recycled back onto the fields during irrigation. The average system export loads (total minus recycled) for 2010 and 2011 irrigation seasons are 29 and 6 ug/acre/day, respectively (Table 8). The rice system loads are about 75% of the rice field loads but are elevated relative to the wet period island drain loads.

Table 8. Comparison of MeHg loads in Twitchell Island drains and other land uses.

Management Area	Wet period u-MeHg loads (micrograms/A-day)	Dry Period u-MeHg loads (microgram/A-day)
Twitchell Island[23] averages Entire Island (2009) Corn/oats (2009) Rice (2009)	 3.3 (Jan-Mar) 3.5 (Jan-Mar 2009) 8.6 (Jan-Mar, June, 2009)	 1.2 (Apr-Jun, 2009) 1.2 (Apr-Jun, 2009) 3.2 (Apr-May, 2009)
Rice (2010)	June-Sept (field): average=38 (3 to 122) June-Sept (system): average=29 (1 to 115) Dec-Mar: average=38 (1-110)	1(May, n=1)
Rice (2011)	June-Sept (field): average= 8.4 (6 to12) June-Sept (system): average= 5.9 (2 to12)	3.3 (Sept-Oct) 1.3(Apr-May)
Twitchell Island[24] Impounded wetlands	31.2 to 58.7	NA
Twitchell Island[25] Corn Impounded wetlands Bouldin Island Tomatoes Rice Other island estimates Entire island avg	 1.8 to 26.3 (Oct-Apr) 5.7 to 56.7 3.2 to 9.7 -0.4 to +0.2 -1.6 to +2.4	 ND NA ND ND ND
Brown's Island Tidal wetland	 17.8 to 28.7	 NA

[23] Values from this study (results to date)
[24] 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.
[25] 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.

Grizzly Island[26] Managed tidal wetland	2.1	NA
Bogs and Fens in WI, MN, NY, Sweden and Ontario, Canada[27]	0.6 to 6.1	NA

3.1.1.4 Water Isotopes

Stable isotopes of hydrogen and oxygen can be used to differentiate water sources and processes affecting water samples. The hydrogen and oxygen atoms that combine to form water molecules exist naturally in different forms (isotopes). Stable isotopes of hydrogen and oxygen, deuterium (D) and oxygen-18 (^{18}O), are not radioactive and do not change composition over time and, therefore can provide reliable information about water sources. Water molecules containing these isotopes are primarily $DH^{16}O$ and $H_2{}^{18}O$, which have larger atomic masses than the most abundant isotope, $H_2{}^{16}O$. The amount of D and ^{18}O in a water sample is expressed as a ratio relative to the amount in a standard (Standard Mean Ocean Water) on a parts per thousand (per mil) basis. The analysis of stable isotopes in a water sample will result in negative values if the sample has less D or ^{18}O than the standard ocean water. This is the case for all the sample results presented in this report

It is standard practice to plot del D (δD)[28] versus del^{18}O ($\delta^{18}O$) for evaluation of variation in isotopic composition among samples. The ratio of D to ^{18}O in rain water tends to remain constant such that plots of δD versus $\delta^{18}O$ fall on a straight line called the meteoric water line (see blue, diagonal line in Figures 22 and 23). When water evaporates, the liquid remaining becomes progressively "heavier" or enriched. That is,

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[26] 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.

[27] 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 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.

[28] δD is equal to the difference of the ratio of D to H in the sample and the ratio of D to H in the standard (Vienna Standard Mean Ocean Water) divided by the ratio of D/H in the standard.
δD = ((D/H)sample – (D/H)standard)/((D/H)standard)
Na analogous equation is used for $\delta^{18}O$

the δD and $\delta^{18}O$ values both become progressively less negative. Because the water molecules containing ^{18}O are heavier than those containing D, during evaporation they diffuse to the atmosphere more slowly. Therefore, there is an increase in ^{18}O relative to D and the isotopic composition plots on a line with a lower slope than the meteoric water line. In other words, evaporation causes the stable isotope results to plot along a line trending upward and to the right, but at a lower slope than the meteoric water line (see black, diagonal line in Figures 22 and 23). The evaporative effect on the isotope composition is well documented in the literature[29] and these evaporative trend lines typically have slopes that range from 3 to 6 for the δD/ $\delta^{18}O$ equation.

Figure 22 shows the relation of δD and $\delta^{18}O$ for all isotope samples collected during the study period and the average of San Joaquin River sample results reported by Deverel et al. (2007)[30]. Almost all the sample results plot on an evaporative trend line with a slope of 4.25 which indicates evaporation from shallow groundwater. The samples collected at TRD 2-2E and Twitchell Island Main drain were the least evaporated and samples collected in other drainage ditches were more evaporated during the irrigation season. The intersection of the evaporated trend line and the meteoric line is close to the average of the San Joaquin River samples reported by Deverel et al. (2007) which is consistent with the San Joaquin River as the source of water in the drainage ditches.

Figure 23 shows that less evaporated samples are generally associated with lower DOC values and more evaporated samples are associated with higher DOC values. Consistently, DOC was significantly correlated with $\delta^{18}O$ ($r^2 = 0.61$) for all samples. Deverel et. al. (2007)[31] attributed a similar correlation to the association of high DOC in the variably saturated zone where water was subject to partial evaporation and DOC accumulated during the growing season due to peat oxidation. This labile DOC was flushed from the variably-saturated zone during the winter and spring. Time series for $\delta^{18}O$ (Figure 24) indicate the likely influence of similar processes and evaporation in rice fields influence the quality of the rice field drains.

During fall and winter flooding during 2008 – 2009 and 2010 – 2011, substantial surface water outflow from the rice fields occurred during November through January[32]. During late January and February, water application ceased and flow to drainage ditches was due primarily to subsurface flow. This resulted in an evaporated isotopic signature and high DOC concentrations during the final sampling events during winter 2009 and 2011 (Figures 13 and 24).

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[29] See Gat, J.R. and Gonfiantini (Eds.). 1981. Stable isotope hydrology-Deuterium and oxygen-18 in the water cycle, Tech. Rep. Ser. International Atomic Energy Agency, 210.

[30] Deverel SJ, Leighton DA, Finlay MR. 2007a. Processes affecting agricultural drainwater quality and organic carbon loads in California's Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science [Internet]. Available from: *http://www.escholarship.org/uc/item/5j76502x*.

[31] ibid

[32] Jim Casey and Bruce Gornto, personal communication, March 2012.

During flooding for irrigation in 2009 and 2010, the most evaporated water samples as indicated by the highest $\delta^{18}O$ values were collected shortly after flooding in early June of both years for all drainage ditches except TRD 2-2E. Del 0-18 values declined after initial flooding indicating decreasing influence of evaporated water in the drainage ditches. Figure 13 shows a similar trend with the highest DOC values occurring during flooding for irrigation. Also, the highest DOC values tended to be associated with the evaporated isotope signal near the end of the winter flooding period during 2009 and 2011. If evaporation of rice field surface water were influencing the drainage ditch samples during growing-season, $\delta^{18}O$ values would have increased with time during flooding. It is therefore likely that dispersive flushing resulted in an initial pulse of resident highly evaporated water with high DOC concentrations. Mixing and dispersion with rice field surface water likely resulted in the decreasing $\delta^{18}O$ values with time.

In contrast, during rice irrigation during 2011, $\delta^{18}O$ values increased during flooding which likely reflects greater influence of evaporation of rice field waters on drain-water composition. Lower dissolved oxygen, ORP, DOC, MeHg and percent MeHg values (Figures 11, 12, 13, 16 and 17) during 2011 relative to previous years likely reflect the dispersive flushing of resident evaporated and oxidized water containing high DOC that was present prior to rice cultivation. Groundwater flow to drains, which is the primary process responsible for removal of evaporated, resident high DOC water to drainage ditches, is slow and flushing occurs over several years. Specifically, Deverel et al.[33] reported hydraulic conductivity values for shallow organic deposits ranging from 0.01 to 38 m/day and a geometric mean of 0.25 m/day. Using a horizontal hydraulic gradient to drains during winter of about 0.2 results in a travel time of 0.05 m/day or about 18.25 m/year. These cursory calculations indicate that several years to decades are required for complete flushing of resident pore water. Because of the large range in hydraulic conductivity and gradients, there is a large range in travel times for water to move to drainage ditches. This slow flushing of high DOC pore water is also consistent with results reported by Fleck et al. (2007) for the Twitchell Island demonstration wetland.

As shown in Figures 22 and 23, drain TMD 2-2E contains less evaporated water and lower DOC values than other drains. This is probably due to lower groundwater levels influencing groundwater flow to the drainage ditch. Deverel et al.[34] showed that pore water flushed to drains during winter and early spring was more evaporated and had higher DOC concentrations than deeper groundwater. During later spring, summer and fall, deeper groundwater with lower DOC concentrations and little or no evaporation

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[33] Deverel SJ, Leighton DA, Sola–Llonch N. 2007b. Appendix C: Evaluation of island drain flow, seepage, and organic carbon loads, Sacramento–San Joaquin Delta. Results from the Delta Learning Laboratory Project, Objectives 2 and 3. Prepared for California Department of Water Resources and CALFED Bay Delta Authority under DWR Agreement 4600000659 CALFED Project 98–C01, January 26, 2007.

[34] Deverel SJ, Leighton DA, Finlay MR. 2007a. Processes affecting agricultural drainwater quality and organic carbon loads in California's Sacramento–San Joaquin Delta. San Francisco Estuary and Watershed Science [Internet]. Available from: *http://www.escholarship.org/uc/item/5j76502x*.

flowed to drainage ditches. This lower DOC and less isotopically enriched groundwater is probably flowing to drainage ditch 2-2E.

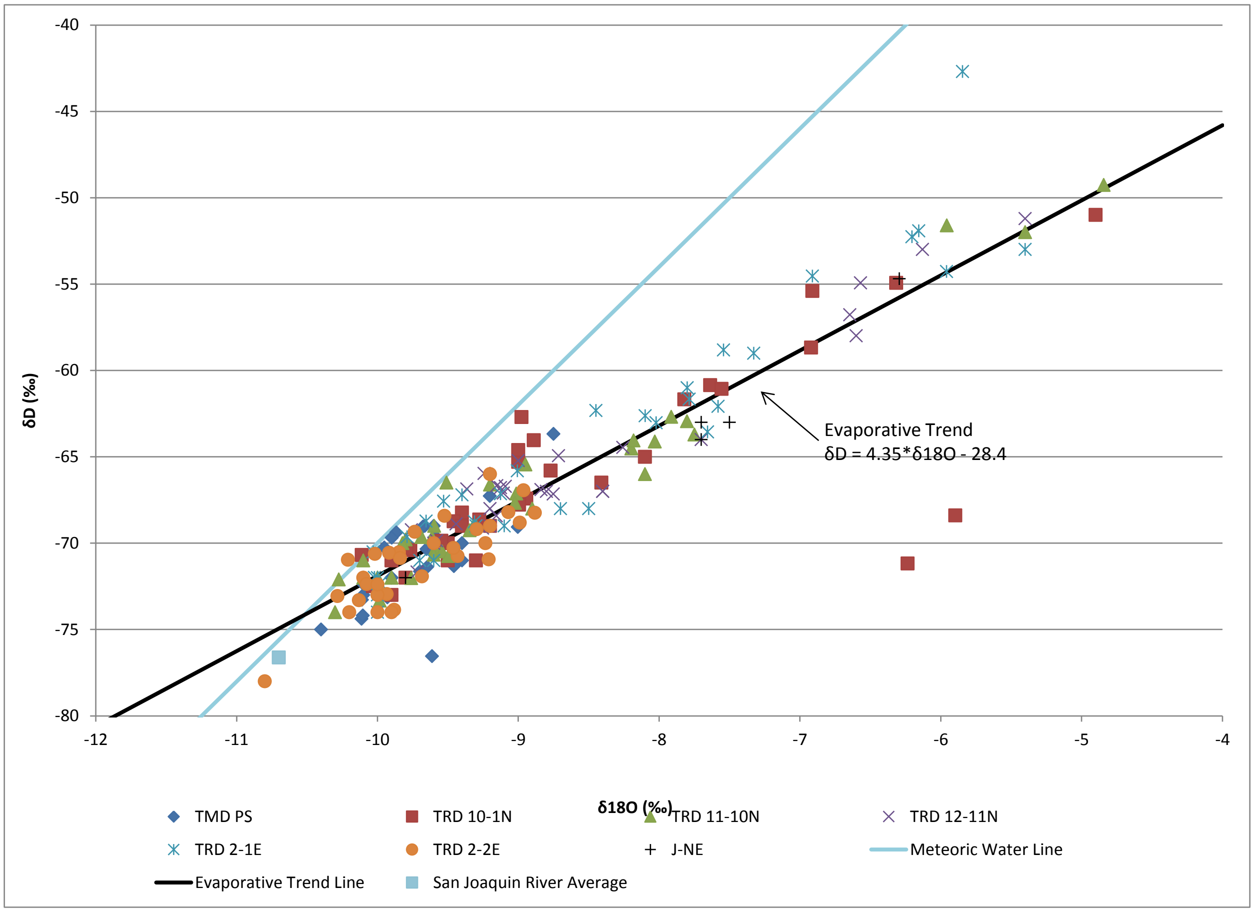

Figure 22. Relation of δD and δ18O for all isotope samples collected during the study period and the average of San Joaquin River sample results reported by Deverel et al. (2007).

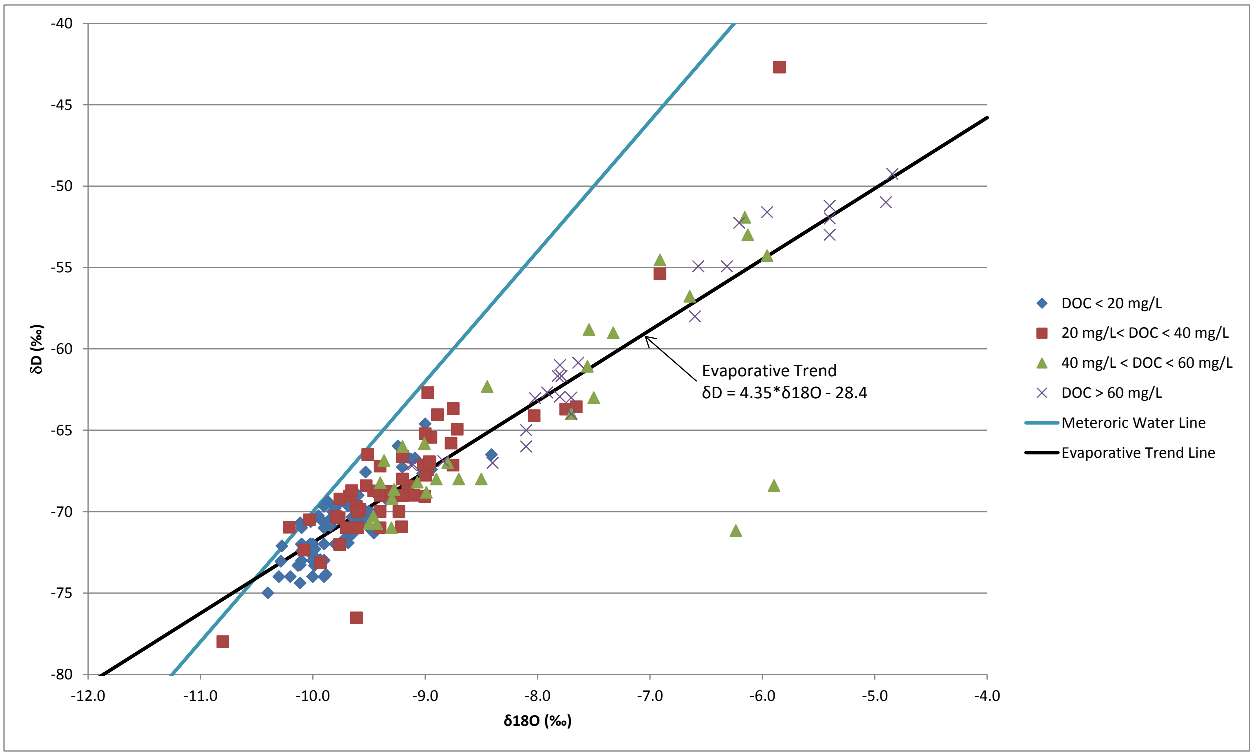

Figure 23. Relation of δD and δ18O for all isotope samples collected during the study period and range of DOC values.

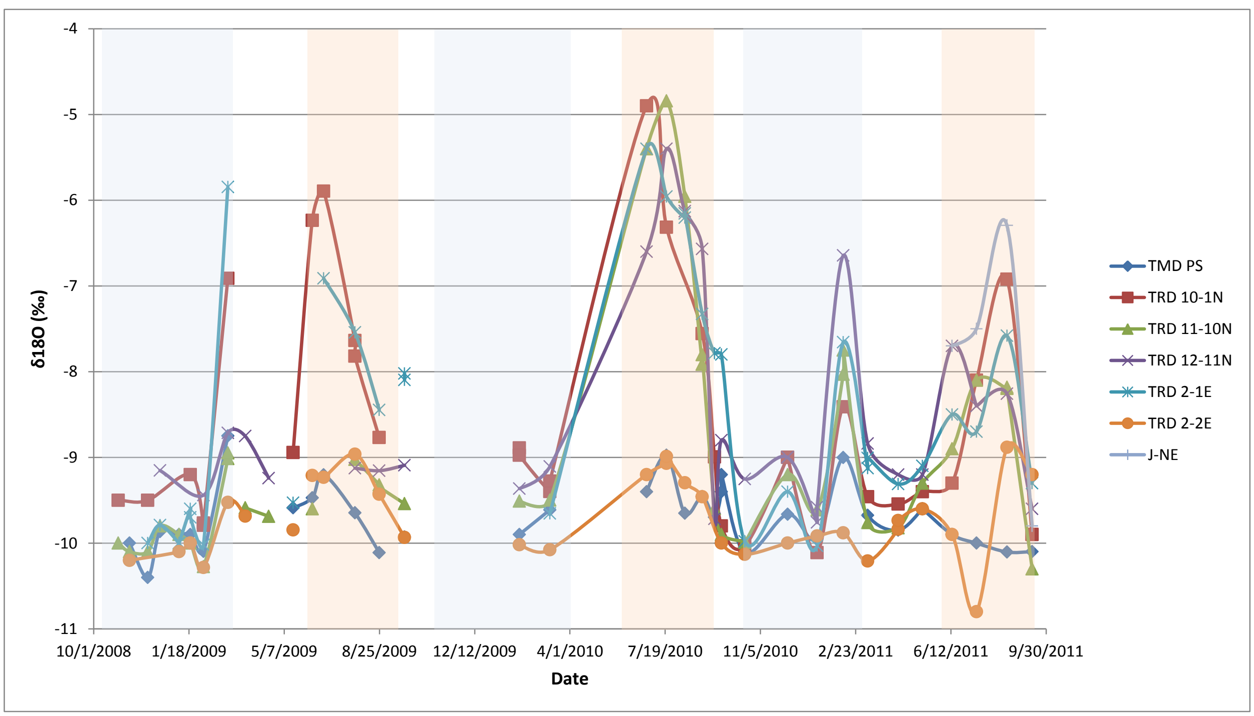

Figure 24. Variation in drain-water δ18O during the study period.

3.1.1.5 Mercury in Fish

In order to evaluate potential changes in MeHg availability and bioaccumulation in delta rice fields, USGS personnel collected and analyzed *Gambusia affinis*; (mosquito fish) at seven sites approximately every two months during 2010 and 2011 and three sites during 2009. USGS personnel analyzed fish samples for total mercury concentrations 90 mosquitofish in 2009, 139 in 2010, and 140 in 2011; a total of 369 mosquitofish were analyzed for total mercury concentrations at 74 different site-dates.

Mercury concentrations in fish are known to increase with fish length. Therefore, to reduce the influence of fish length the size of fish analyzed was constrained to only individuals with a standard length between 21 and 47 mm. Upon sampling, fish were immediately placed in labeled polyethylene bags and held on ice until their return to the laboratory (within 6 hours) where they were stored at -20° C.

Each fish was measured to the nearest 1 mm and weighed to the nearest 0.01 g on a digital balance. 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. Total mercury concentrations were determined in fish tissue 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. Quality assurance measures included certified tissue reference standards, sample duplicates, matrix spikes and matrix spike duplicates, and laboratory control standards.

General linear modeling was used to test for differences in mercury concentrations among sampling sites, month categories, and years using data from 2009 to 2011, while statistically accounting for the effects of fish length. Because water content can vary in individual fish, and mercury is associated with the solid protein lattice in animal tissues, all statistical analyses were conducted on a dry weight (dw) basis. However, to facilitate comparison to regulatory thresholds we present values in wet weight (ww) concentrations. Mean moisture content of mosquitofish was 73% ± 3% (standard deviation).

Across all sites and dates, the geometric mean (± standard error) mercury concentration in mosquitofish was 0.074 ± a standard error (SE) of 0.002 µg/g ww which is 2.5 times the value (0.03 µg/g ww) designated by the Central Valley Regional Water Quality Control Board's TMDL target for mercury concentrations in small fish. This target concentration is intended to be protective of wildlife health. Additionally, these concentrations are approximately 2.5 times higher than inland silversides (0.14-0.15 µg/g dw, or approximately 0.03 µg/g ww) collected from locations in the delta (see page 32 in Slotton et al. 2002[35]). Least squares mean ± SE mosquitofish mercury

[35] Darell G. Slotton,C, Shaun M. Ayers, Thomas H. Suchanek, Ronald D. Weyand, Anne M. Liston, Chance Asher, Douglas C. Nelson, and Brenda Johnson D. Slotton, 2002, personal communication, 2012, The Effects of Wetland Restoration on the Production and Bioaccumulation of Methylmercury

concentrations in 2011 (0.073 ± 0.005 µg/g ww) were similar to those in 2010 (0.077 ± 0.006 µg/g ww), and marginally higher than mosquitofish mercury concentrations in 2009 (0.061 ± 0.004 µg/g ww). However, mosquito fish in 2009 were collected from the Twitchell Main Drain and not the rice drainage ditches. More than 98% of mosquitofish sampled exceeded the TMDL target from 2009-2011 (97% of fish in 2009, 98% in 2010, and 98% in 2011). Figure 25 shows the monitoring locations and concentrations.

Combining data from 2009 to 2011, mercury concentrations in mosquitofish differed among sites ($F_{6, 351} = 6.19$, $P < 0.0001$), differed between month category ($F_{8, 351} = 9.39$, $P < 0.0001$), and were similar among years ($F_{2, 351} = 1.11$, $P = 0.33$), (Figure 26). These results indicate significant seasonal fluctuations in fish mercury concentrations but insignificant differences among years. Mercury concentrations were highest in rice drainage ditches TRD 10-1 and TRD 1-2 (Figure 26), indicating that rice fields promoted methylation and bioaccumulation of mercury in fish similar to the nearby Yolo Bypass[36].

Of all the dates sampled during 2009 to 2011, mosquitofish mercury concentrations were highest at the end of the 2010 rice growing season at sites TMD 11-10 and TRD 1-2, but did not show a similar spike in fish mercury concentrations at the main Twitchell Island outlet at site MD-SJR in 2010 (Figure 26). During both the 2009 and 2010 rice growing seasons, average mosquitofish mercury concentrations decreased from winter into spring but then increased throughout summer. In contrast, during the 2011 growing season, mosquitofish mercury concentrations were highest in late winter and decreased throughout the summer (Figure 27). Overall, mosquitofish mercury concentration site and date effects were large; rice drainage ditches and winter and late summer samples had among the highest fish mercury concentrations.

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in the Sacramento-San Joaquin Delta, California, Final Draft Report submitted to CalFed

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

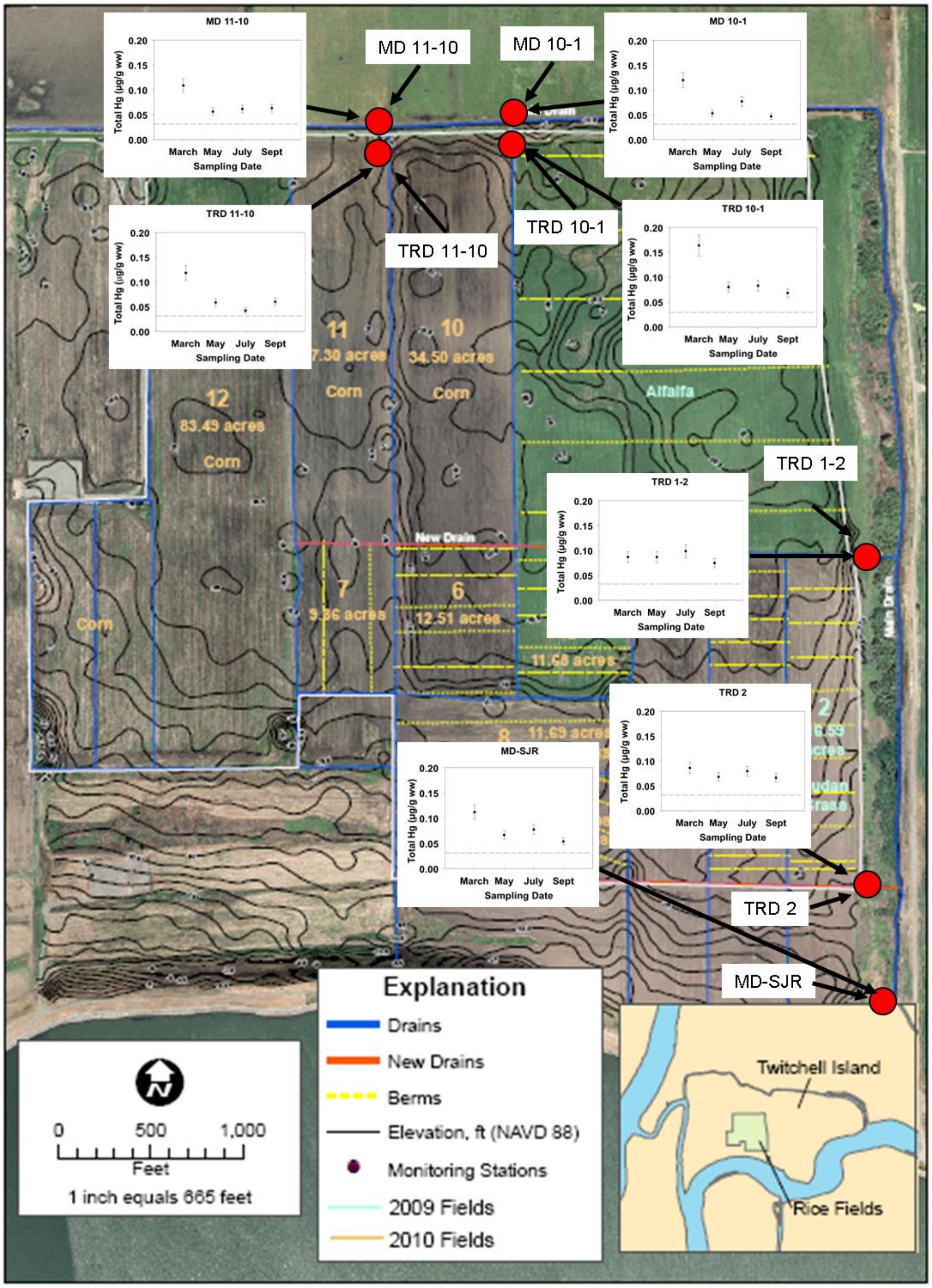

Figure 25. Total mercury concentrations (least squares means ± standard errors; µg/g wet weight) in mosquitofish from Twitchell Island by sampling date during 2011.
Dashed line represents Central Valley Regional Water Quality Control Board TMDL target for protecting wildlife health (0.03 µg/g wet weight). Least-squares means were derived from a global model with year × month interaction and account for fish length effects.

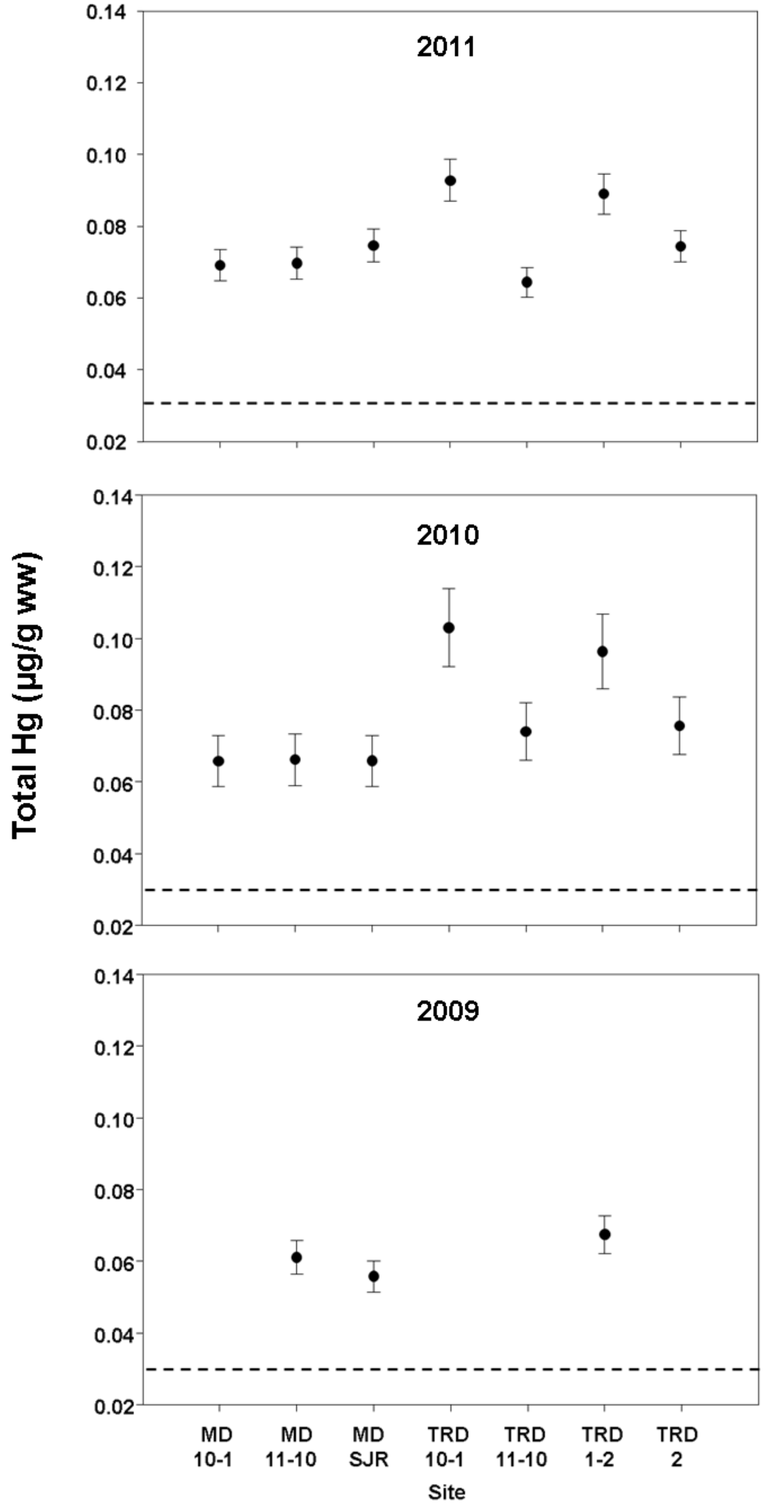

Figure 26. Total mercury concentrations (least square means ± standard errors; µg/g wet weight) in mosquitofish from Twitchell Island rice drainage ditches and outlets during 2010.
Dashed line represents Central Valley Regional Water Quality Control Board TMDL threshold for protecting wildlife health (0.03 µg/g wet weight).

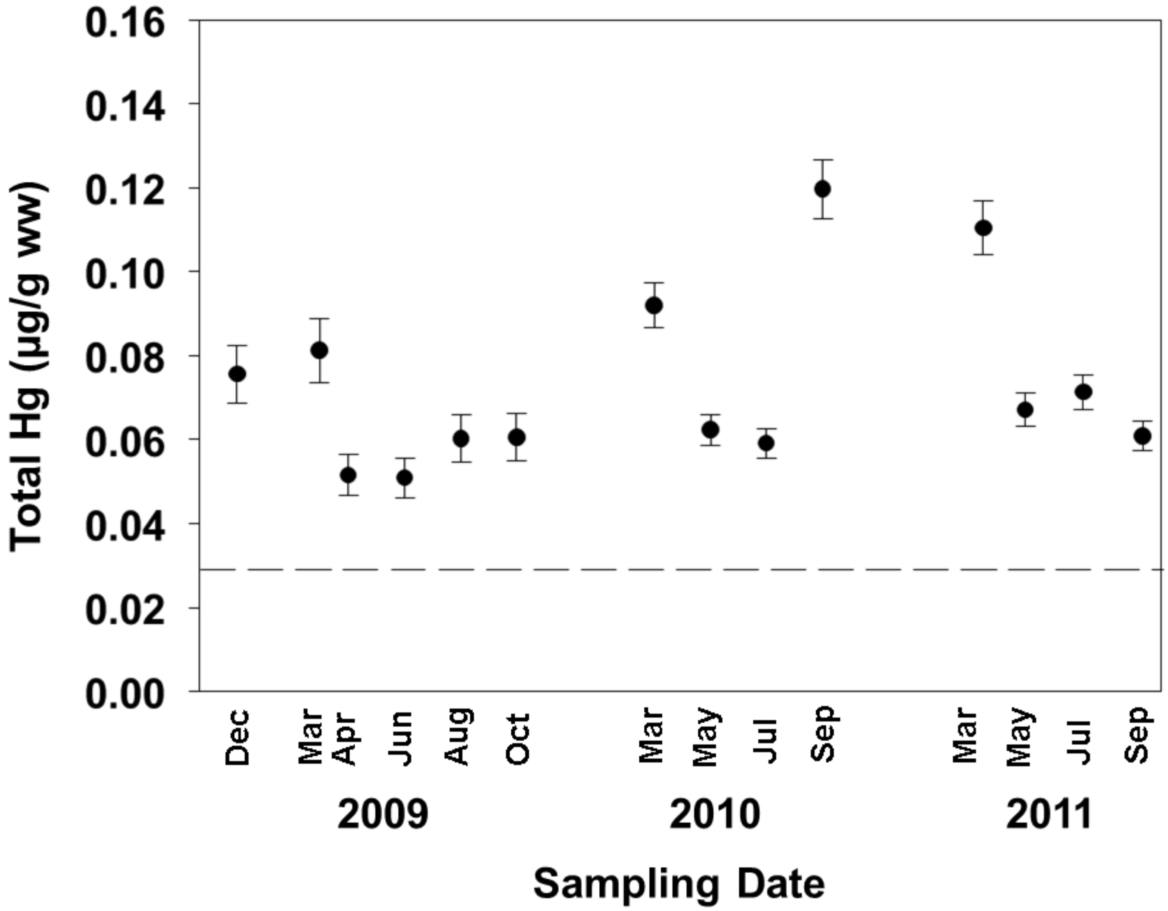

Figure 27. Total mercury concentrations (least square means ± standard errors; µg/g wet weight) in mosquitofish from rice field drainage ditches and outlets on Twitchell Island during 2009 to 2011. Dashed line represents Central Valley Regional Water Quality Control Board TMDL target for protecting wildlife health (0.03 µg/g wet weight). Least-squares means were derived from a global model with year × month interaction and account for site level and fish length effects.

3.1.1.6 Pesticides

USGS personnel collected soil samples on October 29, 2008 in rice fields after leveling and before flooding to quantify residual pesticide concentrations from previous activities. Samples were analyzed using microwave extraction and carbon/alumina cleanup and quantified via GC/MS. Table 9 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[37]. Measured levels of carbofuran, pendimethalin and permethrin were well below EPA screening levels[38].

Table 9. 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 10. Bispyribac sodium and Pendimethalin concentrations decreased with time (Table 10). All concentrations were well below aquatic life levels of concern. Due to the low concentrations detected in 2009, pesticides were not monitored in 2010 or 2011.

[37] 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.
[38] Screening levels were 62,000, 25,000 and 31,000 mg/kg for carbonfuran, pendmethalin and permithrin, respectively.

Table 10. 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

3.1.2 Subsidence

HydroFocus personnel constructed and installed three extensometers, two in the Twitchell Island rice and one in the corn field east of the rice field to monitor small-scale variations in land surface elevation. At all 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, extensometers were installed in field 1 in 2009 and in field 4 in 2010. A steel base support pipe was driven to refusal into the mineral layer underlying the peat soil. A modified sedimentation-erosion table (SET)[39] was inserted into a grooved stainless steel sleeve in the base support pipe which ensured instrument stability and replacement to the exact same position after movement to accommodate field operations (Figure 28). 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 28). HydroFocus personnel fastened a Macro Sensors GHSI 750 linear variable differential transformer (LVDT) to the rod above the plate (Figure 28). 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[40]. Specifically, three metal pipes were driven to refusal into the mineral layer below the peat. Three lengths of angle-iron were welded onto the

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[39] 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.
[40] 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.

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. A malfunctioning LVDT was replaced during October 2011.

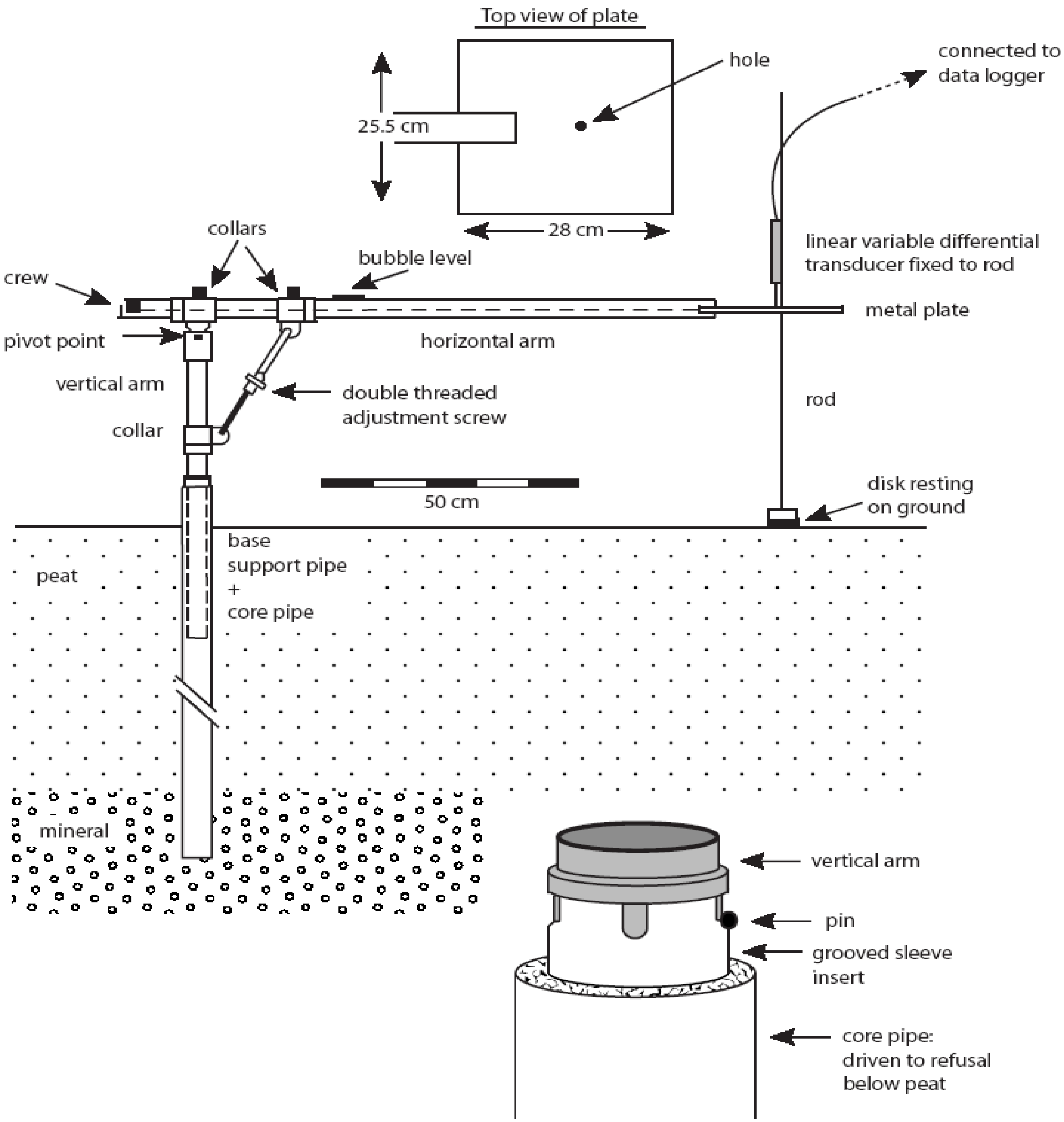

Figure 28. Extensometer in rice field.

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.

During the entire period of record, groundwater levels decreased and land surface levels increased in the rice field from late winter through spring (Figure 29). 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. During 2009 and early 2010, land-surface elevation generally followed groundwater levels although it increased more gradually and continually when the field was flooded. We estimated 42.6 mm of accretion (0.12 mm/d; 44.3mm/year) during a 351-day period from mid-irrigation (6/27/09) to soon after flooding (6/13/10). We discovered that tule growth accounted for the approximately 38.5 mm of accretion during a 69-day period from early in the flooding (7/12/10) to soon after draining (9/19/10) (Figure 29). The initial accretion from 6/27/09 to 6/13/10 was due to peat volume increases due to wetting and uplifting. Figure 29 shows that land surface continued to increase after June 2010. This is also likely due to tule growth. The extensometer arm has been lengthened to extend beyond the tules and was installed during spring 2012.

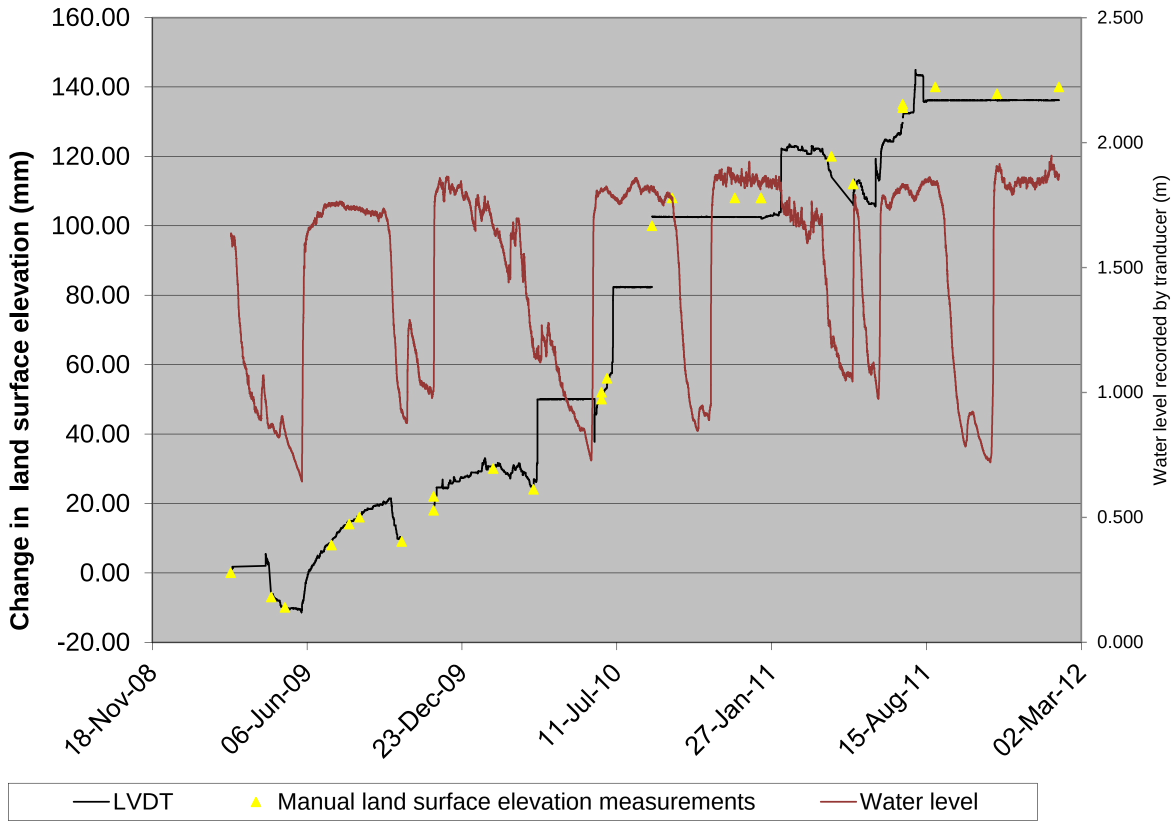

Figure 29. Land-surface elevation and groundwater levels at rice field extensometer. Yellow text and dotted lines represent elevation changes between dates and time where equal groundwater levels were measured.

Surveying occurred at 7 points in fields 1, 4, 8 and 9 during 2009 – 2012. The data indicate that there was an average of 1.2cm of elevation gain between May 2009 and May 2012. . Values at specific locations ranged from 0 to 10.6 cm.

At the corn extensometer land surface and groundwater levels, began to rise in October 2009 and continued to rise through the fall and winter and began to decrease in mid April 2010. In mid-October 2010, the rate of decrease in land surface elevations slowed and elevations began to increase similar to 2009. Water level rose and peaked in April 2011 and then declined to the most recent minimum value in September 2011. We estimated 2.47 cm (inches) of inelastic subsidence during a 2.12-year period from 8/22/09 to 10/6/11 when groundwater levels were equal (Figure 30). This corresponds to an annual rate of subsidence of about 1.2 cm (0.46 in).

Depth to groundwater was about 0.5 foot greater during summer 2009 relative to 2010 and 2011. This may be the key reason the slower subsidence rates during 2010 and 2011. The drainage ditches in the corn field are shallow and the field did not drain as effectively during 2010 and 2011 relative to 2009 when there was less rainfall. Shallow water levels limit the organic soil oxidation. Stephens and others[41] reported that subsidence rates in Florida organic soils decreased by about 30 % with a decrease in groundwater level of about 0.50 foot. These extensometer results in combination with greenhouse gas results described below indicate that rice stops or greatly limits oxidative subsidence.

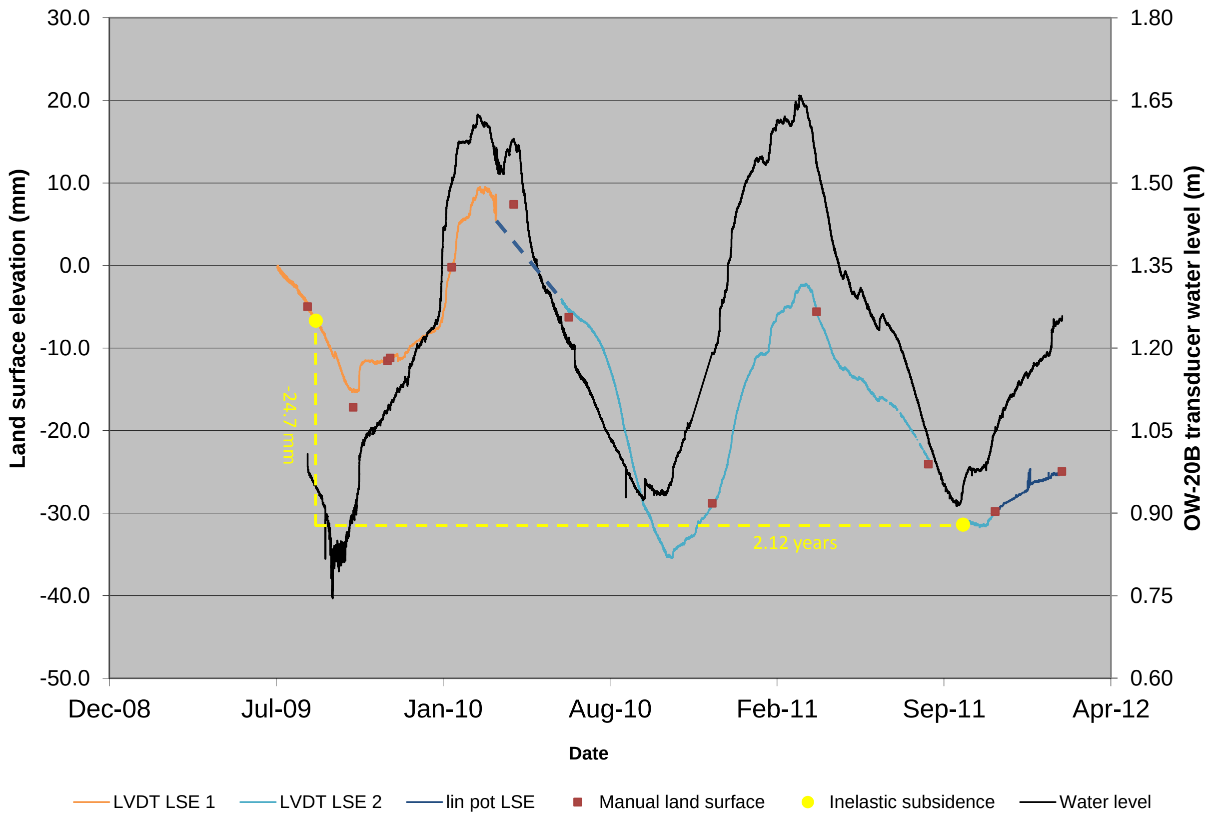

Figure 30. Land-surface elevation and groundwater levels at corn field extensometer. Yellow text and dotted lines represent elevation changes between dates and time where equal groundwater levels were measured.

3.1.3 Gas and Water Vapor Fluxes (UC Berkeley)

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 during 2009 - 2011. In a parallel study, UCBBL is measuring the same parameters on Sherman Island in a degraded peatland pasture infested with pepper weed. A standard set of eddy covariance instrumentation and associated suite of meteorological and soil

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[41] Stephens JC, Allen LH, Chen E. 1984. Organic soil subsidence. In: Holzer TL, editor. Man-induced land subsidence. Reviews in Engineering Geology, Vol. VI.Boulder (CO): Geological Society of America.

instrumentation was installed in the rice field during April 2009. UCBBL measured greenhouse gas fluxes, and associated environmental variables on a quasi-continuous basis.

Greenhouse gas fluxes were measured with the eddy covariance method[42]; 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.

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. Data have been submitted to the AmeriFlux and FLUXNET data archives for use by the wider scientific community.

The UCBBL compared rice greenhouse gas flux measurements with data from the Sherman pasture. Figure 31 shows the integrated CO_2 fluxes for the rice field for 2009 - 2011. The rice field data manifested pronounced year to year variability in net carbon uptake due to differences in planting and agronomic practices, weather and climate and the number of crops grown on this site. Because this organic soil was first planted with rice in 2009, labile carbon pools will likely vary with time as partially decomposed straw accumulates. If we exclude the carbon lost by exporting rice seed from the field, the data show that the system is a net carbon sink that sequestered 84 and 282 gC m^{-2} y^{-1}. Methane emissions, per gram carbon, range between 2 and 7 gC m^{-2} y^{-1}, and are less than 0.5% of gross photosynthesis (Figure 32). In contrast, measurements on a drained and degraded Sherman pasture showed a loss of 380 grams C m^{-2} y^{-1}.(Table 11).[43]

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[42] 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.

[43] Jaclyn A. Hatala*, Matteo Detto, Oliver Sonnentag, Steven J. Deverel, Joseph Verfaillie, Dennis D. Baldocchi, 2012, Greenhouse gas (CO2, CH4, H2O) fluxes from drained and flooded agricultural peatlands in the Sacramento-San Joaquin Delta, Agriculture, Ecosystems and Environment , 150,1-18.

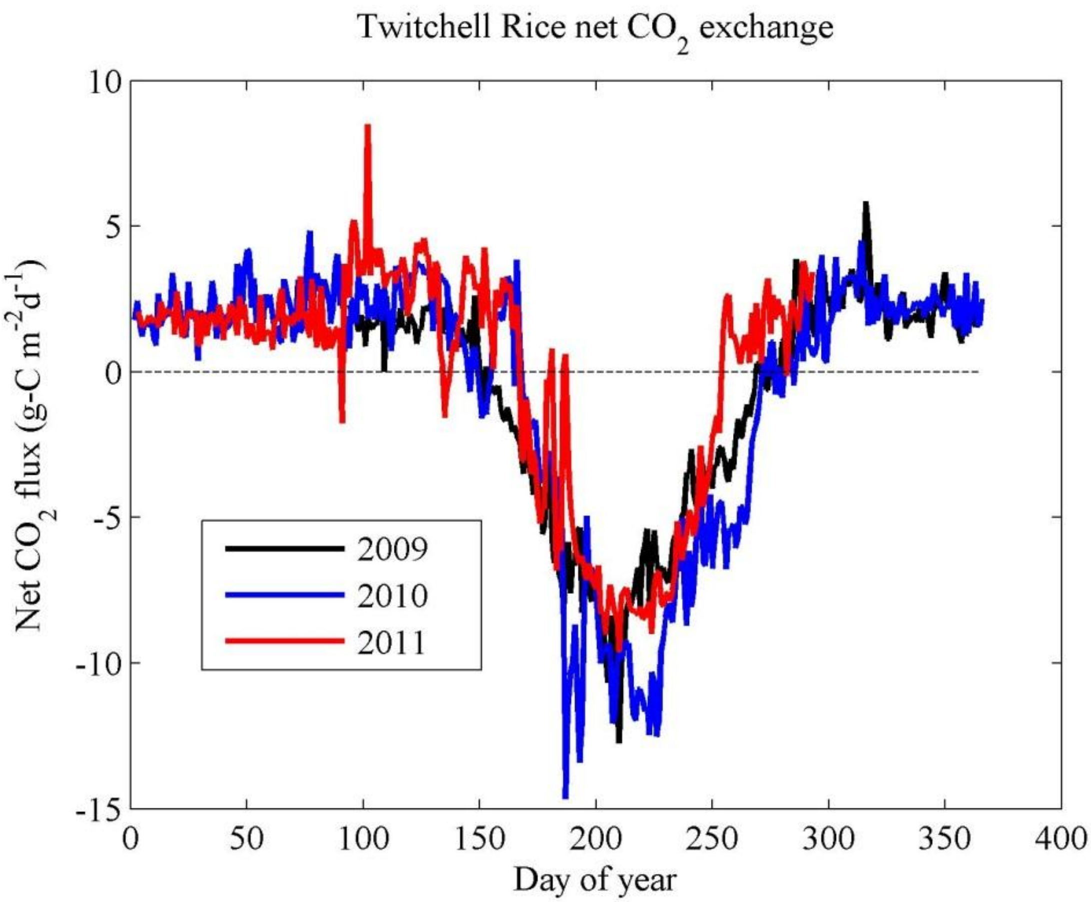

Figure 31. Seasonal change in daily integrated CO_2 flux densities over the rice field on Twitchell Island and over a degraded peat land pasture on Sherman Island.

Table 11. The annual sums of the H_2O, partitioned CO_2, and CH_4 fluxes (with the bootstrapped 95% confidence intervals for the gap-filling procedures in parentheses). Positive values indicate sources to the atmosphere, and negative values are sinks from the atmosphere. At the grazed degraded peatland, the FMA CH_4 sensor did not run for the second half of the 2010-2011 time period, so we considered it imprudent to calculate the grazed degraded peatland CH_4 budget for this year.

Site	Year	H_2O (mm y^{-1})	NEE (g-C $m^{-2}y^{-1}$)	Reco (g-C $m^{-2}y^{-1}$)	Peco (g-C $m^{-2}y^{-1}$)	CH_4 (g-C $m^{-2}y^{-1}$)	Total CO_2-equivalent (g-C m^{-2} y^{-1})
Grazed pasture	2009-2010	614 (602-627)	299 (222-373)	1493 (1418-1582)	-1182 -(1231-1137)	3.3 (2.8-3.9)	382 (293-471)
	2010-2011	757 (741-772)	174 (113-233)	1765 (1691-1850)	-1557 -(1604-1506)	N/A	N/A
Rice paddy	2009-2010	1207 (1178-1234)	-84 -(118-43)	1176 (1145-1209)	-1258 -(1290-1227)	2.5 (2.1-2.9)	-22 -63-29
	2010-2011	1111 (1086-1138)	-283 -(344-226)	1350 (1297-1395)	-1577 -(1630-1525)	6.6 (6.1-7.0)	-119 -(192-52)

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. Figure 33 shows the evaporation for the rice field. Based on ET measurements described above, rice water consumption is about 3.4 feet during the growing season greater than the 2 feet[44] required by corn in the delta. 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.

[44] G. J. Hoffman , E. V. Maas , T. L. Prichard , 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.

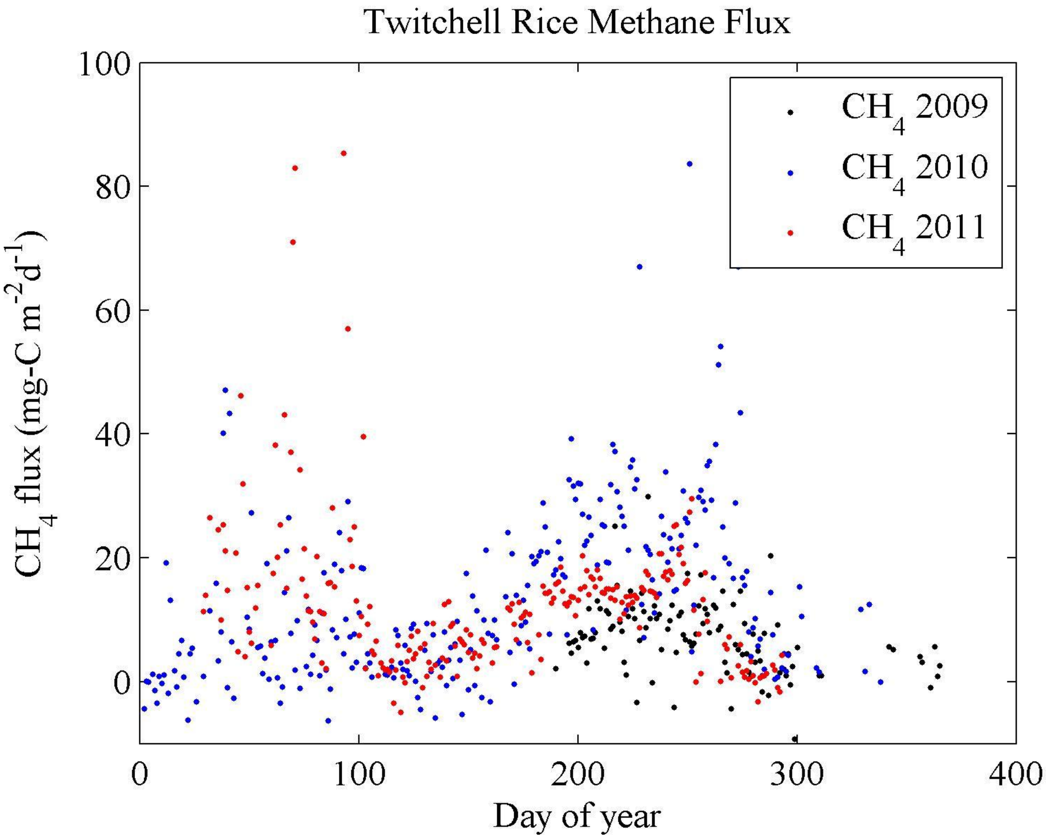

Figure 32. Methane fluxes for the Twitchell Island rice field 1.

Using the partitioned annual CO_2 budgets calculated in this analysis along with soil carbon content and bulk density, it is possible to approximate soil subsidence rates due to microbial oxidation at each of these sites. We can use the following formula to approximate soil subsidence from Deverel and Rojstaczer[45] due to soil oxidation (carbon loss) at each site:

$$subsidence = \frac{NBP}{\chi_C \rho_b}$$

where subsidence is calculated in meters, χ_C is the carbon fraction of the soil, and P_b is the bulk density in g cm^{-3}. NBP is net biome productivity in g-carbon $m^{-2}yr^{-1}$. In the grazed degraded peatland, NBP is equal to the sum of net ecosystem exchange (NEE) and the methane flux, and at the rice paddy is equal to the carbon in harvested grain subtracted from the sum of NEE, methane flux, and the carbon in seeds.

[45] 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.

If we assume that the grazed degraded peatland ecosystem restoration originates from the entire unsaturated thickness and use the average bulk density of 1.02 g m^{-3} and 0.11 for average χ_C, we calculate subsidence of 2.6 mm during 2009-2010 and 1.5 mm during 2010-2011. The estimated rates of subsidence in the degraded peatland are slightly lower than 3.2 mm yr^{-1} reported at a different site on Sherman Island by Deverel and Rojstaczer[46] with χ_C of 0.16. The differences between these rates are likely due to the lower χ_C and shallower water table at the degraded pasture relative to the site where subsidence was measured by Deverel and Rojstczer, which has an average water table of 1.2 m. Stephens and others[47] demonstrated that subsidence rates in Florida peat soils where the depth to groundwater of 1.2 m were about 2-fold larger than rates in soils where the depth to groundwater was 0.6 m. The rates of subsidence at the drained degraded peatland in this study were also lower than rates measured on Sherman Island by Deverel and Leighton (2010) of 5-20 mm yr^{-1} of subsidence from 1988-2006 at power pole foundations. The groundwater table was maintained deeper at these sites than the degraded pasture site in this study.

At the rice paddy, assuming that ecosystem respiration originates above 45 cm and using the average bulk density for this layer of 0.61 g cm^{-3} and χ_C of 0.23, we estimated that the rice paddy subsided 1.0 mm during 2009 – 2010 and 1.4mm during 2010-2011. While the rice paddy acts as a net carbon sink from an atmospheric perspective, it still acts as a net carbon source from a subsidence perspective due to the loss of carbon through harvest. If we do not account for the loss of grain through harvest in the NBP calculation (approximating the flooded rice paddy as a non-harvested ecosystem like a wetland) we calculated rates of soil growth at 0.58 mm during 2009 - 2010 and 2.0 mm during 2010-2011. Although these data were collected only a small period of time after land-use conversion, they do indicate that after two years, subsidence at the rice paddy is less than the drained and grazed degraded peatland and the corn field described above.

It is useful to compare the calculated subsidence with rates from soils with similar organic carbon content with additional agricultural management practices representative of the delta. Since subsidence rates are correlated with soil organic carbon content (Rojstaczer and Deverel, 1995; Deverel and Leighton, 2010), larger subsidence rates than estimated for the degraded peatland are expected for soils with larger organic carbon fractions and deeper depths to groundwater. Indeed, the degraded peatland pasture is atypical as most of the Delta is farmed to corn where groundwater levels are maintained and 1 to 1.2 m below land surface. In the Twitchell corn field on Twitchell Island, an extensometer similar to the one described in Deverel and Rojstaczer operated since 2009 in soil with 0.15 carbon content . We estimated 24.7 mm of inelastic subsidence during a 2.12-year period from 8/22/09 to 10/6/11 when groundwater levels were equal. This corresponds to an annual rate of subsidence of

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[46]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.
[47] Stephens JC, Allen LH, Chen E. 1984. Organic soil subsidence. In: Holzer TL, editor. Man-induced land subsidence. Reviews in Engineering Geology, Vol. VI.Boulder (CO): Geological Society of America.

about 12 mm (0.46 in). On Bacon Island, Deverel and Leighton (2010) reported 22 mm yr^{-1} of subsidence from 1978 to 2006 for an average soil organic carbon content of 0.2 and water table depth of 1.2 m. In light of these data, rice cultivation represents a subsidence reduction of over 87% and substantial benefit for subsidence mitigation relative to other current agricultural management practices.

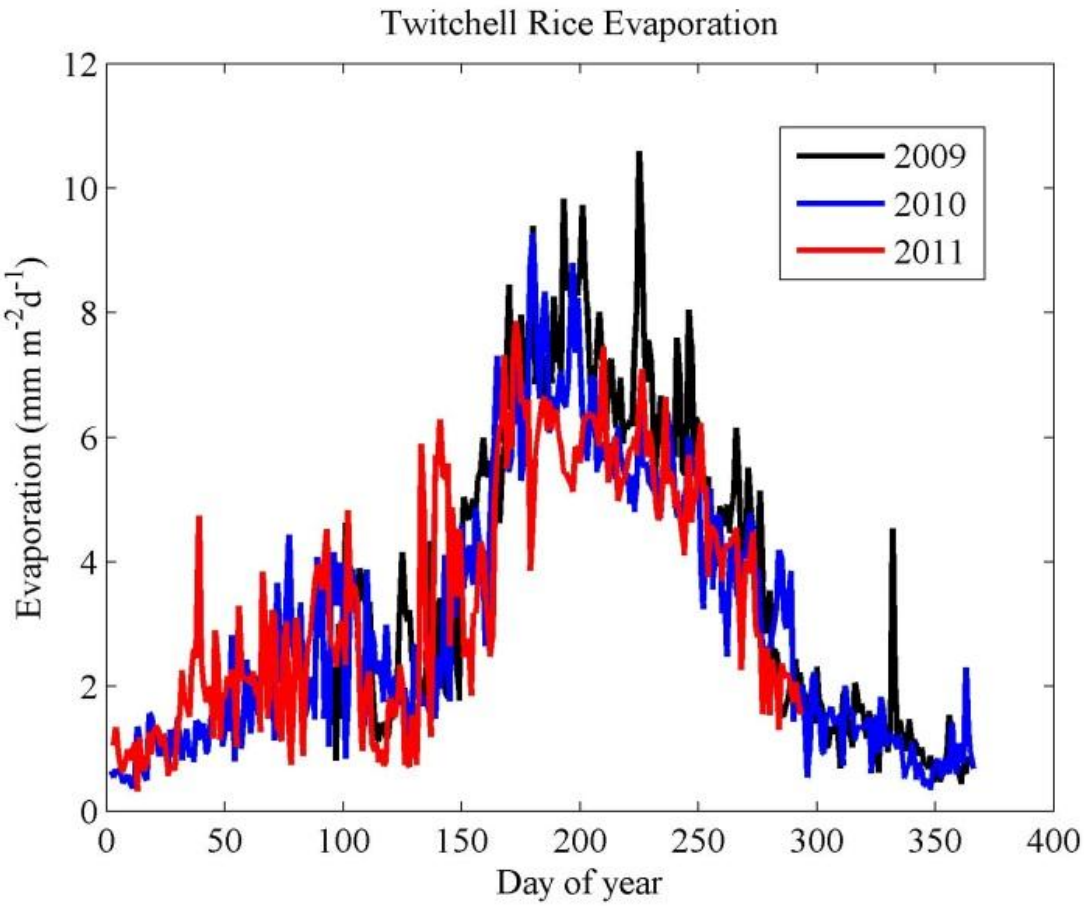

Figure 33. Evaporation in the Twitchell rice field 1.

3.1.4 Soil Carbon and Nitrogen (UC Davis)

University of California Davis (UCD) personnel under the direction of Professor Will Horwath measured soil and plant inorganic nitrogen and carbon, grain yield and total biomass and carbon dioxide, methane and nitrous oxide fluxes using chambers. In rice field 1, above ground plant samples were harvested in randomly placed 0.25 m^2 quadrants. Plants were cut at the base, harvested, separated into vegetative and grain parts, weighed, grounded and analyzed for carbon and nitrogen on an elemental combustion analyzer. Root biomass was estimated from prior work in the rice variety experiment by multiplying the above ground biomass by the root to shoot ratio coefficient for the M-104 and M-206 cultivars. Root carbon content was estimated in the same way.

In the corn field, plant samples were collected at harvest for determination of total above ground biomass, grain yield and total carbon content by collecting plants in 1 m^2 above ground samples. Root biomass was estimated from literature values for corn based on a 0.2 root to shoot ratio that was found under high N availability[48].

In both fields, soil samples were collected for determination of gravimetric water content at every gas sampling except in the rice field when samples were collected during the drained period. At key points during the year, inorganic nitrogen content was determined in soil samples collected at 0-15 cm in rice field 1 and 0-15 and 15-30 cm in the corn field.

Figure 34 shows the mean daily precipitation measured at Twitchell Island during spring 2010 to fall 2011. In 2010, most of the rain was distributed between January-May and October-December while in 2011 the rain continued until late June and was fairly sparse during the fall. Figures 35 and 36 show the relation between groundwater level and measured soil gravimetric moisture content at 0-15 cm as measured and between cumulative precipitation and ground water level in the corn field. Groundwater level is correlated with soil surface moisture levels which were highest during the spring and lowest in the fall. Figure 37 shows the mean soil temperature at 5 cm below soil surface over the sampling period

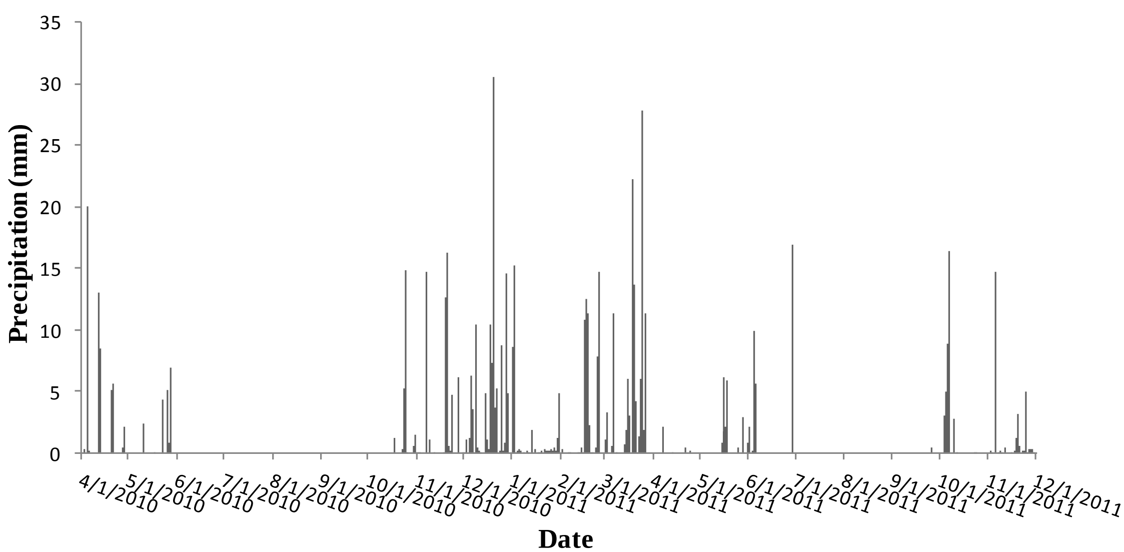

Figure 34. Precipitation at Twitchell Island during Spring 2010-Fall 2011 measured at a CIMIS station (station 140).

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[48] Amos, B. and Walters, D.T. 2006. Maize root biomass and net rhizodeposited carbon: an analysis of the literature. *Soil Science Society of America Journal* 70: 1489-1503; Bonifas, K.D., Walters, D.T., Cassman, K.G., Lindquist, J.L. (2005). Nitrogen supply affects root:shoot ratio in corn and velvetleaf (*Abutilon theopharasti*). *Weed Science* 53(5): 670-675.

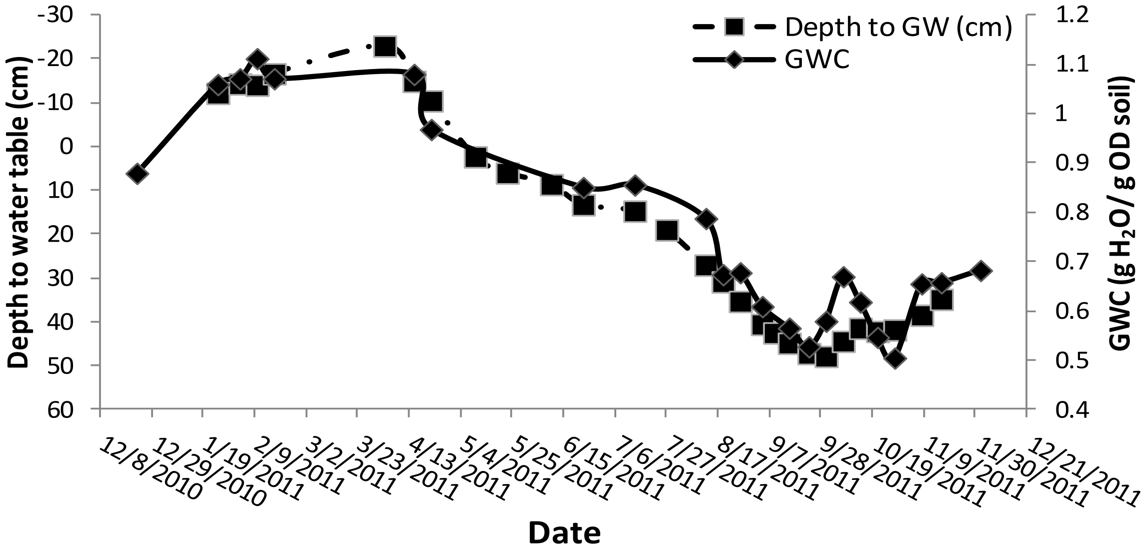

Figure 35. Water table depth (from soil surface) and soil gravimetric water content (GWC) at 0-15 cm soil depth in field 2 (corn) around monitoring well 20 during fall 2010-fall 2011 sampling period. (Data for Depth to GW was obtained from Dr. Deverel at Hydro Focus). Data not presented for field 1 due to the fact that the field was flooded 9 months of the year. (OD- Oven dried soil).

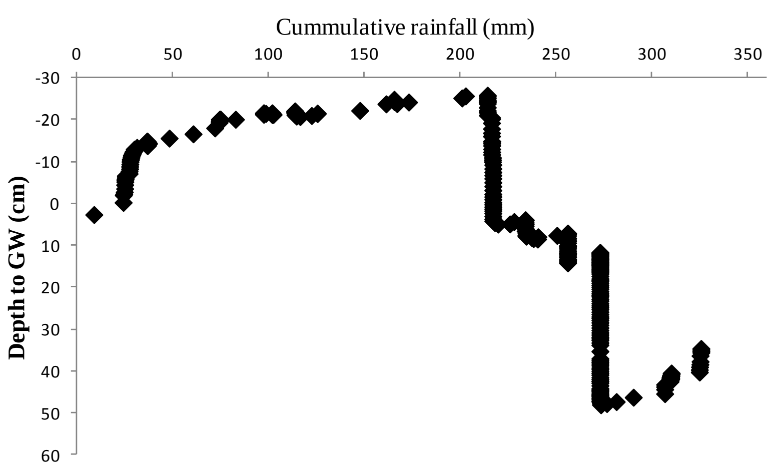

Figure 36. Cumulative rainfall vs. soil groundwater depth (negative values signify surface standing water) for January-December 2011.

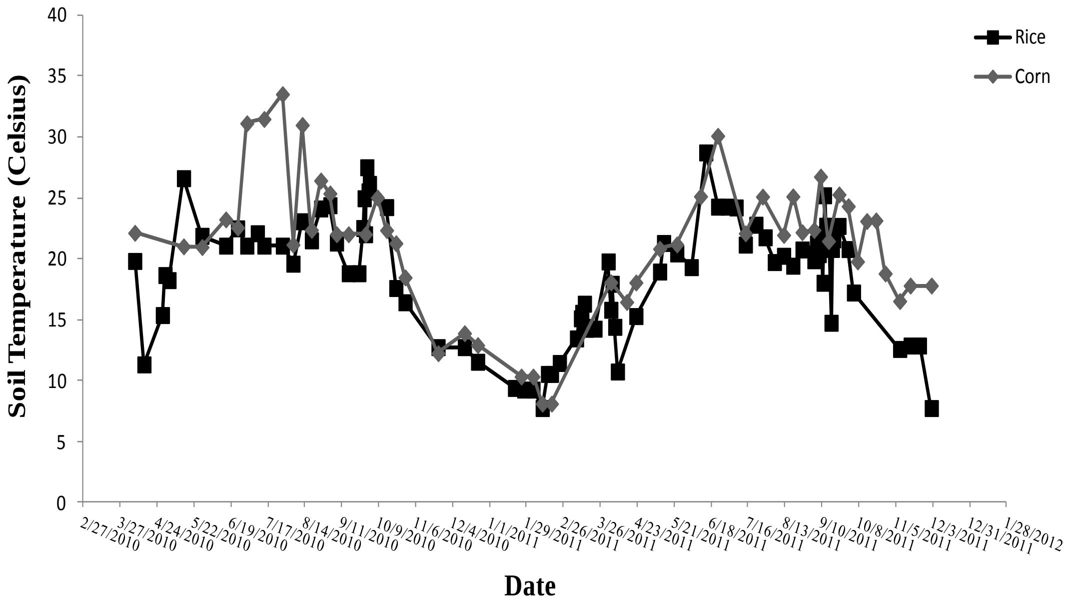

Figure 37. Soil temperature at 5 cm below soil surface for the corn and rice fields during the spring 2010-fall 2011 sampling period.

3.1.4.1 Harvest biomass and soil nitrogen and carbon

In 2010, rice and corn yielded roughly 6 and 9 metric tons of carbon per hectare (2.4 and 3.6 metric tons per acre), respectively (Figure 38). During 2011, both crops yielded about 5 metric tons carbon per hectare (2 metric tons per acre). However, in fall 2011 the above ground corn biomass was baled and removed for cattle feed and the amount of carbon returned to the soil was less than 1 metric ton/ha (0.4 metric ton/acre).

Soil nitrogen as ammonia and nitrate in the 0-15 cm soil depth were determined in both fields. High soil nitrate levels were measured in early spring; 21-97 and 48-68 kilograms nitrogen per hectare (19 to 87.2 pounds and 43 to 61 pounds nitrogen per acre) for rice and corn, respectively. Soil ammonia levels were highest in the rice field. In the corn field, soil ammonia was high during the late fall-winter and low in the summer. In the corn field, there was a net accumulation of over 100 kilograms nitrogen per hectare (90 pounds per acre) as ammonia during 2009 – 2011.

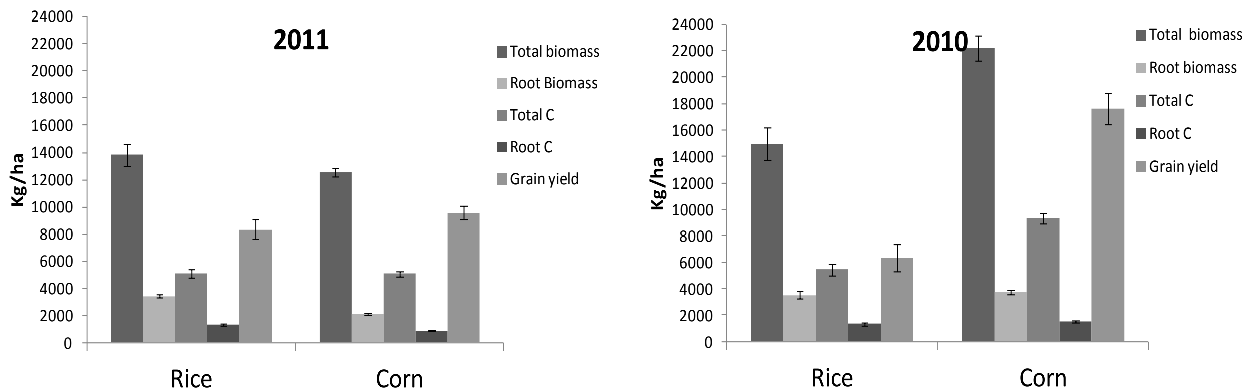

Figure 38. Estimated final biomass, grain yield at harvest, and C input from crop residue for field 1 (rice) and field 2 (corn) for 2010 and 2011.

3.1.4.2 Methane, nitrous oxide and carbon dioxide emissions

Overall, based on chamber measurements, corn and rice fields had comparable total CO_2 and N_2O emissions during 2010 and 2011 (Tables 12 and 13). The primary difference was when the rice field was flooded (Tables 12 and 13). During the periods the rice field was flooded, average CO_2 and N_2O emissions from the corn field were higher than the rice field. Most of the CO_2 in the corn field was emitted during the corn growing season in 2011. In the rice field CO2 was during the drain events and before and after flooding (spring and fall). In 2011, almost 60% of the CO_2 emission occurred during the corn growing season while about 15% occurred during the rice flooded season.

Nitrous oxide emissions were highest in the spring in both fields after winter flooding and fertilization. . In both fields, there was also a large N_2O emission event in the fall after the rice field was drained and after the first rain event, but it was much lower in magnitude than the spring event. Using chambers, total CH_4 emission from the rice field were about six times higher during the 2010 than the 2011 rice growing season (planting to harvest). This may be explained by the residue placement (incorporated vs. buried in 2010 and 2011, respectively) and the length of flooding period (108 vs. 82 days in 2010 and 2011, respectively). If the annual CH_4 emission are integrated from spring 2010-spring 2011, the total CH_4 emission was 520 kg CH_4-C/ha. This might be the scenario if crop residue is incorporated (data for winter 2012 drainage will be used to assess the two years total emissions given the different field conditions).

Table 12. Total CH_4, CO_2, and N_2O (kg/ha) emissions from the rice and corn fields for spring 2010-fall 2010.
The table is broken into different periods of the year to illustrate the temporal and field condition effect on the emissions and shows the flux mean, standard error and 95% lower and upper confidence intervals of the integrated flux of four sites in each field. Note that because the summary statistics was done on the transformed data, the SE and CI are not symmetric about the geometric mean and that the sum of the fluxes for each period may not add up to the calculated total.

					Kg/ha				
Field	**Date**	**Field condition**	**Variable**	**n**	**Mean (geometric)**	**lower SE**	**Upper SE**	**Lower 95% CI**	**Upper 95% CI**
Rice	4/7/10-11/23/10	total for period	CH_4	4	184.29	13.32	14.35	159.10	213.47
			CO_2	4	6609.95	377.56	400.43	5890.26	7417.58
			N_2O	4	13.10	3.36	4.52	7.33	23.41
	4/7/10-6/8/10	field operation and rice planting	CH_4	4	0.37	0.14	0.23	0.14	0.96
			CO_2	4	2324.49	144.95	154.59	2048.91	2637.14
			N_2O	4	9.78	2.63	3.60	5.29	18.09
	6/8/10-9/24/10	Rice-flooded	CH_4	4	137.09	7.08	7.47	123.55	152.11
			CO_2	4	1243.34	90.20	97.25	1072.72	1441.10
			N_2O	4	0.41	0.20	0.37	0.12	1.46
	9/24/10-11/23/10	Rice fall drain to winter flood	CH_4	4	48.49	8.57	10.41	33.12	71.00
			CO_2	4	3621.53	168.55	176.78	3298.55	3976.12
			N_2O	4	2.13	0.89	1.52	0.74	6.13
Corn	4/7/10-11/23/10	total for period	CH_4	4	0.48	0.14	0.20	0.24	0.94
			CO_2	4	7446.64	546.84	590.18	6412.68	8647.33
			N_2O	4	18.87	2.40	2.75	14.45	24.65
	4/7/10-6/8/10	Spring fallow-field operations	CH_4	4	0.39	0.12	0.18	0.19	0.82
			CO_2	4	1939.23	146.23	158.16	1663.00	2261.34
			N_2O	4	16.28	2.30	2.67	12.09	21.94
	6/8/10-11/23/10	Corn planted	CH_4	4	0.06	0.02	0.03	0.03	0.12
			CO_2	4	5520.27	426.75	462.51	4714.92	6463.18
			N_2O	4	2.40	0.27	0.30	1.90	3.03

Table 13. Total CH_4, CO_2, and N_2O (kg/ha) emissions from the rice and corn fields for fall 2010- fall 2011.
The table is broken into different periods of the year to illustrate the temporal and field condition effect on the emissions and shows the flux mean, standard error and 95% lower and upper confidence intervals of the integrated flux of six sites in each field. Note that because the summary statistics was done on the transformed data, the SE and CI are not symmetric about the geometric mean and that the sum of the fluxes for each period does not add up to the calculated total.

Kg/ha

Field	Dates	Field condition	Variable	n	Mean (geometric)	Lower SE	Upper SE	Lower 95% CI	Upper 95% CI
Rice	11/24/10-11/23/11	Year total	CH_4	6	411.73	71.18	86.05	283.83	597.26
			CO_2	6	11622.40	1095.87	1209.96	9571.86	14112.22
			N_2O	6	21.26	1.92	2.12	17.65	25.60
	11-24-11-2/10/11	Winter fallow-field flooded	CH_4	6	67.21	23.99	37.31	28.29	159.69
			CO_2	6	509.20	72.96	85.17	376.05	689.49
			N_2O	6	0.04	0.03	0.08	0.01	0.36
	2/10/11-4/8/11	Winter drainage	CH_4	6	268.71	42.12	49.95	192.39	375.32
			CO_2	6	1451.47	192.36	221.75	1098.47	1917.91
			N_2O	6	2.45	1.17	2.23	0.69	8.72
	4/8/11-6/14/11	field operation and rice planting field not flooded	CH_4	6	1.04	0.31	0.44	0.52	2.07
			CO_2	6	2378.04	195.34	212.83	2010.29	2813.07
			N_2O	6	11.58	1.17	1.30	9.41	14.26
	6/14/11-9/4/11	Rice- field flooded	CH_4	6	18.80	6.50	9.93	8.18	43.17
			CO_2	6	1665.10	213.74	245.22	1272.03	2179.64
			N_2O	6	0.27	0.06	0.08	0.16	0.44
	9/4/11-9/23/11	Rice fall drain to harvest	CH_4	6	8.09	2.26	3.14	4.25	15.39
			CO_2	6	2446.57	196.05	213.12	2077.12	2881.73
			N_2O	6	0.83	0.19	0.24	0.51	1.36
	9/23/11-11/23/11	Harvest to winter flood	CH_4	6	0.78	0.43	0.95	0.16	3.72
			CO_2	6	2949.77	502.57	605.78	2045.49	4253.80
			N_2O	6	4.06	0.49	0.56	3.15	5.24
Corn	11/24/10-11/16/11	Year total	CH_4	6	9582.09				
			CO_2	6	19.89	325.15	336.57	8955.19	10252.87
			N_2O	6		3.31	3.98	13.91	28.43
	11/24/2010-4/3/11	Winter-spring fallow	CH_4	6	1509.74				
			CO_2	6	4.37	133.89	146.92	1258.51	1811.12
			N_2O	6		0.69	0.82	3.12	6.12
	4/3/2011-6/23/11	Spring fallow and Field operation	CH_4	6	2370.36				
			CO_2	6		282.02	320.11	1849.23	3038.36
			N_2O	6	12.60	2.65	3.36	7.92	20.02
	6/23/2011-11/23/2011	Corn planted	CH_4	6					
			CO_2	6	5625.38	424.27	458.88	4823.96	6559.94
			N_2O	6	1.97	0.25	0.28	1.52	2.57

3.1.5 Agronomy

3.1.5.1 Variety Trials

Poor stand establishment, delayed harvest due to direct/dry seeding, and cold temperature induced sterility or “blanking” can affect rice productivity in the western 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. In addition we evaluated the potential of wet seeding rice compared with drill seeding. Wet seeding is the common establishment practice in mineral soils in California and it reduces time to maturity.

The varieties Calmochi-101, S-102, M-104, and M-206 were drill-seeded to a depth of 3.8 cm in one acre plots in Field 3 (Figure 1). Plots were replicated three times. In the small plot test, 12 advanced lines and 6 commercial varieties (including the four tested in large plots) were drill seeded on May 5th, with a small plot research drill seeder in 1.5 x 9.1 m plots. All plots were harvested with a SWECO small plot research combine. In the large plots, a 7.25 x 50 foot swath was harvested from the middle of the plot. In the small plots, alley ways were cut across the ends of the plots prior to harvest and the plot length was measured. The entire plot was subsequently harvested. 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 test plot

A third trial, replicated four times, evaluated establishment method: wet seeding versus dry seeding. Drill seeding is the predominant establishment practice in the delta. Wet seeding, which is the main practice in the Sacramento Valley, would increase the amount of time the field is flooded by about 1 month and may reduce the time to development. In 2010, these practices were evaluated on 1 acre plots using the variety M-104. The drill seeded trial was planted on May 4th and the wet seeded trial on May 5th. In 2011, these practices also were evaluated on 1 acre plots using the variety M-104. The trial was planted on May 9th.

The 2010 climate was unusual with cooler-than-usual growing conditions and a wet spring which delayed planting. Harvest was also delayed until November 6th due to cool weather. For comparison, harvest occurred in October 27th in 2009. The 2011 climate was also unusual with cooler-than-usual growing conditions and a wet spring. This delayed planting to May 9th. In contrast, 2009 planting occurred during April 27th to 29th.

Table 14 shows the results of the large plot test of commercial varieties for 2009, 2010 and 2011. During 2011, yields among varieties were not significantly different; although

S102 and M104 yielded about 1000 lb/ac more than M206 and CM101. Calmochi-101 is well known as the most cold tolerant of commercial California varieties and has become the standard for comparison with other varieties and advanced lines. In 2009 and 2010 it had the highest yields (Table 15). Overall, 2011 yields in the large plot variety trial were higher than previous years. 2011 yields averaged 8,800 lb/ac compared to 6,400 lb/ac in 2010 and 6,900 lb/ac in 2009. Days to 50% heading were the lowest for M104 and highest for CM101 (Table 14). Time to heading varied across years and variety (Table 15).

Table 14. 2011 Twitchell Island very early large plot variety trial.

Variety	Grain Type	Grain Yield at 14% Moisture lbs/acre		Grain Moisture at Harvest (%)		Days to 50% Heading		Plant Height (in)	
S102	S	9310	(1)	15.6	(4)	107	(2)	31	(2)
M104	M	9200	(2)	22.5	(2)	105	(1)	31	(2)
M206	M	8380	(3)	24.7	(1)	112	(3)	32	(4)
CM101	S	8320	(4)	17.2	(3)	117	(4)	31	(1)
MEAN		8800		20		110		31	
CV		5.8		9.3		1.3		4	
LSD (.05)		n.s.		3.7		3		n.s.	
S = short; M = medium; L = long.									
Numbers in parentheses indicate relative rank in column.									
No lodging.									

Table 15. Summary of large plot variety trials from 2009-2010. Numbers in bold show earliest variety or highest yielding for that year.

	Days to 50% heading				Yield (lb/ac)		
Variety	**2009**	**2010**	**2011**		**2009**	**2010**	**2011**
CM-101	**110 a**	109 a	117 c		**9890 a**	**7580 a**	8320 a
S-102	X	**108 a**	107 a		X	6970 a	**9310 a**
M-104	111 a	116 b	**105 a**		6440 c	6490 a	9200 a
M-206	121 b	125 c	112 b		7450 b	4467 b	8380 a
M-202	125 c	X	X		3870 d	X	X

In 2011, the commercial varieties in the small plot tests were ranked differently to the large plot test with M104 ranking at the top followed by M-206, S102 and CM101 (Table 16). In this trial, CM101 had significantly lower yields than M104. Several advanced line cultivars (medium grain) ranked highest in yield thus indicating the potential for medium grain Calrose types to yield well in this environment. In the cold environment at Twitchell Island, the average time to 50% heading for these very early varieties was 119 days after planting, roughly 10 days later than the average days to heading for intermediate to late maturing varieties in Sacramento Valley trials.

During 2010, 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 S-102, M-104 and M-206. The other two commercial varieties, M-202 and L-206 were the lowest of all varieties tested. In the small plot test, there were no significant differences between the top three commercial varieties. However, M-206 yields were significantly lower than the top three ranking commercial varieties. One advanced line cultivar (medium grain) ranked highest in yield. This variety (05Y471E) also had high yields in 2009. During 2009, 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 at Twitchell Island, the average time to 50% heading for these very early varieties was 118 days after planting (in 2009 it was 115), fully 10 days later than the average days to heading for intermediate to late maturing varieties in Sacramento Valley trials.

Table 16. 2011 Twitchell Island very early small plot variety trial.

Variety	Grain Type	Grain Yield at 14% Moisture lbs/acre		Grain Moisture at Harvest (%)		Seedling Vigor (1-5)		Days to 50% Heading		Lodging (1-99)		Plant Height (in)	
06Y565	LR	9580	(1)	21.4	(15)	5	(1)	121	(10)	1	(1)	91	(16)
08Y3016	M	9470	(2)	25.8	(11)	5	(1)	115	(3)	1	(1)	86	(12)
08Y3076	M	9310	(3)	29.3	(5)	5	(1)	120	(9)	1	(1)	83	(7)
08Y3080	M	8970	(4)	28.1	(7)	5	(1)	118	(7)	1	(1)	87	(13)
M105	M	8710	(5)	28.1	(8)	5	(1)	116	(5)	1	(1)	88	(15)
M104	M	8680	(6)	26.6	(9)	5	(1)	113	(2)	1	(1)	83	(9)
06Y513	L	8620	(7)	22.3	(13)	5	(1)	122	(12)	1	(1)	81	(4)
07Y843	M	8430	(8)	30.6	(4)	5	(1)	117	(6)	1	(1)	85	(10)
04Y177	SPQ	8340	(9)	23.5	(12)	5	(1)	116	(4)	1	(1)	74	(2)
M206	M	8190	(10)	30.9	(3)	5	(1)	121	(11)	1	(1)	87	(14)
L206	L	7890	(11)	22.2	(14)	5	(1)	119	(8)	1	(1)	69	(1)
S102	S	7210	(12)	17.9	(16)	5	(1)	108	(1)	1	(1)	83	(7)
CM101	S	7040	(13)	28.2	(6)	5	(1)	124	(15)	1	(1)	82	(5)
09Y3024	M	6900	(14)	31.6	(2)	5	(1)	123	(14)	1	(1)	82	(5)
CH201	SPQ	6300	(15)	26.4	(10)	5	(1)	123	(13)	1	(1)	76	(3)
M202	M	5810	(16)	31.7	(1)	5	(1)	125	(16)	1	(1)	85	(11)
MEAN		8090		26.5		5		119		1		82	
CV		11.1		5				2				5	
LSD (.05)		1270		1.9				3				6	

S = short; M = medium; L = long; LR = leaf rust resistant.
Subjective rating of 1-5 where 1 = poor and 5 = excellent seedling emergence.
Subjective rating of 1-99 where 1 = none and 99 = completely lodged.
Numbers in parentheses indicate relative rank in column.

3.1.5.2 Wet and Dry Seeding

During 2010, a comparison of planting method showed that higher yields were obtained in water-seeded (8213 lb/ac) compared with drill seeded (5916 lb/ac) plots. However, the time to heading was 5 days longer. This delay in maturity for wet seeded rice is contrary to observations in other parts of California and in the southern United States where wet seeding usually increases the rate of crop development by 5 to 10 days. This was the first time wet seeding has been tested in this area and on these types of soils and some problems were encountered, which may explain the delay in crop development. Usually in wet seeded rice the pre-germinated rice seed is broadcast into standing water and the seed is able to establish in the flood water. However in 2010, 10 days after wet seeding there were no rice seedling visible so the water from the plots was drained and re-flooded once the seedlings had emerged from the soil. This probably delayed crop development.

During 2011, another attempt was made to wet seed rice according to traditional California methods. UC Davis researchers were able to apply aqua-N as the N source and the field was rolled with a V-groove roller following N application. When the seed was applied in standing water, the seed fell into the grooves as expected. However the soil covered the seeds which necessitated drainage of water from the field to allow germination. Thus both wet-seeded and dry-seeded fields were managed similarly.

Yields in these two treatments were similar to one another and averaged 9780 lb/ac (Table 17). Based on our results from both 2010 and 2011 wet seeding does not appear to be a viable option, at least where the soil has been tilled. It may work in a no-till system as the soil would be too firm to cover the seed after planting. This will be evaluated in a small trial in 2012.

Table 17. 2011 Twitchell Island rice establishment test.

Planting Method	Grain Type	Grain Yield at 14% Moisture lbs/acre		Grain Moisture at Harvest (%)		Days to 50% Heading		Plant Height (in)	
WS	M	9880	(1)	23.6	(2)	114	(1)	33	(1)
DS	M	9680	(2)	25.0	(1)	116	(2)	33	(2)
MEAN		9780		24.3		115		33	
CV		4.7		12.1		3.4		1.1	
LSD (.05)									
WS=wet seeded' DS = drill seeded S = short; M = medium; L = long.									
Numbers in parentheses indicate relative rank in column.									
No lodging.									

In general, the increased yields during three years is similar to the pattern observed with yield increases over the entire Twitchell Island rice area and is most likely due to increased experience growing rice in this environment. In 2011, yields in yield trials were generally in line with state wide averages – suggesting there is good potential to grow rice in this area. A key emerging agronomic challenge to growing rice on Twitchell Island and the western delta will be effective weed management. In addition, uniform establishment and good nitrogen fertility practices will be key to ensuring that weeds can be managed and that rice can be grown economically.

3.1.5.3 Nitrogen Trial

University of California, Davis personnel conducted an assessment of nitrogen fertilization levels on yields in Field 1 during 2011. Five treatments were applied in four replications: 0, 40, 80, and 120 160 kilograms of nitrogen per hectare (kg/ha) (0, 72, 108 and 144 pounds nitrogen per acre) before June 13th, immediately before flooding. In a sixth treatment also replicated 4 times, 120 kilograms of nitrogen per hectare was applied on May 13th to simulate early nitrogen application which was consistent with the grower's nitrogen fertilizer application. Soil nitrogen levels were measured on June 13th before permanent flooding. Grain yields were compared for the six treatments.

Figure 39 shows the soil mineral nitrogen levels in soil samples collected on June 13, 2011. The 0-nitrogen level treatment soil ammonia and nitrate levels were about 6 and 15.5 kg N/ha, respectively. For the 120-early treatment, nitrate and ammonia levels were substantially higher at 9.5 and 86.5 kg N/ha, respectively.

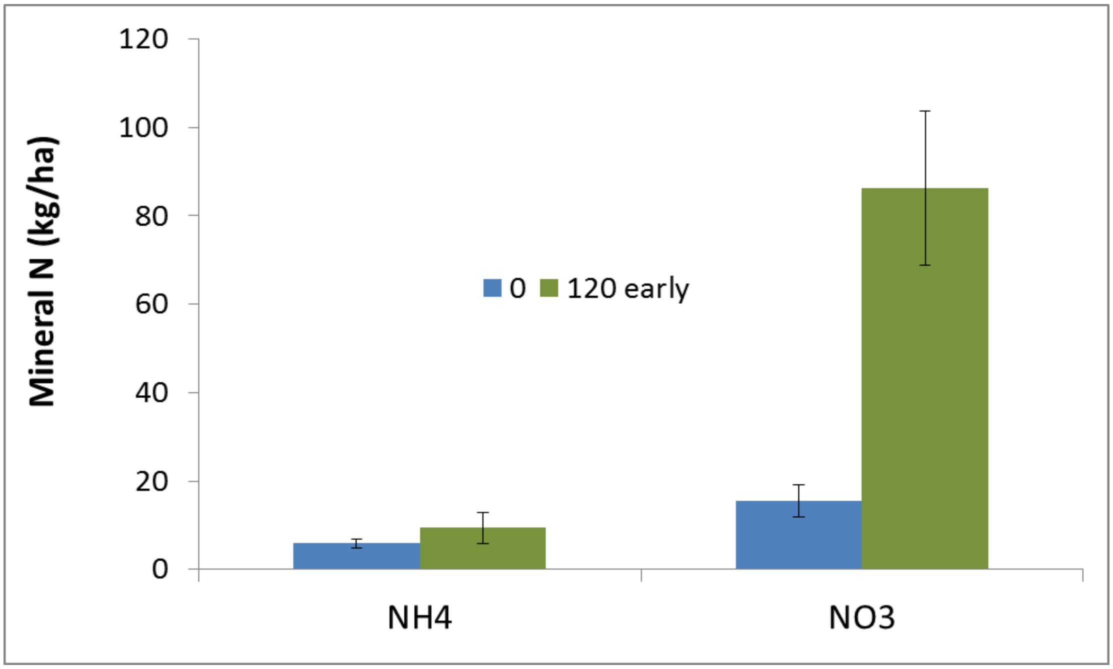

Figure 39. Mineral nitrogen in soil samples.

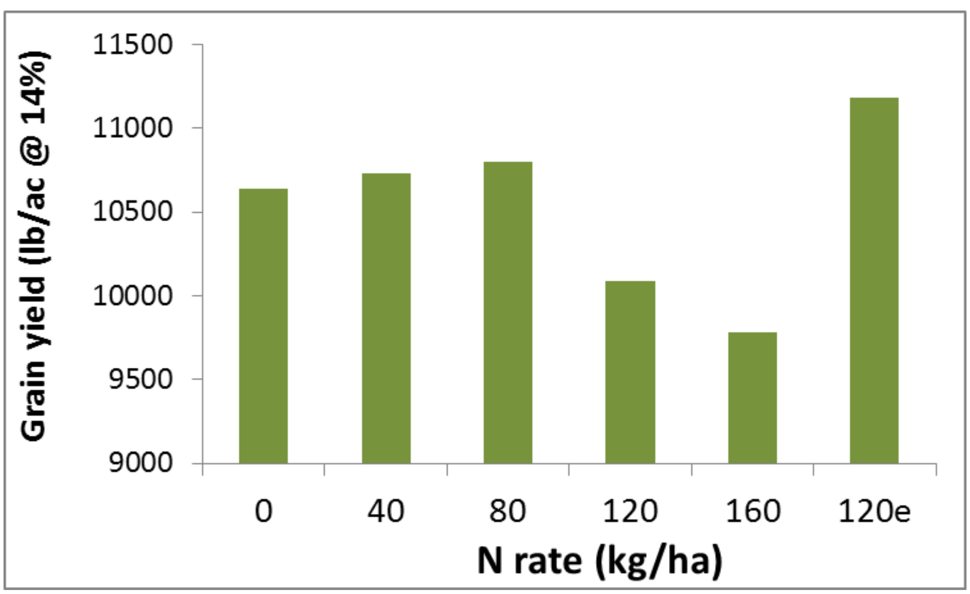

Figure 40. Grain yields for the nitrogen fertilizer treatment.

Figure 40 indicates that there was no significant yield response to N for any treatment and yields were very high for the 0-N treatment. Also, higher nitrogen levels delayed harvest. Results indicate that very little nitrogen is currently needed. To avoid nitrogen loss as nitrous oxide and leaching of nitrate, some nitrogen should be applied about one month after planting immediately before permanent flooding.

4.0 Key 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. 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. Starting in fall 2008, in cooperation with Reclamation District 1601 and DWR, representatives from UC Davis, 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. In 2010, rice was planted on 310 acres. During 2011, an additional 12 acres were planted in field 12 for a total of 322 acres. The following summarizes key conclusions.

- Drain flow from rice fields is recycled within the rice system. Flows from the rice system were highest during the fall and winter. Outflow from the rice fields also increased during the irrigation season, although water recycling resulted in relatively low rice system outflow.

- During 2009 - 2011, drain water levels were managed differently and pumping rates for rice water supply generally decreased. In 2009, the most seepage occurred because rice field water levels were high and ditch levels were low. In 2010, both rice field and ditch water levels were kept high and in 2011, both field and ditch water levels were kept low. This resulted in lower seepage losses and pumping rates.

- Maximum flows for rice and from the island occur during the winter.

- DOC concentrations in all rice drain samples were elevated relative to the San Joaquin River and the Twitchell Main Drain (TMD). DOC drain-water concentrations increased during periods of rice flooding. There was not a statistically significant difference among years for rice drain-water concentrations measured during 2009 and 2010. DOC concentrations in drain water were lowest in 2011.

- Consistent with previous studies, rice-field high drain-water DOC concentrations results from flushing of DOC generated during oxidation in shallow soils during drained periods.

- Isotope data indicate that partially evaporated pore water with high DOC concentrations present prior to rice cultivation is progressively flushed from the soils in the rice fields. Substantial flushing apparently occurred during 2009 and 2010.

- Flushing of high DOC and oxidized pore water present prior to rice cultivation during 2009 and 2010 is likely the cause of lower DOC, MeHg and dissolved oxygen concentrations, oxidation-reduction potential values and MeHg percentages measured in drain water during 2011.

- During 2011, rice field DOC drain-water loads measured during spring were comparable to dry period drain-water loads for the entire island and for individual drains for non-flooded crops. Winter and irrigation season drain-water loads during the growing season were generally comparable to wetland loads.

- Net dissolved organic carbon loads (exports minus import) for the rice system during the irrigation season for 2010 and 2011 varied substantially (see Figure 15). During the 2010 irrigation season, measured net loads were primarily negative and the inner quartile range was from and -1,000 to 200 grams per acre per day. In contrast during 2011, DOC net loads were consistently positive. This difference may be related to higher DOC concentrations in inflow water during 2010 as compared to 2011...

- Methyl mercury loads calculated from concentrations in unfiltered samples varied less than dissolved organic carbon loads (Figure 15). The inner quartile range for loads during the 2010 irrigation season varied more than during 2011; the inner quartile ranges were -30 to 18 and -3 to + 3 micrograms per acre per day for 2010 and 2011, respectively.

- Concentrations of MeHg in unfiltered drain water samples ranged from 0.1 to 13 nanograms per liter (ng/L) and were elevated in all rice drains relative to the nearby San Joaquin River water. The highest MeHg concentrations were measured in fields that were converted or in the process of conversion to rice. The lowest MeHg concentrations occurred shortly after field inundation from intentional flooding or periods of increased rainfall.

- Drain water in fields under the typical crop management in the delta (corn/oats) had significantly lower in MeHg concentrations than the fields than were converted to rice production. There was no significant difference in MeHg concentrations between the groups of fields planted to rice during 2009 and 2010 or between the three years between groups.

- Per acre MeHg loads from rice drains were two to three times greater than the corn/oats drains in 2009 and the island averages for both periods.

- Most drain water from rice was recycled back onto the rice fields during the irrigation season. Any water deficit was made up with pumping water from the Twitchell Main Drain. Therefore during the irrigation season the Twitchell rice system loads for DOC and MeHg are lower than the loads off of the fields but still tend to be above per acre loads for the entire island.

- For mosquito fish sampled during 2009 - 2011 data, total mercury concentrations were highest in rice drainage ditches TRD 10-1 and TRD 1-2. Concentrations at all sites which included sites in the main drain the rice field, exceeded the 0.03 mircograms/gram (wet weight) designated by the Central Valley Regional Water Quality Control Board mercury TMDL for protection of wildlife health. During 2009 - 2011, across all sites and dates, the geometric mean (± standard error) mercury concentration in mosquito fish was 0.074 ± 0.002 µg/g.

- 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 3.4 feet during the growing season and greater than the 2 feet required by corn.

- 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.

- Carbon dioxide flux data and corn extensometer data indicate that rice will greatly limit subsidence. The corn extensometer measured about 1.2 cm/year of inelastic subsidence whereas estimates of rice subsidence were about 0.1 cm/year.

- Overall, rice yields were low relative to the Sacramento Valley and delta rice growing areas but increased during 2009 - 2010. In 2009, the average yield was 25 hundred-weight per acre. In 2010, the average yield was about 43.5 hundred weight per acre. In 2011, the average yield was about 51 hundred weight per acre. Typical yields for the delta and Sacramento Valley range from 70 to 100 hundred-weight per acre.

- Yields in the rice variety trials were generally consistent with typical yields for the delta and Sacramento Valley suggesting that there is good potential to grow rice in the area. The emerging agronomic challenges to growing rice on Twitchell Island will be effective weed management.

- Results of the trials among commercial medium grain varieties demonstrated that Calmochi-101 consistently ranked at the top followed by S-102, M-104 and M-206. The other two commercial varieties, M-202 and L-206 were the lowest yielding of all varieties tested. In the small plot test, there were no significant differences between the top three commercial varieties. However, M-206 yields were significantly lower than the top three ranking commercial varieties. One advanced line cultivar (medium grain) ranked highest in yield and thus indicates the potential for medium grain Calrose types to yield at the level of Calmochi-101.

- Wet seeding does not appear to be a viable option for delta rice using current cultivation practices. However, it may work in a no-till situation.

- Nitrogen trial results showed no significant yield response for any level of nitrogen fertilization from 0 to 160 kilograms per acre. Also, grain yields for zero fertilizer were high at over 10,500 pounds per acre. Excess nitrogen fertilizer contributes to nitrous oxide emissions. To avoid nitrogen loss as nitrous oxide and leaching of nitrate, some nitrogen should be applied about one month after planting immediately before permanent flooding.

5.0 Indicated Best Management Practices

Based on data collection efforts during 2008 – 2011, the following best management practices are indicated for rice production the western delta.

- Rice will greatly reduce and likely stop subsidence relative to current cultural practices that require drained conditions.

- Excess loading of dissolved organic carbon and methyl mercury may result from conversion of large acreages to rice in the delta. To minimize loads of these constituents to delta surface water bodies, island strategies should be developed that promote recycling and reuse of island and rice field drainage water. These strategies will include use of rice drainage water for irrigation of other crops and wetlands, irrigation with water from other crops and recycling of rice drainage water.

- Maintenance of high water levels in rice drainage ditches will minimize seepage from rice fields and reduce water application needs.

- Drain water quality and flow monitoring will aid in managing on-island and off-island constituent loads.

- Concomitant with recycling and reuse is the need to assess and manage soil and irrigation-water salinity. Rice is a salt sensitive crop and the reported threshold for the soil saturation extract salinity for yield declines in rice is 3,000 μS/cm[49]. For continued rice production, salt leaching will be required where soil salinity approaches this value.

- Minimal nitrogen fertilizer is needed for high yields. To maximize nitrogen availability to the crop and minimize nitrous oxide emissions, a small amount of fertilizer should be applied about a month after planting immediately prior to flooding.

- Results presented here for Twitchell Island indicate less than 72 pounds nitrogen per acre are required and high yields were obtained with no addition of nitrogen. Soil nitrogen levels should be used to determine fertilizer requirements.

- For optimum yields, cold tolerant varieties such as Calmoche 101 should be planted to the extent possible.

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[49] Maas, E.W., 1990, Crop Salt Tolerance in Tanji, K.K. (ed.) Agricultural Salinity Assessment and Management, American Society of Civil Engineers, New York