Water Quality

Water is essential to agriculture. Without it, farmers could not grow crops or produce livestock. Fertilizers and crop protection chemicals are also essential to agriculture and their application needs to be carefully controlled to prevent contamination of water. People are becoming increasingly concerned about environmental issues and the safety of their water for drinking. Since some of the water used in rice irrigation passes through the field and is reused downstream, often for urban domestic purposes or for recreation, it is critical that rice growers and chemical applicators maintain the quality of drainage water. In the 1980s fish kills in the Sacramento River and off tastes in Sacramento drinking water (Fig. 1) due to pesticides in the waterways highlighted the importance of being good stewards of water resources. This chapter discusses current water quality regulations, what are the potential problems in regards to water quality for rice growers and how can we best manage rice systems to maintain high water quality standards.

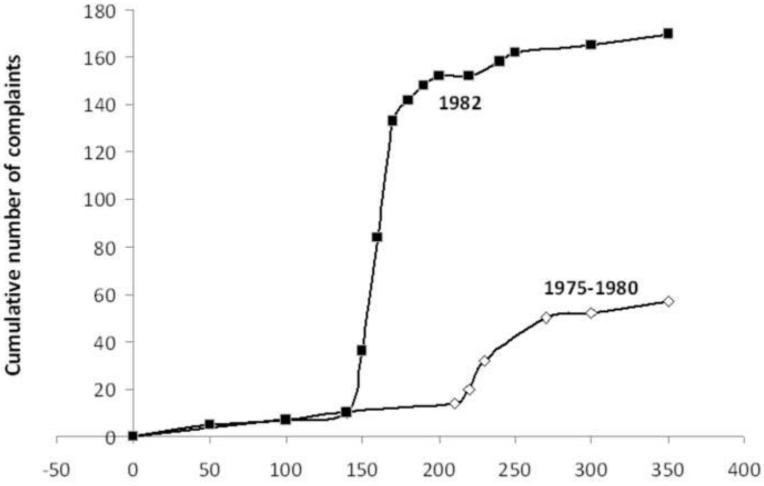

Figure 1. *Water taste complaints received by the City of Sacramento prior to (1975- 1980) and during the use of thiobencarb (1982).*

Water quality regulation in California's rice systems

The Clean Water Act (CWA) is the source for water quality regulation in California and the United States. In California, additional water code requirements, enacted by the Porter-Cologne Water Quality Control Act are found in California Water Code, Division 7. The California Water Code provides a broad scope in regulating waste or proposing to discharge waste within any region that could affect the quality of waters of the State. The term "waste" is a broad definition and the term "waters of the state" includes all surface water and ground water within the State. The California Water Code applies to point and non-point sources. Regulation occurs in several ways to dischargers: prohibition of discharge, waste discharge requirements (permit), or a waiver of waste discharge requirements.

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The California agricultural community received a waiver from a permit for discharging waste into waters of the State. The waiver expired on December 31, 2002. Since, 2003, all agriculture in California must comply with an agricultural discharge program referred to as the Ag Waiver. In 2008, the pro-gram was renamed the Irrigated Lands Regulatory Program (ILRP) because the word "waiver" implied that agriculture was exempt from regulation. Instead, agriculture is exempt from a permit as long as there is compliance with ILRP conditions to monitor pesticides and other constituents of concern (waste) discharged from the land into waters of the State. Current requirements allow for development of management plans when a certain number of exceedances occur. The California Rice Commission (CRC) manages the only commodity specific, general program under the waiver of waste discharge requirements (or ILRP program).

Constituents of concern

There are many constituents of concern listed in the ILRP as this program is for all irrigated lands. The constituents of concern for the rice industry are listed in Table 1. These constituents have been monitored by the CRC or during a two-year UC Davis study. While many of these constituents will be discussed in more detail later it is important to understand the effect of rice systems on these con- stituents. Natural waters do not contain pesticides and it is through the process of growing rice that pesticides are introduced into the water. Water does, however, contain carbon, nutrients and metals. Results from the UC Davis study found that water leaving rice fields (tailwater) had generally higher concentrations of dissolved organic carbon (DOC), total suspended solids (TSS), total disolved solids (TDS) and to a lesser extent ammonium and potassium (Fig. 2) throughout the year than the inlet water. Also, in the winter, phosphorus concentrations were higher in tail water than in the inlet water. This indicates that rice systems contribute to increases in these values.

Definitions

What is a "discharge"? A discharge would occur when any amount of wastewater that leaves your property enters surface waters of the State. The discharge does not have to be directly to surface water. For purposes of this program, it may first flow over a neighbor's property or through a toe drain along the edge of the field.

Who is a "discharger"? A discharger may include persons, individuals, corporation cities, special districts, farm owners, tenant farmers who release waste that could affect the quality of the water of the State.

What is "waste"? Waste is broadly defined in the California Water Code to include any and all waste substances that may include, but are not limited to soil, silt, sand, clay, rock, metals, salts, boron, selenium potassium, nitrogen, pes- ticides and fertilizers.

What are "waters of the State"? Waters of the State include any surface or groundwater with- in the boundaries of the Slate. Waters of the State include, for example natural streams, irri- gation ditches or canals, ponds, agriculturally- dominated waterways, and constructed agri- cultural drains.

Table 1. . *Constituents of concern monitored by the CRC or evaluated in a 2006/07 study.*

Constituent of Concern	*Water quality objective*	*Comment*
Herbicides		
Carfentrazone-ethyl (Shark)	ne*	
Clomazone (Cerano)	ne	
Cyhalofop-butyl (Clincher)	ne	
Fenoxaprop-p-ethyl (Whip)	ne	
Propanil (Stam)	ne	
Triclopyr TEA (Grandstand)	ne	
Thiobencarb (Bolero/Abolish)**	1.5 ug/L	Basin Plan performance goal under prohibition of discharge
Insecticides		
Diflubenzuron (Dimlin)	ne	
(s)-cypermethrin (Mustang)	ne	
Lambda cyhalothrin (Warrior)	ne	
Fungicides		
Azoxystrobin (Quadris)	ne	
Trifloxystrobin/ Propiconazole (Stratego)	ne	
Physical parameters		
pH	6.5-8.5	
Electrical conductivity (EC)	700 umhos/cm	CVRWQCB threshold
Dissolved oxygen (DO)	7 mg/L	Basin Plan water quality objective for lower Sacramento R.
Temperature	68^{o} F	Basin Plan water quality objective for lower Sacramento R.
Color	ne	
Turbidity	ne	
Total disolved solids (TDS)	ne	
Dissolved organic carbon (DOC)	3 mg/L	CALFED drinking water control program
Nutrients		
Total N	ne	
Nitrite-N	ne	
Nitrate-N	10 mg/L	EPA standard
Ammonia-N	25 mg/L	
Total phosphorus	ne	
Soluable phosphorus	ne	
Potassium	ne	
Metals		
Copper	10 ug/L	
Biological		
E. coli	235 CFU	

** ne=not established, ** City intakes have a thiobencarb maximum contamination level (MCL) of 70.0 ug/L (toxicity), and a secondary MCL of 1.0 ug/L (off taste), CVRWQCB=Central Valley Regional Water Quality Control Board*

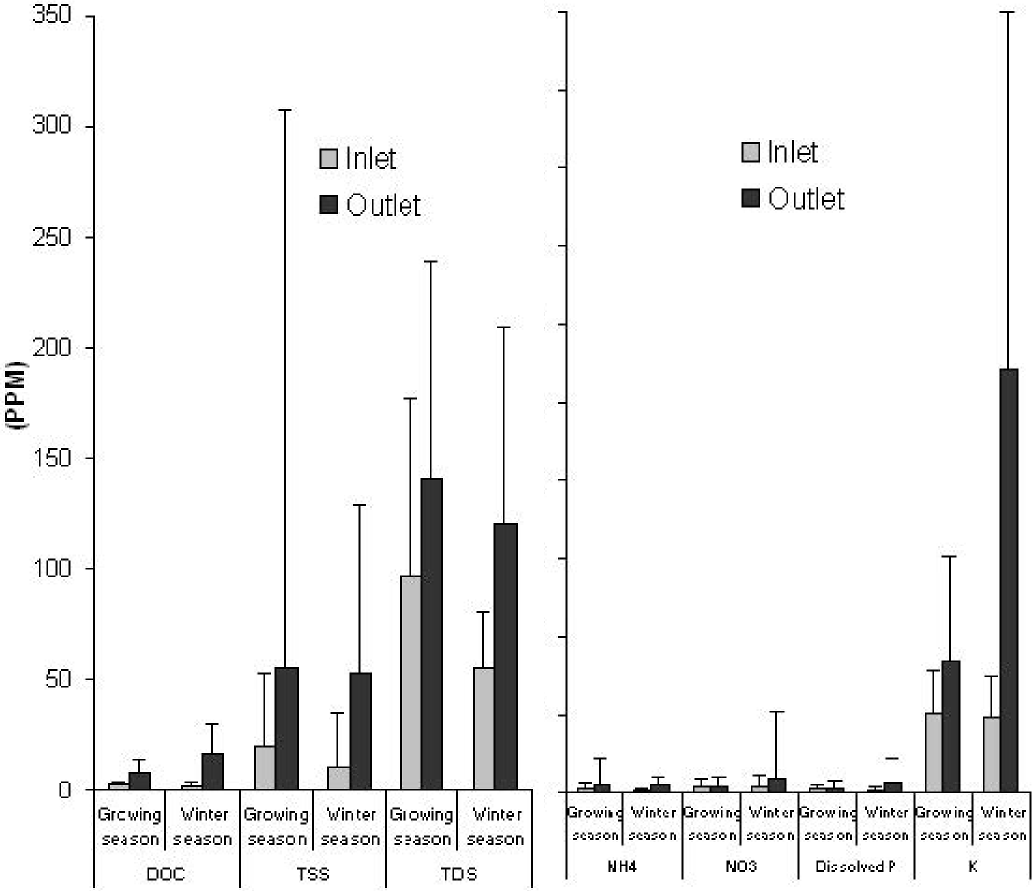

Figure 2. *Concentrations of dissolved organic carbon (DOC), total suspended solids (TSS), total dissolved solids (TDS), ammonium (NH4), nitrate (NO3), dissolved phosphate and potassium (K) from rice field water inlets and outlets averaged over two growing and winter seasons. Error bars are standard deviations of all of the fields and sampling events within that period.*

Pesticides

California rice growers receive regulations under a prohibition of discharge program, the Rice Pesticides Program (RPP). The RPP began in the late 1970's, early 1980's and was officially adopted into regulation under the Basin Plan in 1990. Under the RPP, rice growers must follow approved management practices and monitor specific pesticides to meet performance goals in agricultural drains. The five pesticides under the RPP include two herbicides thiobencarb, molinate (cancelled and no longer monitored after 2009), and three insecticides no longer monitored: carbofuran (cancelled and no longer monitored on rice), malathion and methyl parathion (little or no use on rice).

Monitoring for thiobencarb in 2008 found that there were 37 detections of thiobencarb in water from the main rice drains and the Sacramento River. However, only two of these samples had thiobencarb concentrations above the performance goal of 1.5 ug/L (1.5 ppb). Monitoring results at the city intakes show two detections at Wes Sacramento, and one detection at Sacramento with no exccedances of the secondary max- imum contaminant level (MCL) for off taste of 1.0 ug/L (1.0 ppb). During this same period there were only three detections of molinate and no exceedances (greater than 10 ppb).

Propanil is an important herbicide in the rice industry. It was reintroduced in the rice industry after being cancelled for drift issues in 1969. Propanil was never a consideration for the RPP because the product never caused any water quality impairments. The water board currently has concerns only because propanil is used a lot. The majority of loca- tions sampled by the CRC had no detectable levels of propanil; howev- er, it was detected during a one to two week period from the mid to end of June. This highlights the importance of all growers to adhere to the hold times for all pesticides as indicated on the label. This will be dis- cussed later.

Physical parameters

Dissolved oxygen (DO)

DO is the amount of gaseous oxygen (O_2) dis- solved in water. Oxygen diffuses into water from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. Adequate DO is necessary for good water quality as oxygen is a neces- sary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for fish and other aer- obic life forms.

Factors that contribute to low DO values are biological oxygen demand from the decomposition of organic matter. Low DO may also be caused by high levels of algae in the water (and the resulting diurnal oxygen depletion resulting from nighttime algae uptake), and/or flow of water that limits natural aeration. Warm water temperature can also contribute to low DO values. As temperatures increase oxygen solubility decreases. Due to the above factors (primarily temperature) low DO values were found in some of the major rice drains between June and September.

pH

The pH of water is a measure of the concentration of hydrogen ions. The pH determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients and heavy metals (i.e. lead, copper, cadmium). In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble. The water quality objective is to maintain water pH values between 6.5 and 8.5. Sampling the main rice drains in 2008 found no water samples outside of this range.

Electrical conductivity (EC)

EC estimates the amount of total dissolved salts, or the total amount of dissolved ions in the water. The salt content of water has a large impact on aquatic life and can have a negative impact on rice. The threshold cited by the CVRWQCB for reporting is 700 umhos/cm (NOTE: this value is for monitoring purposes only and should not be adopted as a salinity water quality objective). The 2008 sampling season yielded three samples above this critical level. These were all during storm events which occurred outside of the growing sea- son.

Total Suspended Solids (TSS)

Total suspended solids include all of the particulates suspended in water. In a two year UC Davis study TSS ranged from almost 0 to over 500 mg/L; however in most cases it was less than 100 mg/L (Fig. 3). High TSS is most likely the result of wind or storm events that stir up the water. Also, high TSS values are found when the flash boards are first removed and the high volume of water flowing out of the outlet churns up the soil around the outlet.

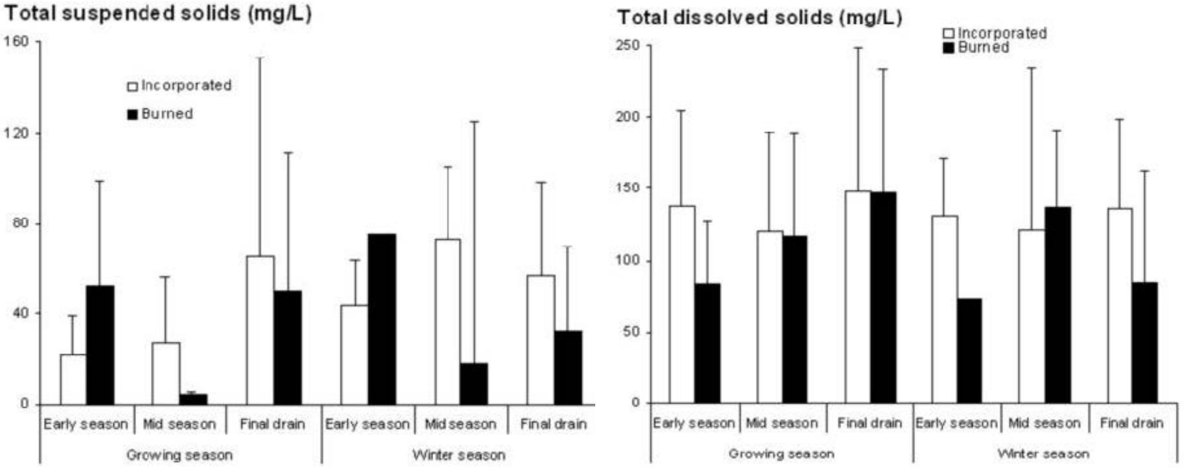

Figure 3. *Total suspended solids and total dissolved solids in water leaving rice fields. Data are averaged over two growing seasons.*

Total Dissolved Solids (TDS)

TDS is an expression for the combined content of all inorganic (minerals and salts) and organic substances in water. Although TDS is not generally considered a primary pollutant (e.g. it is not deemed to be associated with health effects), but it is rather used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of presence of a broad array of chemical contam- inants.The Sacramento River typically has TDS values less than 100 mg/L and agricultural watersheds are generally between 250 and 500 mg/L. A UC Davis study found only one water sample with a TDS greater than 500 mg/L. Most of the values were less than 200 mg/L(Fig. 3).

Dissolved organic carbon (DOC)

The amount of dissolved organic carbon (DOC) in water is often used as a non-specific indicator of water quality. Organic carbon is a precursor to the formation of harmful disin- fection byproducts (DBPs) in municipal water supplies when water is treated with chlorine. For example, trihalomethanes are one DBP that is considered to be a potential carcinogen. Source water with high DOC concentrations requires additional treatment steps to remove DOC and this increases the cost of treatment. Since the tap water of 22 million Californians originates in the Delta, DOC is an important public health concern. The CALFED Drinking Water Quality Program has the goal of achieving an average TOC concentration of 3 mg/L.

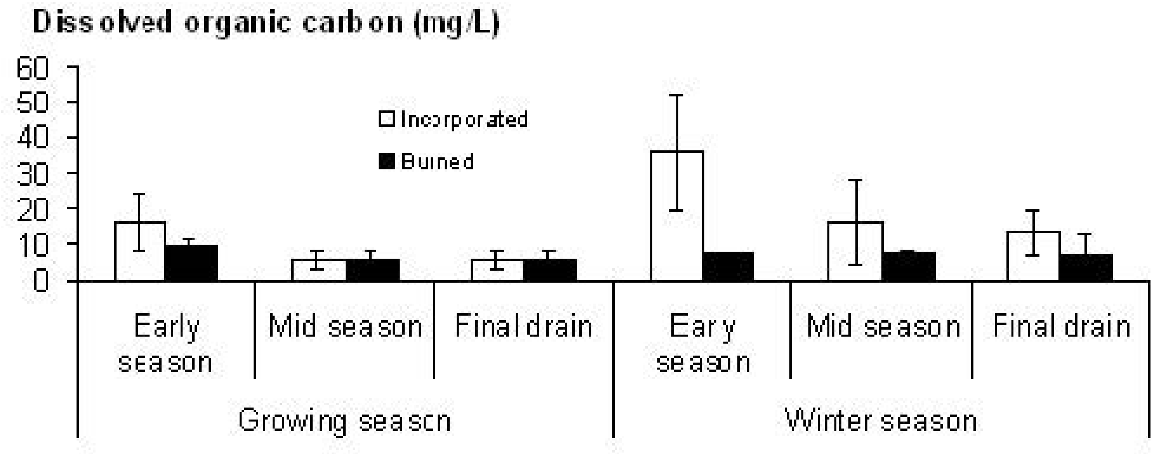

Figure 4. *Dissolved organic carbon in water leaving rice fields. Data are averaged over two growing seasons.*

A UC Davis study found that the DOC in rice tail water was higher than that entering the field (Fig. 2). On average the water entering the rice fields had DOC concentrations of 2.4 (+/- 2.4) mg/L which is low because none of the fields in the study used recycled water. While the average is below the 3 mg/L water quality objective, there were samples that were above 3 mg/L. On average, the DOC of the tailwater was 8.6 (+/- 5.4) mg/L. There were seasonal and straw management effects on DOC concentrations (Fig. 4). During the winter and early part of the growing season straw incorporated fields had higher DOC levels than burned fields. This difference was most pronounced at the onset of the winter flood period. During the growing season straw incorporated fields had slightly higher DOC levels at the beginning of the season. Best management practices (BMP) could be developed from this study; however, until critical levels of DOC are established for drainage waters from agricultural fields it is not necessary to adopt management strategies to control it.

Nutrients

Nutrients occur naturally in water as is shown in Figure 2 but they are also added to the water such as when fertilizers are applied. Good management of fertilizers will help ensure that nutrient levels remain low in rice field tailwater. Nitrogen (N), phosphorus (P) and potassium (K) are applied to farm fields as fertilizers but become a problem only when precipitation or flood water washes nutrients off the land and into water- ways.

Nitrogen (N)

High levels of N in water can to produce algae blooms. When the algae blooms die and decompose, oxygen in the water is depleted which causes problems for many aquatic plants and animals that require oxygen.

Some nutrients may pose a health risk to humans. Nitrates, a byproduct of N, are especially dangerous. In drinking water for instance, babies under 6 months of age can develop blue baby syndrome. Nitrates in the infant are converted by the body to nitrites that oxidize blood hemoglobin to methemoglobin. The altered blood cells can no longer carry oxygen, which can result in brain damage or suffocation. Epidemiological studies also show a correlation between high nitrate levels and gastric and stomach cancers in humans. The risk is so serious that the environmental protection agency (EPA) tightly regulates the levels allowed in drinking water. The upper limit for nitrates in drinking water is 10 mg/l as N which is about 45 mg/l of the nitrate ion.

In a two year study, NO_3-N water concentrations ranged from almost 0 to 2 mg/L, however, 85% of the waters sampled had NO_3-N levels less than 0.1 mg/L (Fig. 5). During the growing season the highest NO_3-N values were at the beginning of the season and may relate to fertilizer management practices-especially the application of starter fertilizers to the soil surface. In the winter, NO_3-N values varied throughout the season. High values in the winter may relate to water fowl. However, these values are well below 10 mg/L which is the drinking water quality standard.

Ammonia-N values were less than 1 mg/L in our study (Fig. 5). These values are very low and there was not a large affect of season or straw management.

Phosphorus (P)

Phosphorus is one of the principle causes of algal blooms in waterways. In rice fields high concentrations of P in the water also lead to algae problems. In a two year study, P concentrations in the outlet water was always less than 1.0 mg/L with the exception of one sample (Fig. 5). 77% of the samples had P values less than 0.1 mg/L which was the average P concentration of the inlet water. The highest P values were recorded during the winter from fields where the straw had been burned. The ash following burning is high in soluble P and may have accounted for the high P values found in water leaving these fields.

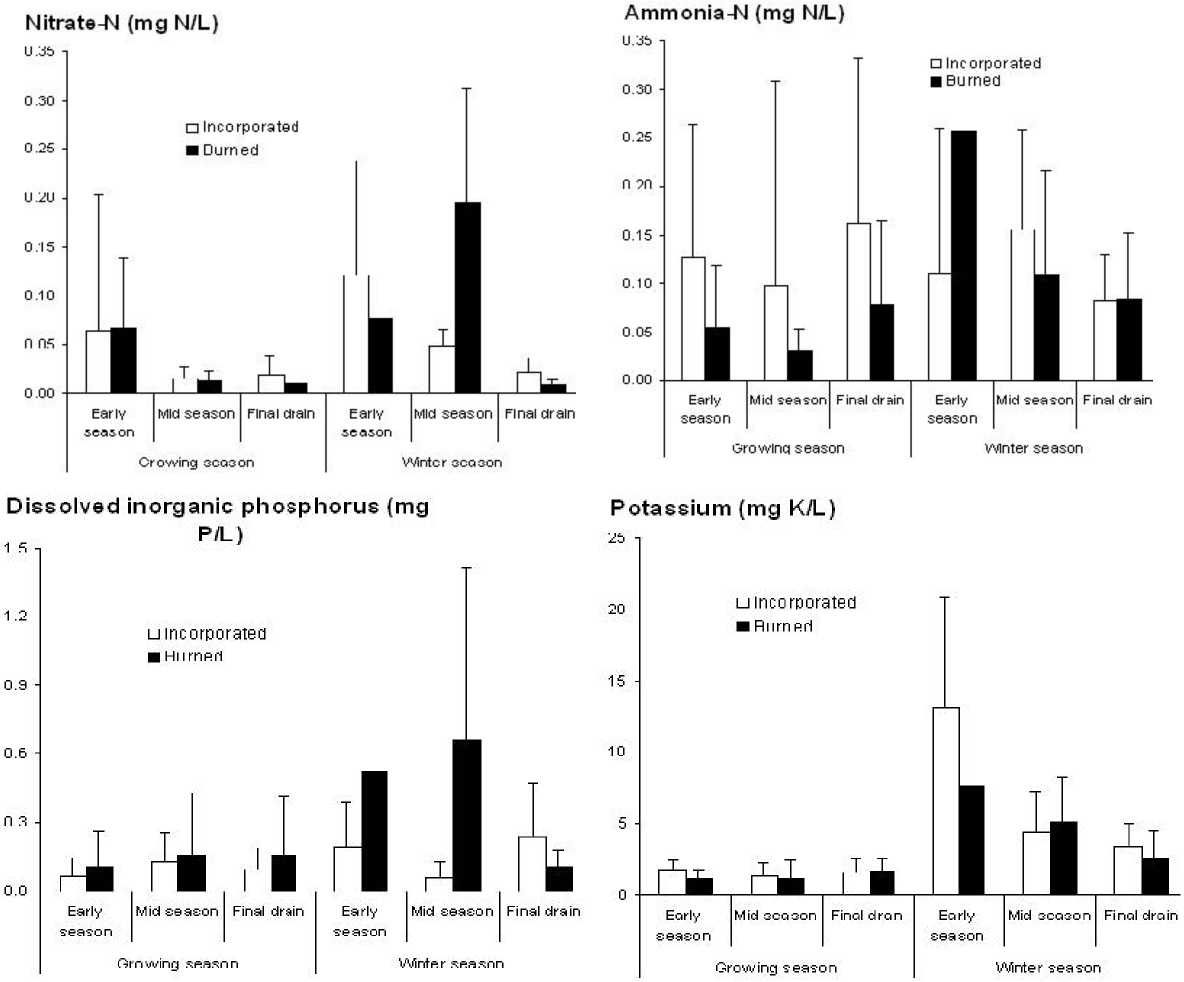

Figure 5. *Nitrate-N, ammonia-N, phosphorus and potassium concentrations in water leaving rice fields. Data are averaged over two growing seasons.*

Potassium (K)

Potassium is not normally considered a water quality problem and it is present in most irrigation water. The highest water K concentrations were during the early part of the winter season in fields where straw was incorporated (Fig. 5). Rice straw has a high amount of K in it which can be readily leached out into the flood water. K concentrations were also high in burned fields during the winter period. The rice straw ash contains a high amount of soluble K. The ash and remaining rice stubble are likely the source of water K from these fields.

Metals

Copper (Cu) is the only metal being monitored from rice fields. The source of copper is from the pesticides that are used at the beginning of the growing season primarily to control algae and other pests. In 2006 almost 200,000 rice acres were treated with copper sulfate. In a two year study, Cu in rice tailwater was not detectable, however, copper sulfate was not used on any of the study fields.

E. coli

E. coli is a type of fecal coliform bacteria that comes from human and animal waste. Elevated levels of E. coli is an indicator that disease-causing bacteria, viruses and protozoans may be present. The water quality limit is 235 CFU (coliform forming units). Water was sampled from rice field inlets, outlets and drains over a two year period were conducted to determine if E. coli may be a concern. Importantly, the sample size in this study was very small, however, there are some trends worth discussing. First, E. coli levels were generally higher in the winter than during the growing season (Table 2), possibly due to the presence of waterfowl. Second, water entering and leaving rice fields was generally low in E. coli. In one rice field outlet sample the E. coli levels were above the 235 CFU limit. Third, the drains accepting rice field outflows is higher than the rice outlet water and in four cases exceeded the 235 CFU limit. High E. coli values in the drain may be the result of water fowl and other animals that live in and around the drains.

Table 2. *E. coli (CFU – coliform forming units) in water samples from rice field inlets, outlets and drains.*

Sample location	Season	Total number of samples	Fields sampled	Range	Mean	Number of samples above 235 CFU
				CFU		
Inlet	Growing	5	5	0-49	16	0
	Winter	3	3	22-80	44	0
Outlet	Growing	5	5	0-62	21	0
	Winter	5	6	0-551	133	1
Drain	Growing	3	1	82-3460	1410	2
	Winter	6	4	4-351	139	2

Management methods to maintain water quality - Nutrients

There are currently no water quality guidelines for nutrients, TDS, TSS, and DOC; therefore, we will not discuss in detail management options for these constituents. However, we can provide some general guidelines to reduce the levels of some of these constituents from rice field tailwater.

DOC

DOC concentrations are lower in burned vs incorporated fields during the onset of the winter flood period. Flooding is necessary when straw has been retained in rice fields to encourage straw decomposition. The primary way to reduce the amount of DOC leaving rice fields during the winter is to restrict the flow of water leaving the field.

Phosphorus

While P levels were generally low, levels can be high when P fertilizer is left on the soil surface prior to flooding for planting. Water P levels are greatly reduced by incorporating fertilizer or applying the P fertilizer at a different time (i.e. before fall straw incorporation, before spring tillage, or up to 30 days after sowing). These practices reduce P levels in water and also reduce algae growth in fields. Reductions in algae will reduce the amount of copper applied to fields which is another constituent of concern.

Alternative establishment systems

Alternative establishment systems can reduce herbicide use. California rice systems have more herbicide resistant weeds than any other single crop or geographic area in the US. In an effort to control these weeds growers may apply multiple applications or additional herbicides. Applying more herbicides increases the possibility of increasing resist- ant weed populations and increases the potential for herbicide drift which can end up in surface waters even if hold times are adhered to.

No spring tillage, combined with a stale seedbed, offers new opportunities to control herbicide-resistant weeds and use less and more environmentally friendly herbicides. A stale seedbed refers to the practice of flushing or flooding a field with water to induce weed seed germination and then killing the weeds (usually with glyphosate) before planting. The choice between flushing or maintaining the soil surface fully saturated depends on whether or not the field is infested with aquatic obligate weeds which require water saturation to germinate. The soil is then left undisturbed (no tillage) to ensure that buried weed seeds are not brought to the surface to germinate. This practice can be effective for controlling all types of herbicide-resistant weeds in rice systems because they are not resistant to glyphosate. In some studies conducted at the

California Rice Experiment Station the single application of glyphosate was the only herbicide needed season-long.

Holding periods for pesticides.

The primary water quality concern of the California rice industry is residue from pesticides applied to the fields. In 1984, state regulations began which required rice growers to hold pesticide-treated waters on their fields. Long term water holding following application is the primary management method for reducing pesticide concentrations in rice tailwater. This allows for degradation of pesticides within the field (Fig. 6). Different pesticides have different rates of degradation and thus different lengths of required holding periods (Table 3).

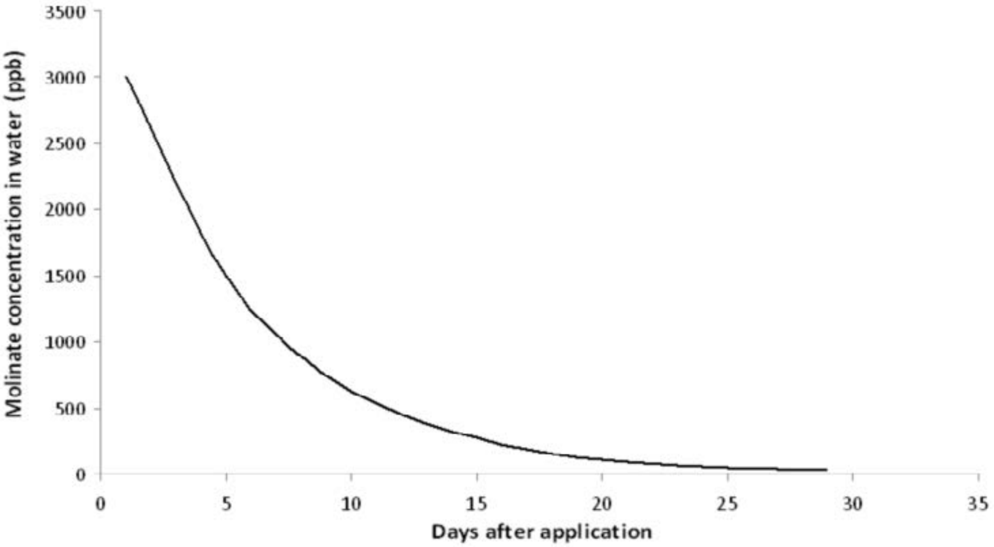

Figure 6. *E. Typical dissipation curve of molinate (Ordram®) in a typical commercial rice field. While molinate is no longer used in rice systems, such dissipation curves lead to the required holding period for molinate shown in Figure 7.*

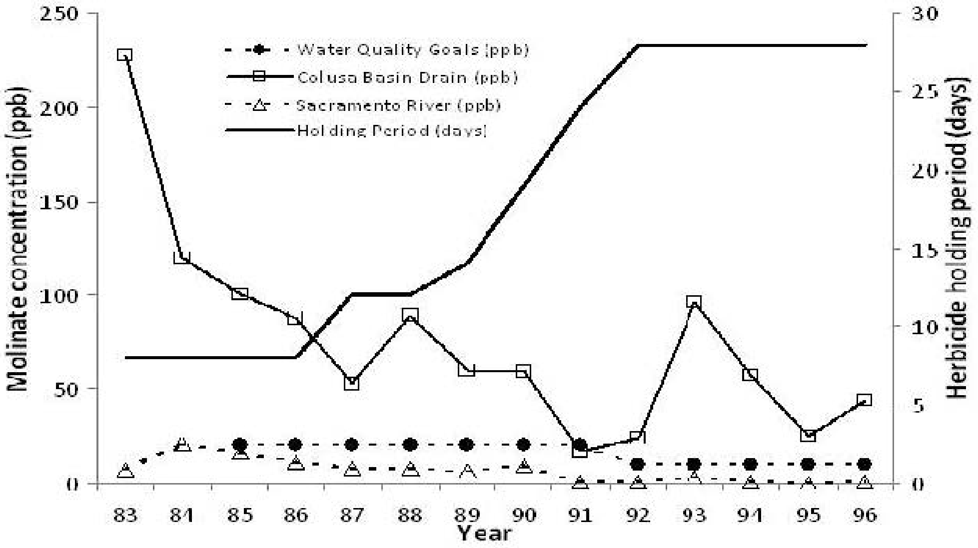

Figure 7. *Maximum concentrations of molinate (Ordram®) in the Colusa Basin Drain and the Sacramento River. While molinate is no longer used on rice this figure shows the effect of holding periods on water quality.*

Table 3. *Water holding and reentry requirements for various pesticides used in rice.*

COMMON TRADE NAME[1]	ACTIVE INGREDIENT	WATERHOLD TIME	PRE-HARVEST INTERVAL (PHI)	RESTRICTED ENTRY INTERVAL (REI)
INSECTICIDES:				
Sevin® Brand 4F	Carbaryl	0-days	14-days; propanil timing	12-hours
DuPont™ Coragen®	Chlorantranilprole	14-days	0 – soil applied	4-hours
Belay® Insecticide	Clothianidin	14-days	Up to 3rd leaf	12-hours
Mustang® Max Insecticide	(s)-cypermethrin	7-days	14-days	12-hours
Dimlin® 2L Insect Growth Regulator	Diflubenzuron	14-days	80-days	12-hours
Warrior® Insecticide	Lambda cyhalothrin	7-days	21-days; 27-days at the higher rate	24-hours
Malathion 8	Malathion	4-days	4-days: propanil timing	12-hours
FUNGICIDES:				
Quadris® Flowable Fungicide	Azoxystrobin	14-days	28-days	4-hours
Tilt® (propiconazole) Stratego® Fungicide	Propiconazole/ Trifloxystrobin	7-days	35-days	12-hours
HERBICIDES:				
Solution Water Soluble®	2,4-D	0 - days	60-days	48-hours
Londax® Herbicide	Bensulfuron-methyl	7-days static	80-days	24-hours
BUTTE® Herbicide	Benzobicyclon	20 - days	82-days	12-hours
Shark® Herbicide	Carfentrazone-ethyl	5-days static 30-days release: less closed system	60-days	12-hours
Cerano® 5 MEG Bombard™ Herbicide	Clomazone	14-days	120-days	12-hours
Clincher® CA Clincher Granule®	Cyhalofop-butyl	0 or 7-days	60-days	12-hours
Sandea® Herbicide	Halosulfuron-methyl	0 - days	69-days	12-hours
Granite® SC & GR	Penoxsulam	0-days	60-days	12-hours
Stam® 80 EDF	Propanil	7-days: less closed system	60-days	24-hours
Abolish® 8EC Bolero® UltraMax League® MVP	Thiobencarb	See table on reverse		7-days
Grandstand® CA Herbicide	Triclopyr TEA	20-days: less closed system	60-days	48-hours

The use of holding periods has been highly successful in reducing the level of rice pesticides in public waters. For example, molinate concentrations in the Colusa Basin Drain dropped from 230 to about 120 ppb in the first year that holding periods were required (Fig. 7). As the required holding period increased molinate concentrations continued to decline. However, water quality goals in the Colusa Basin Drain, and elsewhere, were exceeded in a number of years suggesting that seepage and off tar- get applications (e.g. drift) remain important sources of pesticides.

Current regulations provide for emergency release if a written request documents the crop is suffering because of the water management requirements. Emergency release will only be granted for problems related to rainfall, high winds, other extreme weather or salinity.

Adoption of other rice irrigation systems for tailwater management

Mandatory holding periods have made it difficult for rice growers with conventional irrigation systems to maintain flexibility in managing their irrigation water. Two systems are discussed in this section that will provide greater management flexibility and reduce or eliminate the possibility of spillage during water holding periods.

Gravity tailwater recapture irrigation system. The gravity tailwater recapture irrigation system utilizes pipes and gravity flow to divert tailwater from field to field thereby keeping drain water and pesticide residues out of public waterways. The water flows by gravity, eliminating tailwater pump and sump. Bypass drain pipes in upstream fields are installed in bottommost basins (checks) for maximum effectiveness. The pipe can enter the downstream field at any point, although entry into the upper portion of the field allows the greatest flexibility. The advantages of this system include improved tailwater and pesticide residue containment, management flexibility during water holding periods, and low construction and operation cost. The disadvantages are: when many basins are interconnected, the large water surface area may make quick and precise water management difficult; requires coordination of water among many fields; the system is not completely closed and may allow some tailwater and pesticide residue to enter public waterways.

The float valve rice box

The conventional irrigation system can be improved by replacing the conventional rice weir with a “smart box”. A smart box operates on the same principle as a toilet tank or a horse- trough valve. The plastic container or float of a smart box is adjusted so that it opens and closes a vertically-hinged butterfly valve. When the water in the downstream basin is low, the plastic container floats downward and opens the flap gate, allowing water into the basin. When the water depth reaches the set level (adjustable by adding or removing water from the hollow plastic float) the container floats upward, closing the valve: water cannot enter the basin. As long as a source of water is available to the topmost basin, the series of basins is regulated. Each basin takes in water as needed, and shuts off when the desired water depth is reached, thereby eliminating much of the day-to-day manage- ment associated with traditional flashboard weirs. Once smart boxes are properly adjusted, no spill should occur from the bottommost basin.

Seepage water management

Seepage is the lateral movement of irrigation water through a rice field levee or border to an area outside of the normally flooded production area. Seepage can occur through levees into adjacent dry fields or into existing drains and canals. Leakage caused by crayfish and rodent burrowing is not considered seepage, but can also result in the movement of irrigation water off rice fields. Seepage will be readily apparent later during the growing season as water accumulates and by green weedy growth along the edge of the field. Occasionally, seepage appears as a wet area that can damage a perimeter road. It is not currently regulated, but recommendations to reduce seepage include,

- Block any exits of seepage ditches that may drain into agricultural drains;
- For severe seepage, pump the water back into the field or fallow land;
- Inspect levees for crayfish or rodent damage, and repair any leaks;
- Build levees in the fall so they will compact;
- Build levees with enough soil moisture for good compaction;
- Avoid building levees with excessive straw;
- Compact levees with a tracklayer;
- Control crayfish and rodents.

Seepage water that contains high concentrations of pesticides can hinder efforts to comply with California's water quality goals. Efforts to meet these goals depend on long holding periods, which allow pesticides to dissipate almost completely in rice fields before release. Nevertheless, the concentrations of rice pesticides found in many agricultural drains exceed the levels found in tailwater released from rice fields after an adequate holding period. Therefore, seepage and off-target applications (for example, drift) are believed to be the source of the high concentrations currently found in agricultural drains. As holding periods for rice pesticides increased during the last decade, and the contribution of tailwater runoff to pesticide loading of surface waters declined, the relative contribution of seepage to such loading was recognized. Currently, seepage is regarded as an important contributor to pesticide loading in Sacramento Valley waterways.

Rice pesticides that do not strongly adsorb to soil particles, for example, molinate can move with seepage water from treated fields into agricultural drains or other nontarget areas. This seepage water will contain approximately the same concentration of certain rice pesticides as in the field.

In an effort to determine if rice pesticides, particularly molinate, can move with seepage water, the Department of Pesticide Regulation undertook a study to determine the extent of molinate movement from treated commercial rice fields through levee banks into adjacent ditches or fallow fields. In 1992, two sites, located in commercial rice fields in Colusa County, were chosen because they were known to have seepage problems in previous years. Prior to the application of molinate, the suspected seepage areas were covered with heavy plastic tarps to prevent contamination from aerial drift and kept covered throughout the study. At the first site, on a Willows clay, the molinate concentration in the seepage water peaked two days after application at 205 parts per billion (ppb). At the second site, on a Wikoda silty clay, concentrations at six days after sampling were as high as 720 ppb. At the time of the study the water quality goal for molinate was 10 ppb for all public waterways. While this study was not able to determine the extent of seepage throughout the Sacramento Valley, it did show that molinate can move with seepage water through levees to nontarget areas. Other studies conducted by the Central Valley Regional Water Quality Control Board found that both molinate and carbofuran are present in seepage water in ditches adjacent to treated fields. The concentration of these pesticides is likely to be present in the seepage water soon after the field has been treated.

Recognizing seepage and what causes it as well as when and where it occurs can be the first step to good seepage or leak control. For a more complete discussion, see “Seepage Water Management, Voluntary Guidelines for Good Stewardship in Rice Production”, UC Division of Agriculture and Natural Resources Pub. 21568.

Maintaining ground water quality

The above discussion has largely focused on maintaining surface water quality. However, there is increased interest by the ILRP in maintaining ground water quality.

Most rice is grown on impermeable heavy clay soils and thus there is relatively little percolation of surface water to below the root zone. Therefore, it is expected that constituents of concern do not readily leach below the root zone and into ground water in most rice fields.

There has been limited research on how rice farming affects ground water quality outside of research done on nitrate leaching (Liang et al., 2014). Research focused on nitrate leaching has shown that less than 2.5% of fertilizer N moves below the root zone annually. This is much lower than other crops grown on more permeable soils. The low amount of nitrate leaching in rice fields is due to several things:

1. The low permeability of soils
2. Fertilizer N is applied as ammonium or a form that quickly concerts to ammonium. Fertilizer N is not applied as nitrate.
3. Soils remain flooded or saturated for much of the season. This creates anaerobic conditions which prevents the ammonium from nitrifying to form nitrate.

This low potential for nitrate leaching is also seen in ground water monitoring wells in the Sacramento Valley (Figure 8). In just about all cases, ground water wells near rice fields had less than 5 ppm nitrate-N.

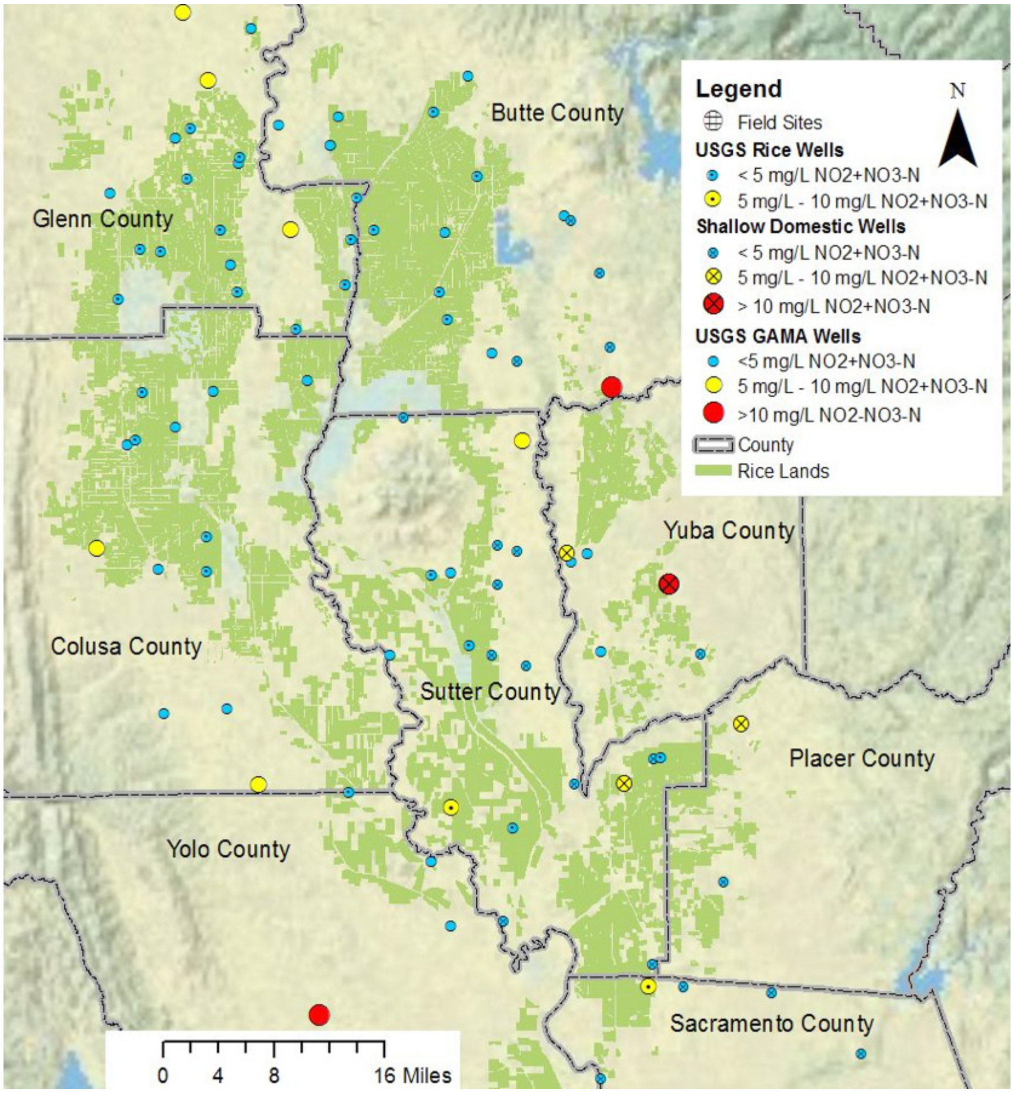

Figure 8. *Locations of Sacramento Valley monitoring wells.*

Further reading:

1. Ruark, M.D., B.A. Linquist, J. Six, C. van Kessel, C.A. Greer, R.G. Mutters and J.E. Hill. 2010. Seasonal losses of dissolved organic carbon and total dissolved solids from rice production systems in northern California. Journal of Environmental Quality 39:304-313.
2. Krupa, M., R.G.M. Spencer, K.W. Tate, J. Six, C. van Kessel and B.A. Linquist. 2012. Controls on dissolved organic carbon composition and export from rice dominated systems. Biogeochemistry Journal 108:447-466.
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6. Lundy, M.E., D.F. Spencer, C. van Kessel, J.E. Hill and B.A. Linquist. 2012. Managing phosphorus fertilizer to reduce algae, maintain water quality, and sustain yields in water-seeded rice. Field Crops Research 131:81-87.