Development of a Conceptual Model to Estimate Pesticide Concentrations for Human Health Drinking Water and Guidance on Conducting Ecological Risk Assessments for the Use of Pesticides on Rice

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Abstract

The Pesticide in Flooded Application Model (PFAM) is used by the United States Environmental Protection Agency (USEPA) to estimate pesticide concentrations in surface water from the use of pesticides in flooded fields, such as rice paddies. PFAM simulates water and pest management practices, pesticide degradation in soil and aquatic environments, as well as discharge of paddy waters to lotic or lentic user defined water bodies. The first version of PFAM was developed and made available for use in EFED risk assessments in January 2013. While PFAM has been used for many years and a general scenario for modeling pesticides concentrations in the rice paddy water has been used on a regular basis, a module for estimating pesticide concentrations in a receiving water body was not used because a conceptual model had not been developed. This document describes the development of conceptual models and scenarios to use with PFAM for estimating pesticide exposure to human health (drinking water) and for ecological risk assessments for pesticides applied to rice.

Conceptual models for drinking water were developed to simulate drinking water concentrations that may occur from rice grown in California for a simulated drinking water intake near Sacramento and for rice grown in Missouri and Arkansas with the drinking water intake on the Black River near Pocahontas, Arkansas. Monitoring data were used in the evaluation of the conceptual models, and concentration-adjustment "bias factors" for estimating a true peak concentration were applied to monitoring results with a less frequent sampling frequency. Four pesticides were evaluated for each conceptual model. Overall model generated Estimated Drinking Water Concentrations (EDWC) based on the developed conceptual models resulted in pesticide concentrations higher than monitoring results but within a factor of ten of the highest grab sample monitoring results when not considering bias factors. The results demonstrate that the developed conceptual models provide conservative and reasonable EDWCs.

Guidance on which taxa to assess, where to assess taxa, and an approach for conducting ecological risk assessments is discussed in this white paper. This paper also describes how the pesticide concentrations in tailwater, after a holding period, are used to help characterize the potential risk to organisms outside of the rice paddy. Risk to aquatic animals is assessed in the rice paddy with exposure estimated using PFAM. Risk to aquatic plants and aquatic animals is also characterized by assessing pesticide concentrations in tailwater after a specified holding period. Risk to terrestrial organisms is evaluated using currently available terrestrial models (*e.g.*, TREX, KABAM, AgDRIFT, and AgDISP). For terrestrial plants, only risk due to exposure to spray drift is assessed as runoff is expected to be minimal from applications of pesticides to rice. Risk for terrestrial organisms is assessed for dry-seeded rice only. These recommendations are consistent with previous assessments completed on the evaluation of ecological risk assessment for pesticides applied to rice paddies.

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Abbreviations/Nomenclature

AR	Arkansas
AgDRIFT	Modified Version of the Agricultural Dispersal model
BF	Bias Factor
BW or bw	Body Weight
CA	California
CBD	Colusa Basin Drain
CDL	Cropland Data Layer
DW	Drinking Water
DWI	Drinking Water Intake
EDWC	Estimated Drinking Water Concentration
EFED	Environmental Fate and Effects Division
FIFRA	Federal Insecticide, Fungicide, and Rodenticide, Act
KABAM	K_{ow} Based Aquatic Bioaccumulation Model
LD50	Median Lethal Dose
MO	Missouri
NASS	National Agricultural Statistics Service
NLCD	National Land Cover Database
NOAEC	No Observed Adverse Effect Concentration
NOAEL	No Observed Adverse Effect Level
OPP	Office of Pesticide Programs
PFAM	Pesticides in Flooded Applications Model
SAP	Scientific Advisory Panel
TREX	Terrestrial Residue Exposure Model
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WQP	Water Quality Portal

1 Introduction

The Pesticide in Flooded Application Model (PFAM) is used by the United States Environmental Protection Agency (USEPA) to estimate pesticide concentrations in surface water from the use of pesticides in flooded fields, such as rice paddies. PFAM simulates water and pest management practices, pesticide degradation in soil and aquatic environments, as well as discharge of paddy waters to lotic or lentic user defined waterbodies (**Figure 1-1**). PFAM was developed and made available for use in Environmental Fate and Effects Division (EFED) risk assessments in January 2013 (USEPA, 2013b). While PFAM has been used for many years and a general scenario for modeling pesticides concentrations in the rice paddy water has been used on a regular basis, a module for estimating pesticide concentrations in a receiving water body was not used because a conceptual model had not been developed (**Figure 1-2**). This document describes the development of conceptual models and scenarios to use with PFAM for estimating pesticide exposure to human health (drinking water) and for ecological risk assessments. Conceptual models for drinking water (DW) were developed for rice grown in California (CA) and Missouri (MO)/Arkansas (AR). Monitoring data were used in the evaluation of the conceptual models. Concentration-adjustment “bias factors” for estimating a true peak concentration were applied to monitoring results with a less than daily sampling frequency.

Chapter 2 provides an overview of rice growing practices. Chapter 3 provides guidance and considerations for conducting an ecological risk assessment for pesticides applied to rice. Chapter 4 describes how the assumptions and conceptual models pertaining to the waterbody, watershed, and area of rice treated for simulating exposure in DW were developed. Chapter 5 describes the development of an approach for determining how spray drift may impact pesticides in DW. Chapter 6 describes the collection and analysis of monitoring data to support the DW conceptual models. Chapter 7 compares modeled concentrations simulated for DW with monitoring data collected in the areas simulated.

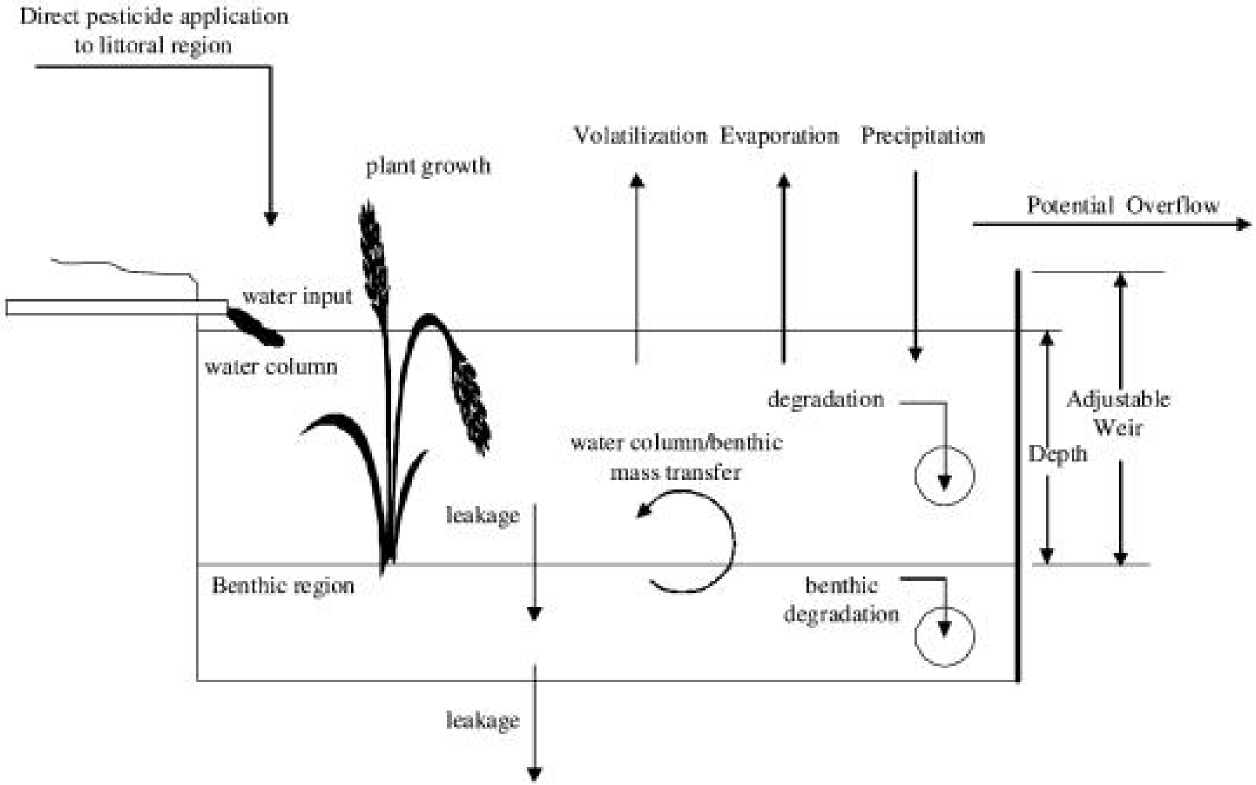

Figure 1-1. The conceptual model for PFAM model

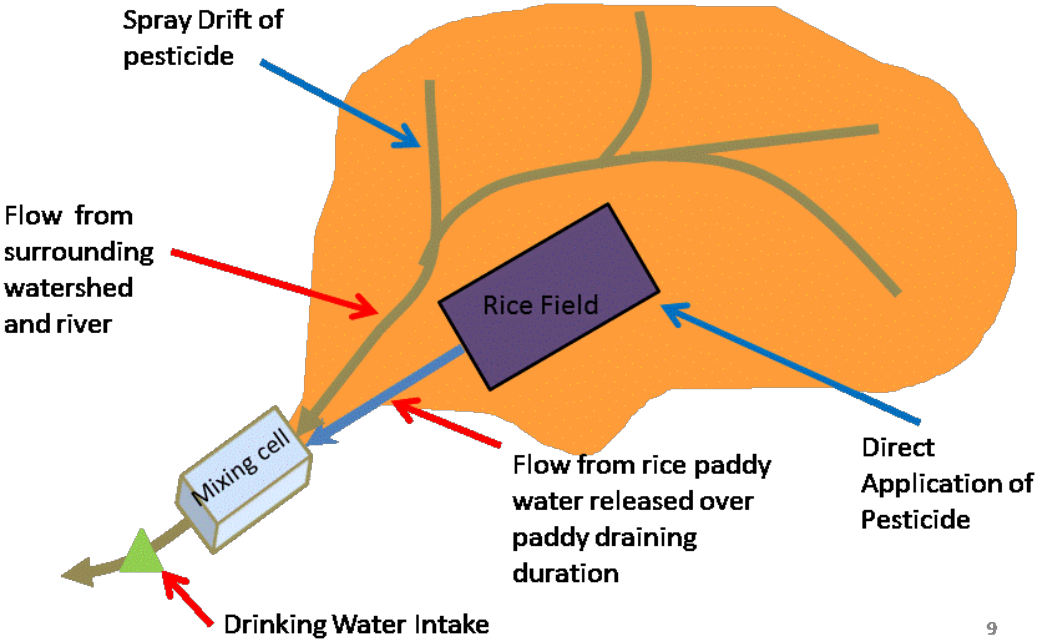

Figure 1-2. The conceptual model for simulating drinking water concentrations from applications of pesticides to rice

2 Background on Rice-growing Cultural Practices

2.1 Background on Rice-growing Cultural Practices

Greater than 85% of the rice production in the United States occurs in Arkansas, California, Mississippi, Louisiana, and Texas. Rice has also been grown in Florida, Missouri (MO), Oklahoma, and Tennessee[1]. Survey data from the National Agricultural Statistics Service (NASS) on rice acres planted in the United States for the year 2010 are provided in **Figure 2-1**.

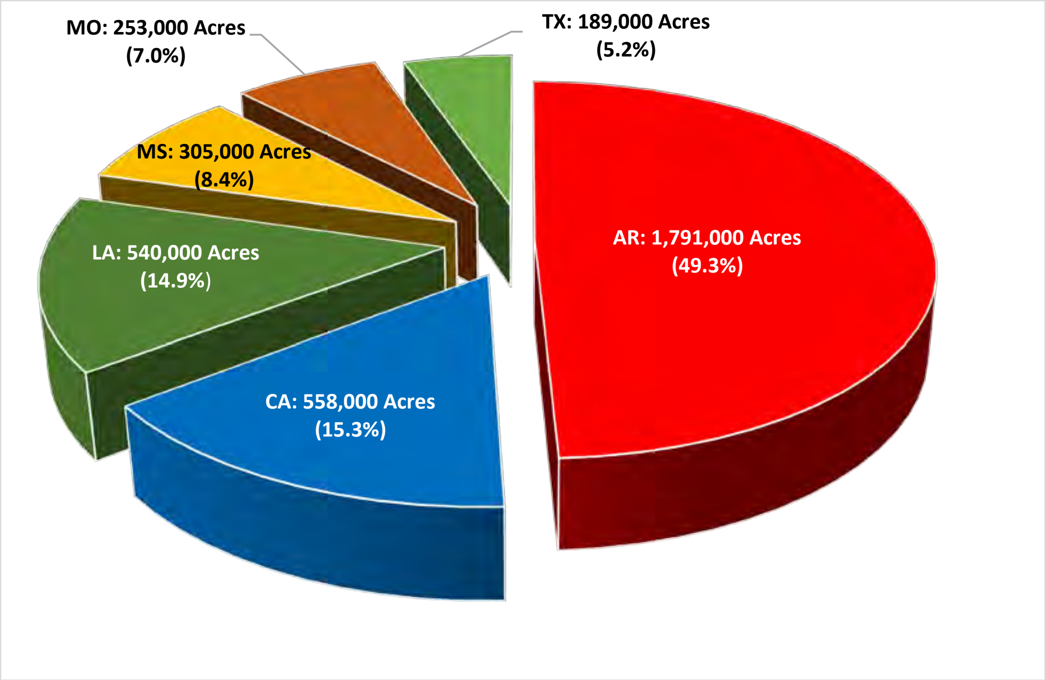

Figure 2-1. Distribution of rice acreage in the major rice producing states in the USA[1]

In general, rice fields are prepared (disking and harrowing) prior to seeding in order to destroy winter vegetation and reduce the chance of seedling drift. The fields are then leveled in order to maintain a flood and reduce runoff. After land preparation, rice seeds are planted via water-seeding or dry-seeding on well prepared seed beds. If dry-seeded, the fields are then flushed with irrigation water to obtain a uniform seed germination and seedling emergence. In between planting and establishment of permanent flood (3 to 4 weeks after the seeding), fields may be flushed several times to maintain moisture in the soil. Once the permanent flood is established, it is maintained until 2 to 3 weeks before harvesting. Flooded water is released and fields are drained 2 to 3 weeks before harvesting to facilitate harvesting operations that use machines.

Typical planting and harvesting periods were collected from the USDA (2010) and are provided in **Table 2-2** below.

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[1] Based on 2007 census data from the Quick Stats Database of the National Agricultural Statistics Service available at http://quickstats.nass.usda.gov.

Table 2-1. Typical planting and harvesting dates*

State	Planting	Harvesting
Arkansas	April 14 – May 19	Sep 9 – Oct 10
California	May 1 - 25	Sep 15 – Nov 1
Louisiana	March 28 – May 1	Aug 4 – Sep 15
Mississippi	April 18 – May 16	Sep 5 – Oct 6
Missouri	April 20 – May 19	Sep 14 – Oct 18
Texas	March 23 – April 26	Aug 7 – Sep 4

* Data from USDA (2010). Specific crop practices for each of the rice-growing states are provided in the sections below.

2.2 Arkansas

The information in this section regarding Arkansas rice agronomy has been taken from the *Arkansas Rice Production Handbook* (Hardke, 2006, 2013).

Rice in AR is grown in the eastern half of the State, the AR River Valley, and Southwest AR (Hardke, 2006, 2013). **Figure 2-3** and **2-3** provides rice acreage by county in the State of AR. Approximately 55, 35 and 9 percent of the rice grown in AR is produced on silt loam, clay and sandy loam soils, respectively. About 70 percent of the rice is drill-seeded, 28 percent is broadcast-seeded, and only about 2 percent is water-seeded.

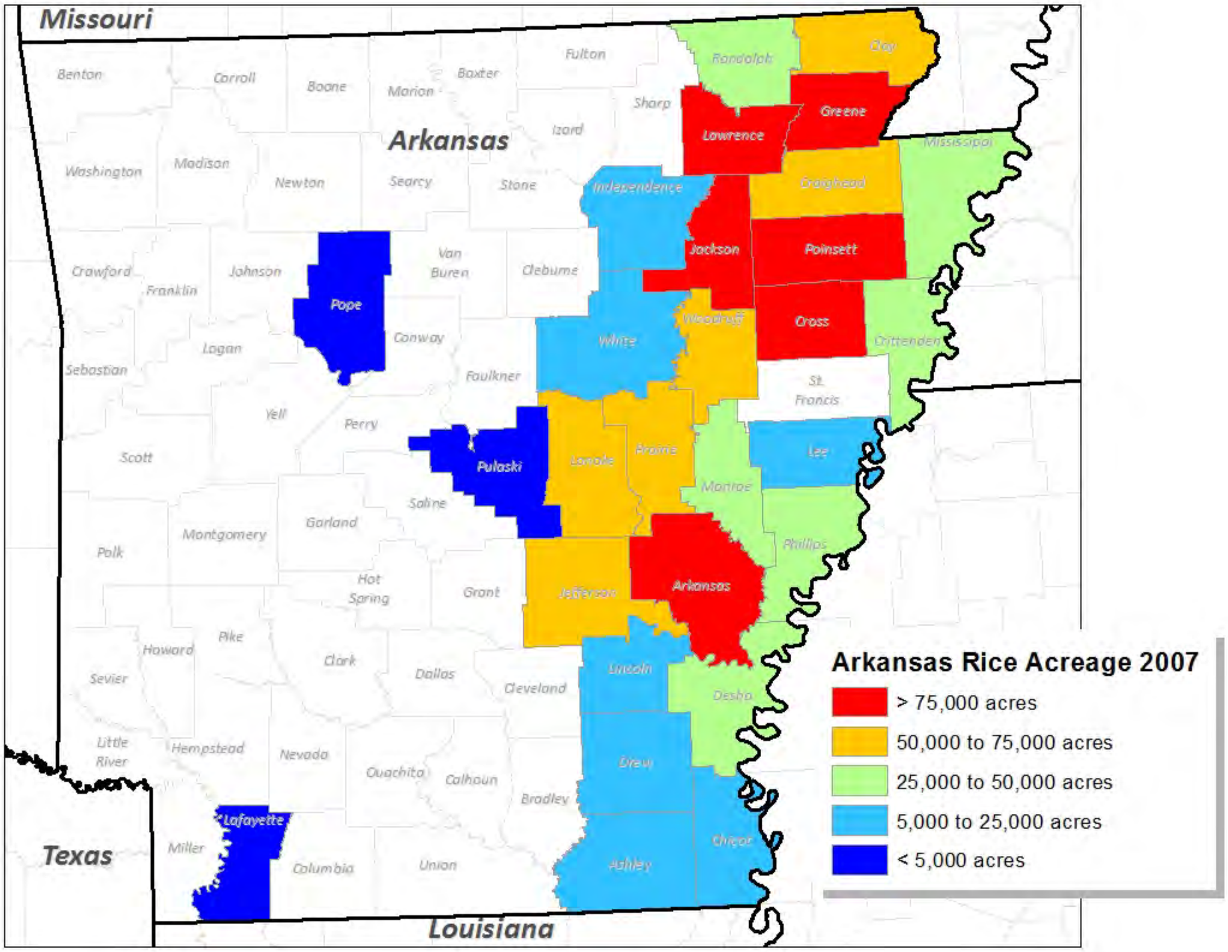


Figure 2-2. Arkansas rice growing areas based on NASS Agricultural Census data from 2007

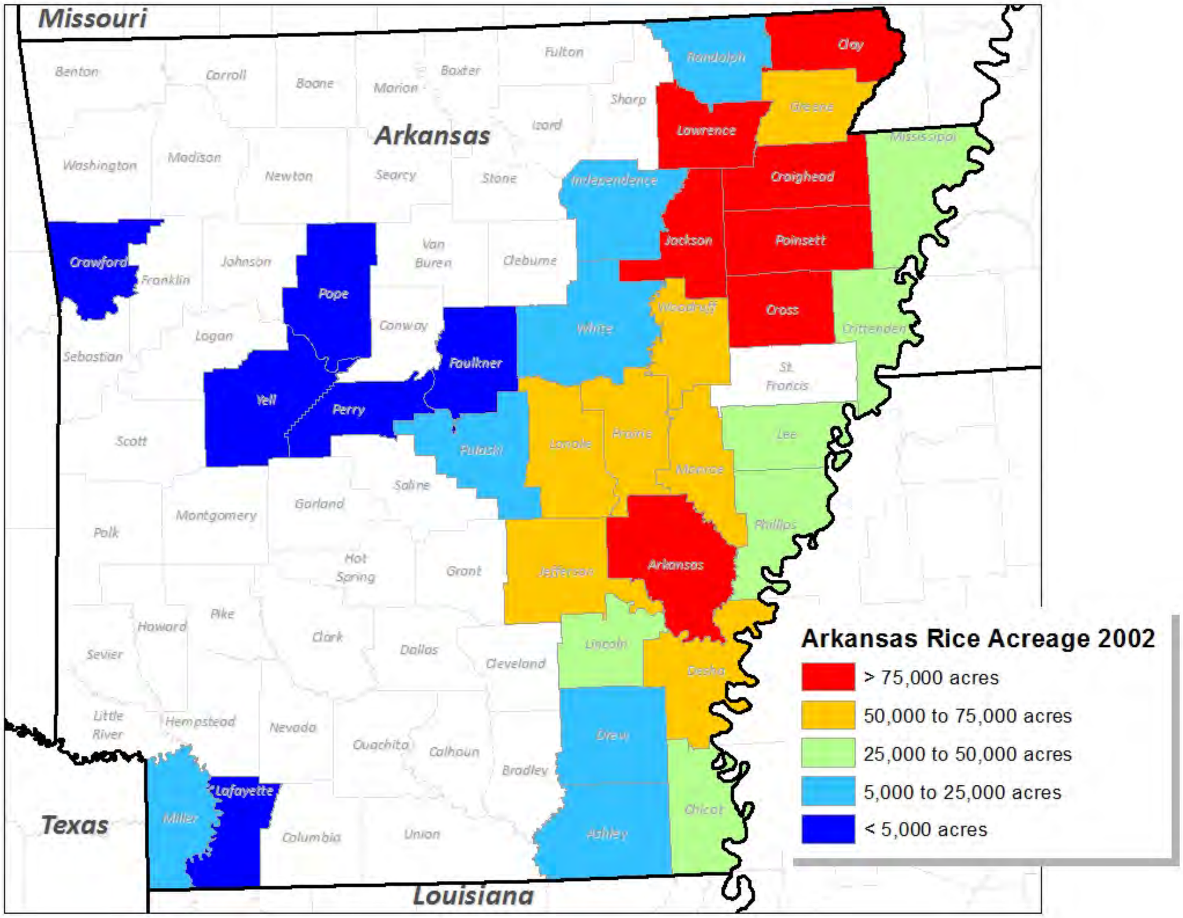


Figure 2-3. Arkansas rice growing areas based on NASS Agricultural Census data from 2002

Water depth of the paddies is based on water management guidance that a continuous, shallow flood of 2 to 4 inches should be maintained from beginning tillering until two weeks prior to harvest. The first flush coincides with providing moisture for germination. Germination usually occurs 2 days after planting. Then 3-5 days after planting, a first flush normally occurs, and the field is drained 2 days later. The 1st leaf is expected to appear 5-20 days after germination or an average of 8 days. The 1st leaf to 5th leaf period is 15-25 days long, yielding an average of a leaf every 4 days. During this time, barnyard grass may emerge, at which time a second flush, lasting 2 days, is necessary. The second flush is scheduled to occur right after the 3rd leaf stage, or 20 to 22 days after planting. When the rice reaches 6 to 8 inches in height, the permanent flood occurs. This is roughly between the 5th leaf stage or the first tiller, or 30 days after planting. Approximately 10 to 14 days after heading (when the rice panicle begins to exert from the boot) of the rice, irrigation to the rice paddy is discontinued and permanent flood waters are allowed to evaporate or be absorbed by the rice in preparation for harvest. In instances where evapotranspiration does not occur quickly enough, or unexpected precipitation occurs, water from paddies are released prior to harvest. This release occurs approximately 2-3 weeks prior to harvesting.

Seed treatments (fungicides, growth regulators, and insecticides) are commonly used. Most seed treatments are applied to seed by commercial applicators, but some seed treatments are available for planter box treatments (Hardke, 2006). Rice seed is planted at a maximum rate of 129 lbs seed/A and a minimum rate of 77 lbs seed/A.

Stubble management in Arkansas includes tillage, burning, rolling, and winter flooding. In 2009, approximately 33% was rolled, 24% was tilled, 20% was managed with a winter flood, and 15% was burned (Norman and Moldenhauer, 2009).

Figure 2-4 provides a timeline of typical agricultural practices and pesticide applications in Arkansas rice production.

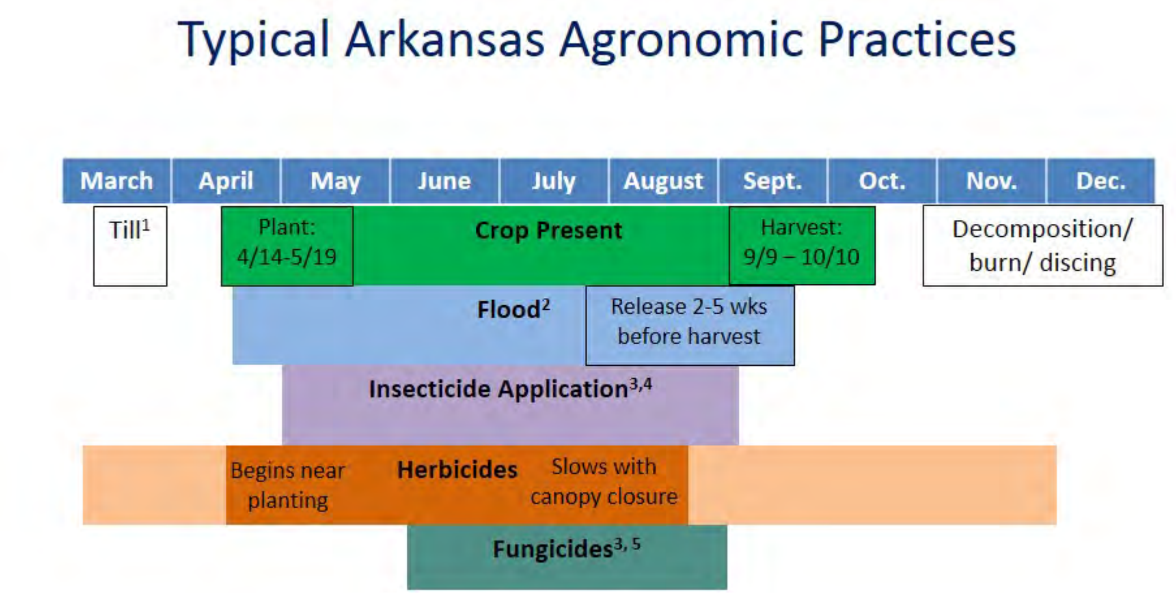
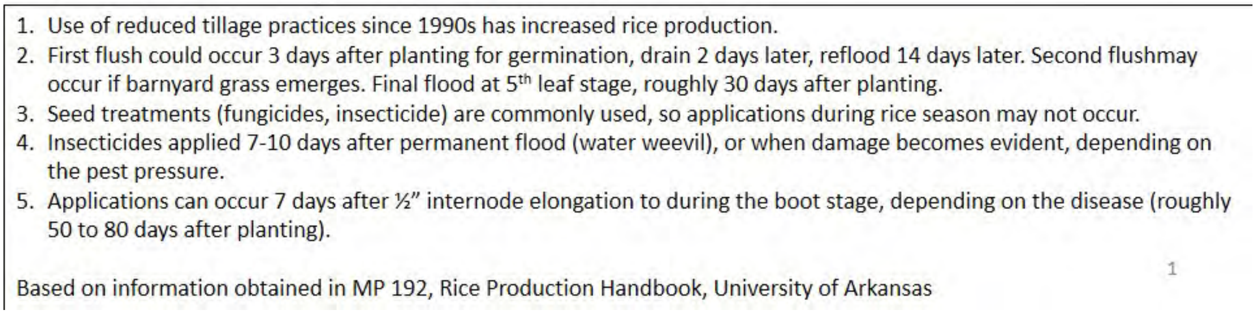


Figure 2-4. Typical agronomic practices for rice grown in Arkansas


1. Use of reduced tillage practices since 1990s has increased rice production.
2. First flush could occur 3 days after planting for germination, drain 2 days later, reflood 14 days later. Second flushmay occur if barnyard grass emerges. Final flood at 5th leaf stage, roughly 30 days after planting.
3. Seed treatments (fungicides, insecticide) are commonly used, so applications during rice season may not occur.
4. Insecticides applied 7-10 days after permanent flood (water weevil), or when damage becomes evident, depending on the pest pressure.
5. Applications can occur 7 days after ½" internode elongation to during the boot stage, depending on the disease (roughly 50 to 80 days after planting).

1

Based on information obtained in MP 192, Rice Production Handbook, University of Arkansas

2.3 California

In CA, approximately 500,000 acres are devoted to rice production.[2] Most of this land is in the Sacramento Valley (**Figure 2-5**). California rice is grown on heavy clay soils of river valley floors and on eroded terrace soils on the Valley's rim. These soils restrict deep percolation, which can reduce the amount of water that must be applied to produce a rice crop (California Rice Commission, 2013)

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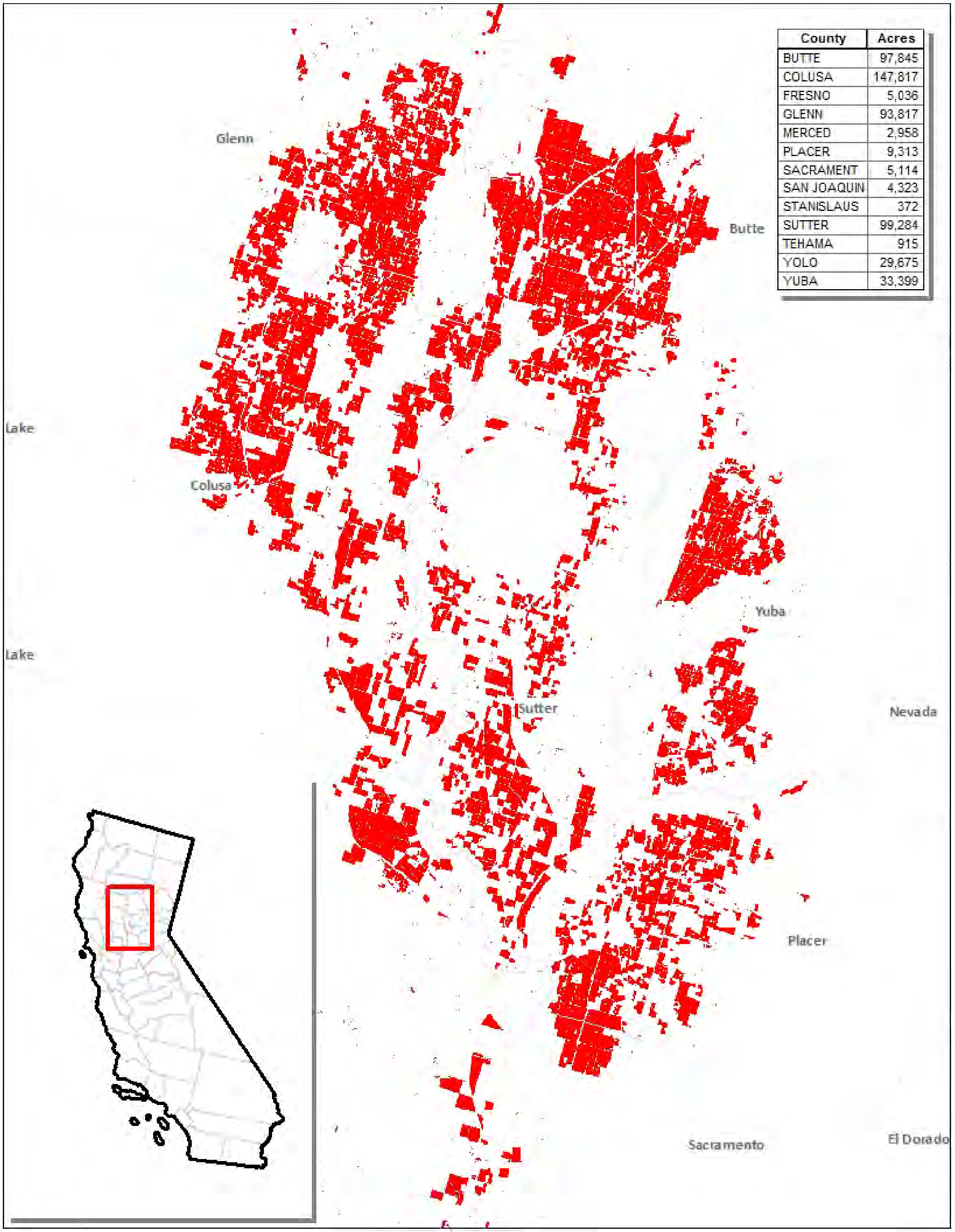
[2] National Agricultural Statistics Service Quick Stats



County	Acres
BUTTE	97,845
COLUSA	147,817
FRESNO	5,036
GLENN	93,817
MERCED	2,958
PLACER	9,313
SACRAMENT	5,114
SAN JOAQUIN	4,323
STANISLAUS	372
SUTTER	99,284
TEHAMA	915
YOLO	29,675
YUBA	33,399

Figure 2-5. Areas of rice production in California based on NASS 2007 Agricultural Census data and the 2015 Cropland Data Layer

In California, germinated rice seed is typically broadcast directly into rice field floodwaters from an airplane. The heavy seed sinks, pushes its shoots above the water, and grows into a healthy rice plant.

So that it is properly prepared for planting, the seed is soaked in a solution of water and fungicide until the tip of the radicle, or primary root, emerges from the rice seed. At this point, the seed is heavy enough to sink in water and make essential soil contact, will complete germination rapidly, and will resist fungal pathogens during germination (California Rice Commission, 2013).

Any straw remaining from the previous season's harvest must be decomposed, burned, or baled and removed prior to planting rice. Historically burning was the preferred method because of its low cost and because it destroyed disease-causing organisms in the straw. However, its use has been reduced due to air quality concerns. Decomposition is hampered by the natural resistance of rice straw, a characteristic that helps it retain its structural integrity under flooded conditions. Additionally, straw must be put into contact with the soil and kept moist to accelerate decomposition. Baling and removal are costly relative to current returns from the sale of rice straw (California Rice Commission, 2013). Winter flooding[3] is now the preferred method to accelerate the decomposition process for straw. Fields flooded from October to February, with their rich load of residual grain and native invertebrates, provide excellent habitat for migratory waterfowl. They also provide water storage volume that can be used strategically as part of the regional water management system (California Rice Commission, 2013).

Before planting, rice farms are commonly tilled, which consists of lifting, sometimes inverting, and pulverizing the soil until a seedbed of relatively small clods covers the surface. Tillage serves to bury weed seeds scattered on the surface from the previous season and to provide a surface on which the rice seeds can more easily establish themselves as seedlings. The land is then usually fertilized before tillage is completed, so that fertilizer is mixed into the soil. Lastly, the surface material is smoothed with land planing equipment, removing localized high and low spots for a more even flood. Precise leveling of land is conducted using laser-guided earth moving equipment drawn by tractors (California Rice Commission, 2013).

After tilling, channels, levees, and checks are constructed around the rice fields to control flood irrigation. Levees are the long mounds around and within the fields that block the free flow of water. Checks are the basins surrounded by levees, where the rice crop is grown. Weir boxes, or simply "boxes," are set into the levees to control the flow of water from channel to check, check to check, or check to channel. To regulate water flow through the box, the height of the weir can be adjusted by adding and removing boards of various widths (California Rice Commission, 2013).

After tillage is complete and the levees are in place, rice fields are flooded by allowing water to flow into the checks. Outflow is controlled so that, water soaks into these heavy clay soils and ponds, and eventually covers the field in a layer 3 to 5 inches deep. Although rice will emerge from floodwaters, some planting systems and specific management problems require flushing, or draining and re-flooding of the planted field. Flood levels can exceed 8 inches, 7 to 21 days before heading and after panicle initiation (70 days after planting in some rice varieties) (Dickey, 2015). Rice fields are typically planted in from the beginning of April to the end of May (California Rice Commission, 2013).

Harvest requires that the land be drained at the end of the season, allowing the field to dry out sufficiently to accommodate traffic during harvest. At this point, the crop is nearly mature and weed

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[3] The winter flood may occur between October and February and water is held at a similar depth to the in season flood.

growth is not generally a concern. Fields are usually drained 2 weeks before harvest (typically in mid-September to mid-October).

Three main water management systems are currently being used by rice growers: conventional, recirculating, and static systems (**Figure 2-5**) (California Rice Commission, 2013; Dickey, 2015).

In the past, almost all rice farms were irrigated with conventional flow-through systems where water flows into one "check" or basin (a rice field is subdivided into checks by levees) and then to the next check. Finally, the water flows out of the bottom check and into a drain. It has been estimated that 20 percent or more of the applied water with a conventional system is spillage. Conventional system water management problems have made it increasingly difficult for rice growers to comply with the required water-holding periods (California Rice Commission, 2013; Dickey, 2015).

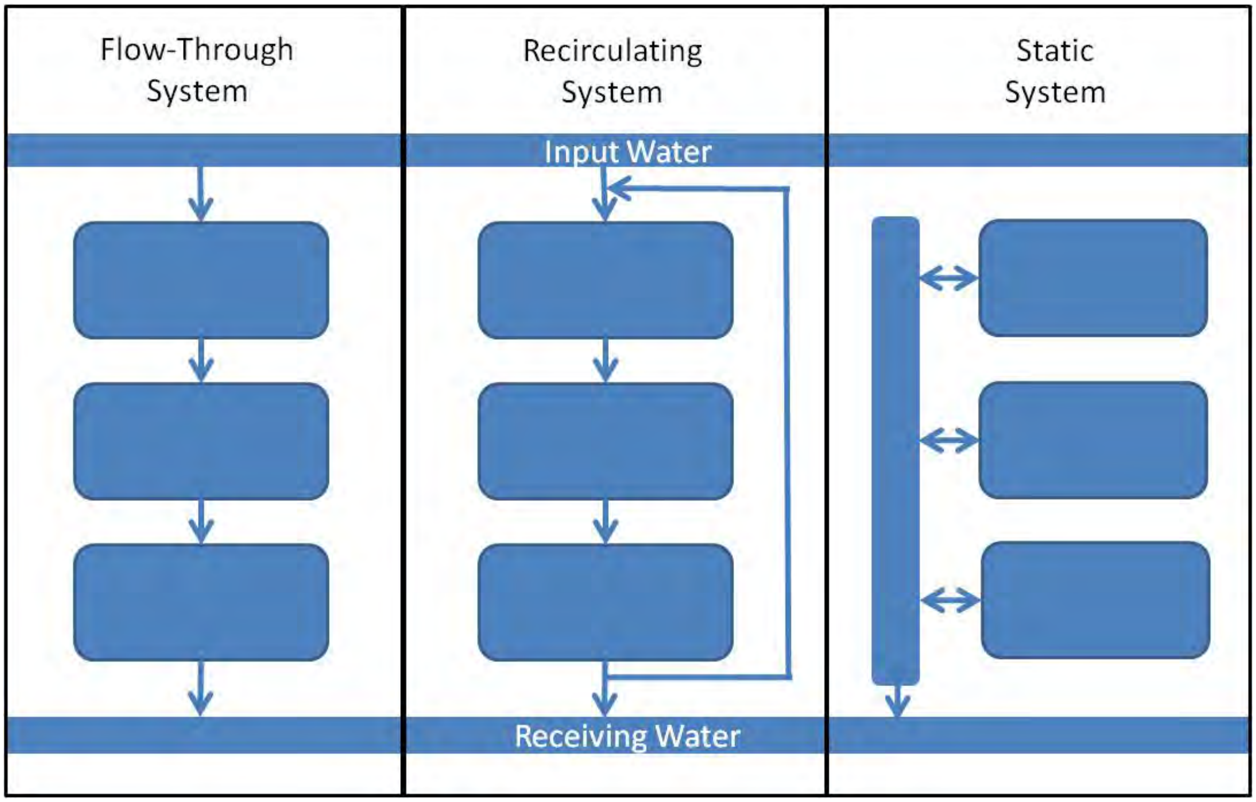

Figure 2-6. Typical water systems used for rice growing in California

Closed systems, such as the recirculating and static systems, are considered to be best management practices for holding treated water because they can reduce pesticide residue mass discharge by up to 97 percent over conventional systems. Additionally, they provide improved water management flexibility that can contribute to water conservation efforts (California Rice Commission, 2013; Dickey, 2015).

In recirculating systems, water is pumped from the bottom check back to an uphill field, usually on the same farm. Some of these systems have been implemented at the irrigation district level, but most have been built by individual farming operations (California Rice Commission, 2013; Dickey, 2015).
A static system independently controls inflow into each basin and limits it to the amount required to replenish applied water lost to evapotranspiration and percolation. It also eliminates the possibility of spillage of field tailwater into public drains. This practice is a recent innovation, and precise water management is easier than with other systems (California Rice Commission, 2012a, 2013; Dickey, 2015).

Rice growers are adopting closed systems in an effort to improve water quality of rice field drain water according to a recent study: *Rice Water Management Adoption Trends In California* (Dickey, 2015). This study encompasses four major rice growing counties (Colusa, Glenn, Yolo, and Butte). Results from the four-county area show an increase in closed system usage from 74,600 acres in 1991 to 136,200 acres in 1994, a 58 percent increase in closed systems. However, the total number of acres in rice production also increased during the same time period. Of the total acreage, closed systems increased from 31.8 to 36.5 percent between 1991 and 1994, while conventional systems decreased from 68.2 to 63.5 percent. The substantial acreage converted to closed systems is an indication of the commitment of rice farmers' resources to meet the water quality and conservation challenges before them (California Rice Commission, 2013; Dickey, 2015).

Pest populations are frequently monitored. Pest abundance is compared against critical levels (levels at which probable economic damage exceeds the cost of a pest control action). If critical levels are not exceeded, then the pest control action is not undertaken (California Rice Commission, 2013; Dickey, 2015).

Pests of rice include vertebrates (*e.g.*, rats, certain birds immediately before harvest), insects (e.g., rice water weevil, rice midge), and other invertebrates (*e.g.*, tadpole shrimp). A variety of cultural (non-chemical) and chemical means are employed to control these pests when they reach critical levels of abundance (California Rice Commission, 2013).

Weed pests of rice are aquatic grasses (*e.g.*, watergrass), broadleaved weeds (e.g., annual arrowhead), sedges (*e.g.*, rough-seeded bulrush), and algae. Cultural control is principally by tillage, proper timing and depth of flood irrigation, and achievement of a dense and competitive stand of healthy rice. Herbicides are applied to most of CA's rice fields for control of grass, sedge, and broadleaved weeds. After herbicides have been applied to the rice field, the farmer must hold water in the field, or within a complex of fields, for a specified period of time. This practice allows the organic herbicides to biodegrade in the rice fields, so that water released to the drainage system is of acceptable quality for other beneficial uses (California Rice Commission, 2013; Dickey, 2015).

Figure 2-7 presents a timeline of typical agricultural practices and pesticide applications in CA rice production.

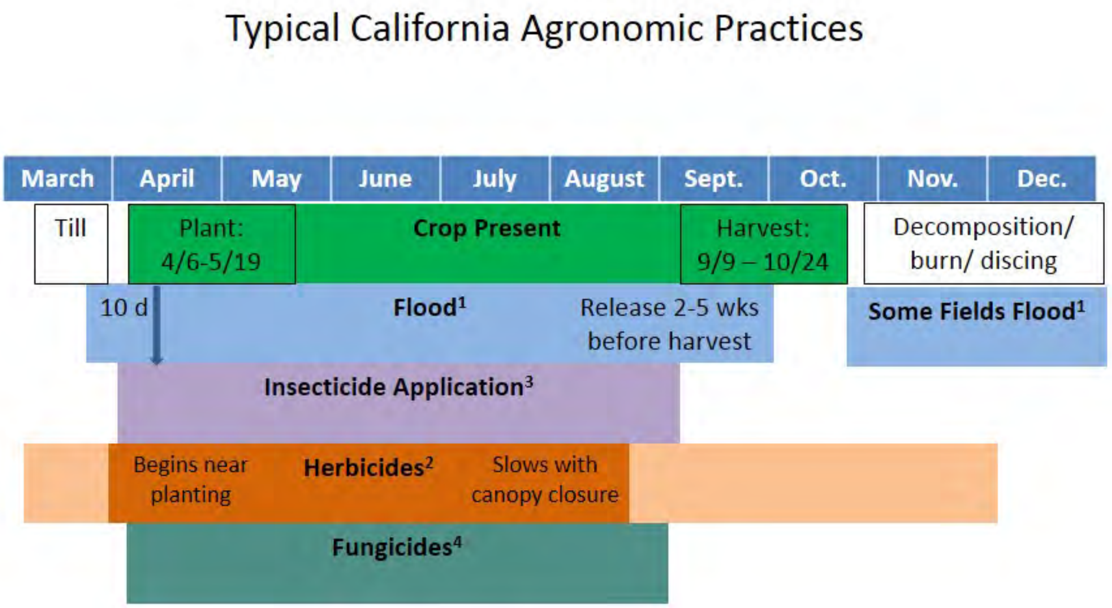

Figure 2-7. Typical agronomic practices for rice grown in California

1. Flood 10 days before plant. Sometimes they will flush (drain 2 days after plant, reflood 7 days later). Winter flooding (October – February) sometimes may be used.
2. April through August is when most herbicide applications occur. However, herbicide applications do occur throughout the year and were reported in every month but December in the CA PUR database in 2009.
3. Insecticide applications to rice were reported in the CA PUR database in April, May, June, July, and August in 2009. Insecticide applications to wild rice were reported in January, October, and November 2009.
4. Fungicide applications to rice were reported in the CA PUR database in May, June, July, August, and September 2009.

2.4 Louisiana

According to the Louisiana Rice Production Handbook (Saichuk, 2009), most rice is grown on the silt loam soils derived from either loess or old alluvium that predominate the southwestern region and, to a lesser extent, the Macon Ridge area of northeast Louisiana. **Figure 2-8** depicts areas in Louisiana that produce rice. The clay soils in the northeastern and central areas derived from more recent alluvial deposits are also well adapted to rice culture. Historically, 75 percent of Louisiana's rice has been grown in south Louisiana. The majority of this acreage has been planted using a water-seeded system. The remaining 25 percent of Louisiana's acreage has been grown in northeast Louisiana where a dry broadcast or drill-seeded system has been more common (Saichuk, 2009).

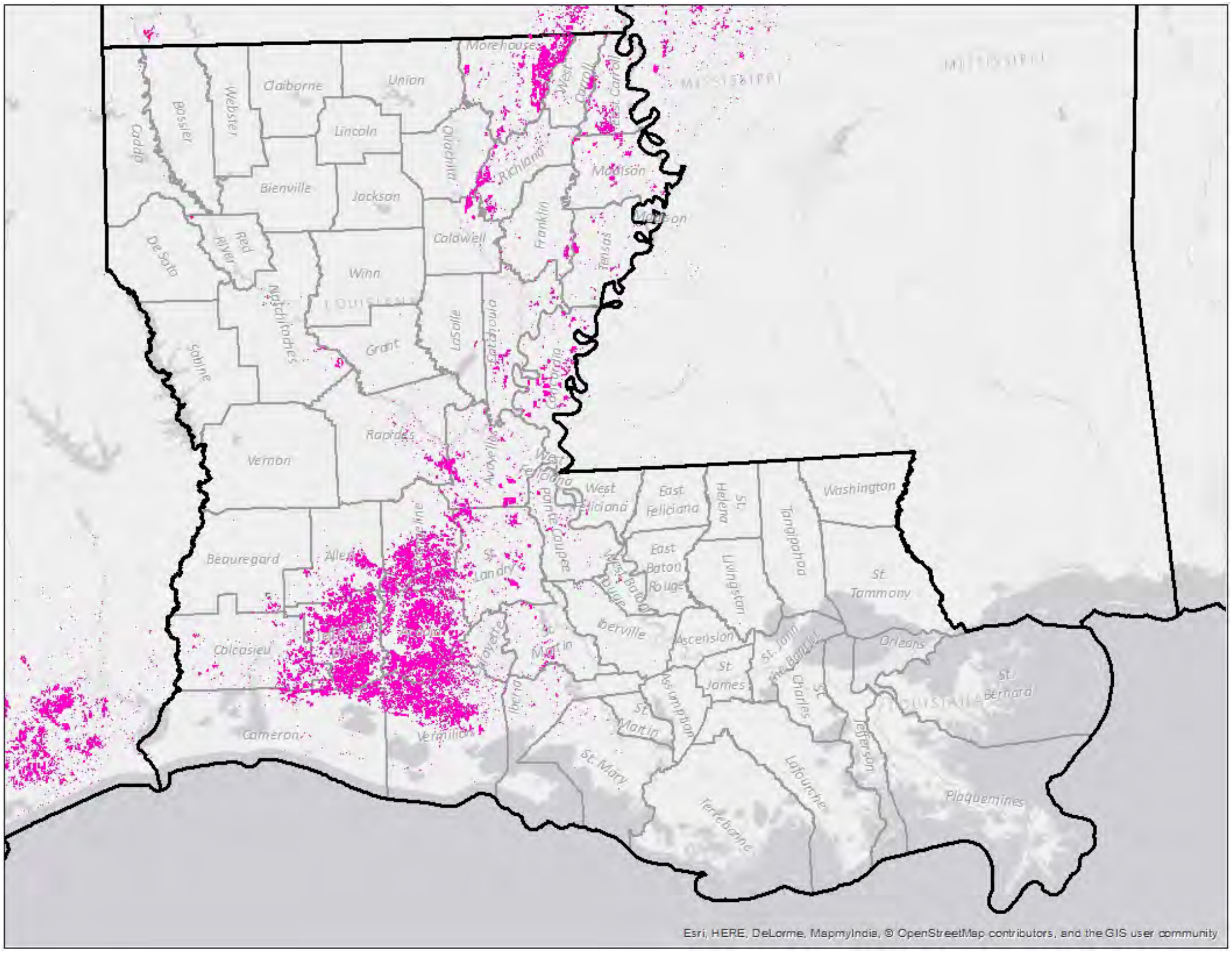

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Figure 2-8. Louisiana rice production areas (2015 Cropland Data Layer)

With water seeding, the seedbed is left in a rougher condition than for dry seeding. This is accomplished by preparing a seedbed consisting primarily of large clods (approximately baseball-size), which is often easier to attain with heavy-textured soils. A flood is established as soon as possible following tillage, and rice is seeded within 3 to 4 days. Three water management methods are then typically used in LA for water seeded rice: delayed flood, pinpoint flood, and continuous flood systems. In a delayed-flood system, fields are drained after water seeding for an extended period (usually 3 to 4 weeks) before the permanent flood is applied. The most common water-seeding method is the pinpoint flood system. After seeding with pre-sprouted seed, the field is drained briefly. The initial drain period is only long enough to allow the radicle to penetrate the soil (peg down) and anchor the seedling. A 3- to 5-day drain period is sufficient under normal conditions. The field then is permanently flooded until rice nears maturity (an exception is midseason drainage to alleviate straight head). Use of a continuous flood system is limited in Louisiana. Although similar to the pinpoint flood system, the field is never drained after seeding (Saichuk, 2009).

For dry-seeded rice, 4 to 6 weeks may elapse between planting and permanent flood establishment. In south Louisiana, permanent floods are generally established on two- to three-leaf rice; in northeast Louisiana, the permanent flood may not be established until rice is in the five-leaf to one-tiller stage. When soil moisture is insufficient and rainfall is not imminent, the field should be flushed within 4 days of seeding to ensure uniform seedling emergence (Saichuk, 2009).

The rice paddy area between levees is kept as uniformly level as possible. If the water depth in a cut is less than 2 inches in the shallow area and greater than 6 inches in the deep area, the crop will not emerge and mature uniformly. A uniform flood depth of fewer than 4 inches (1 or 2 inches) is maintained before rice emergence. As the rice gets taller, the water depth is increased to 4 inches (Saichuk, 2009; USDA, 2002).

Six basic herbicide application timings are considered when choosing a herbicide: (1) burndown prior to planting, (2) preplant incorporated, (3) preemergence prior to planting, (4) preemergence after planting, (5) delayed preemergence (drill-seeded only) and (6) postemergence. Based on Louisiana State University Agricultural Center recommendations (Saichuk, 2009), burndown herbicides should be applied no earlier than 6 to 8 weeks prior to planting and no later than 3 to 4 weeks prior to planting. Preemergence application is used on a regular basis throughout Louisiana, especially in water-seeded rice production in south Louisiana. In south Louisiana, producers often impregnate starter fertilizer with an herbicide with preemergence activity. The field is flooded for seeding, starter fertilizer is impregnated with the herbicide and then is applied to the flooded field. Preemergence herbicide application following planting is used most often in drill-seeded rice. Immediately after rice is planted, an herbicide is applied to the soil surface. Within a 24- to 48-hour period after herbicide application, adequate rainfall (1 inch or more) must occur or the field must be flushed for herbicide activation. Delayed preemergence herbicide application is primarily, if not exclusively, used in a drill-seeded rice production system. The rice crop is planted and 4 to 7 days after planting the herbicide is applied. This delay after planting allows the rice seed to begin the germination process, allowing the young seedling to get an initial growth advantage prior to herbicide application. This application usually follows a surface irrigation or rainfall within the 4- to 7-day interval after planting. Postemergence herbicide applications are made any time after crop emergence, from very early postemergence on one- to two-leaf rice to salvage treatments applied late in the season to aid in harvest efficiency. Postemergence herbicide applications are the most common timings for weed management in rice (Saichuk, 2009).

2.5 Missouri

Based on personal communication with scientists at the University of Missouri, rice in this state is grown either east or west of the Crowley Ridge, a landform that runs from near Memphis, TN to Cape Girardeau, MO (**Figure 2-9**). The soils that support rice production include the Calhoun silt loam, Amagon silt loam, Crowley silt loam, Foley silt loam, Kobel clay, and Sharkey clay. The Calhoun and Crowley Silt loams are a 6-inch soil layer over a subsoil of clay. The Crowley soil is found to the west of the Crowley Ridge and the Sharkey clay is found to the east of the Crowley Ridge. About 80-85% of the approximately 200,000 acres of MO Rice is dry-seeded, while the remaining 15-20 % is water-seeded in a manner consistent with how CA water seeds (pre-soaked seeds flown into permanent flood) (personal conversation between Jim Breithaupt, EPA/OPP/EFED, Mr. Bruce Beck (Agronomist) and Drs. Andy Kendig (Weed Scientist), Allen Wrather (Plant Pathologist), and Michael Boyd (Entomologist), University of MO).

For water-seeded rice practices, the field is initially graded to a zero or near-zero grade. A shallow flood is established immediately following grading to suppress the germination of red rice and other weeds before the rice is planted. After planting, the field is drained immediately after seeding in order to allow the seed to "peg." Then "pin-point" flooding is practiced up to the time of tillering in order to keep the soil saturated (muddy) at all times. The soil is kept saturated or flooded throughout the season to avoid cracking. Deep flooding is avoided before tillering, as it retards rice growth and tillering (USDA, 2000).

For dry seeding, after the field is prepared and planted, the field is flushed when necessary to promote uniform crop germination. After flooding, the field may need to be drained and treated for zinc deficiency. A permanent flood of 2-4 inches is maintained for the remainder of the season. The field is drained 2 weeks prior to harvest. Fields can be re-flooded during winter to attract ducks (Kaminski *et al.*, 1999).

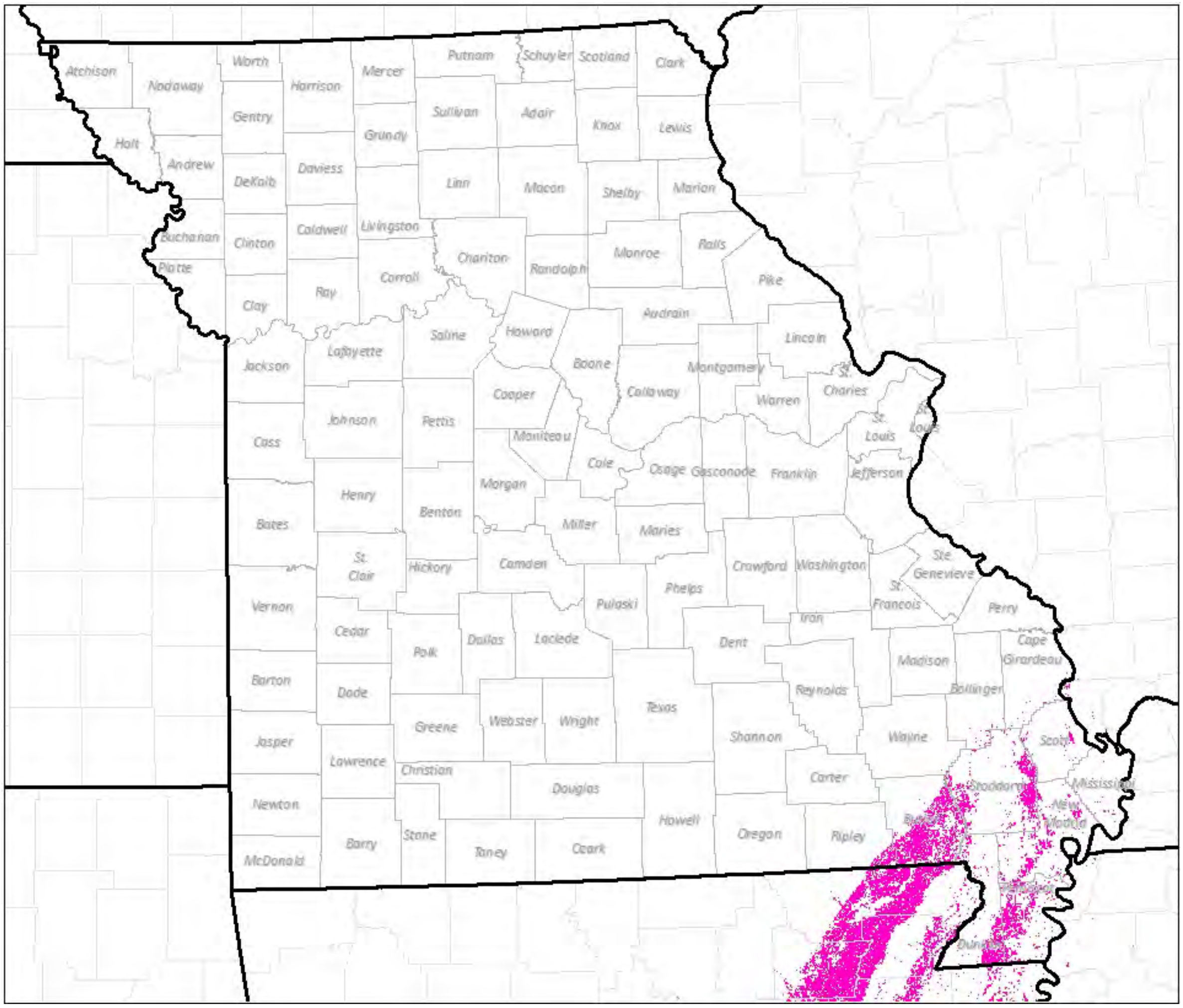

Figure 2-9. Missouri rice production areas (2015 Cropland Data Layer)

2.6 Mississippi

According to the *Mississippi Rice Growers Guide* (Miller *et al.*, 2008), rice production in Mississippi has been almost totally limited to the Mississippi-Yazoo Delta, with very little production outside this area (**Figure 2-10** and **2-11**). The central-Delta counties of Bolivar, Washington, and Sunflower have been the leading rice-producing counties. According to Bulletin 991, *Rice Levee Construction and Seepage Losses on Sharkey Clay* (Pringle, 1992), rice grown in the Mississippi Delta is on predominantly clay soils with a substantial percentage being on Sharkey clay. The clay soils, large and flat fields, high quality of available water, and climate are excellent for rice growth. Over 85% of pesticides are applied by air (USDA, 2005).

Flood depths are maintained less than 6 inches, or tillering may be inhibited.

To reduce the amount of vegetation at planting, burn down applications typically occur around February or March.

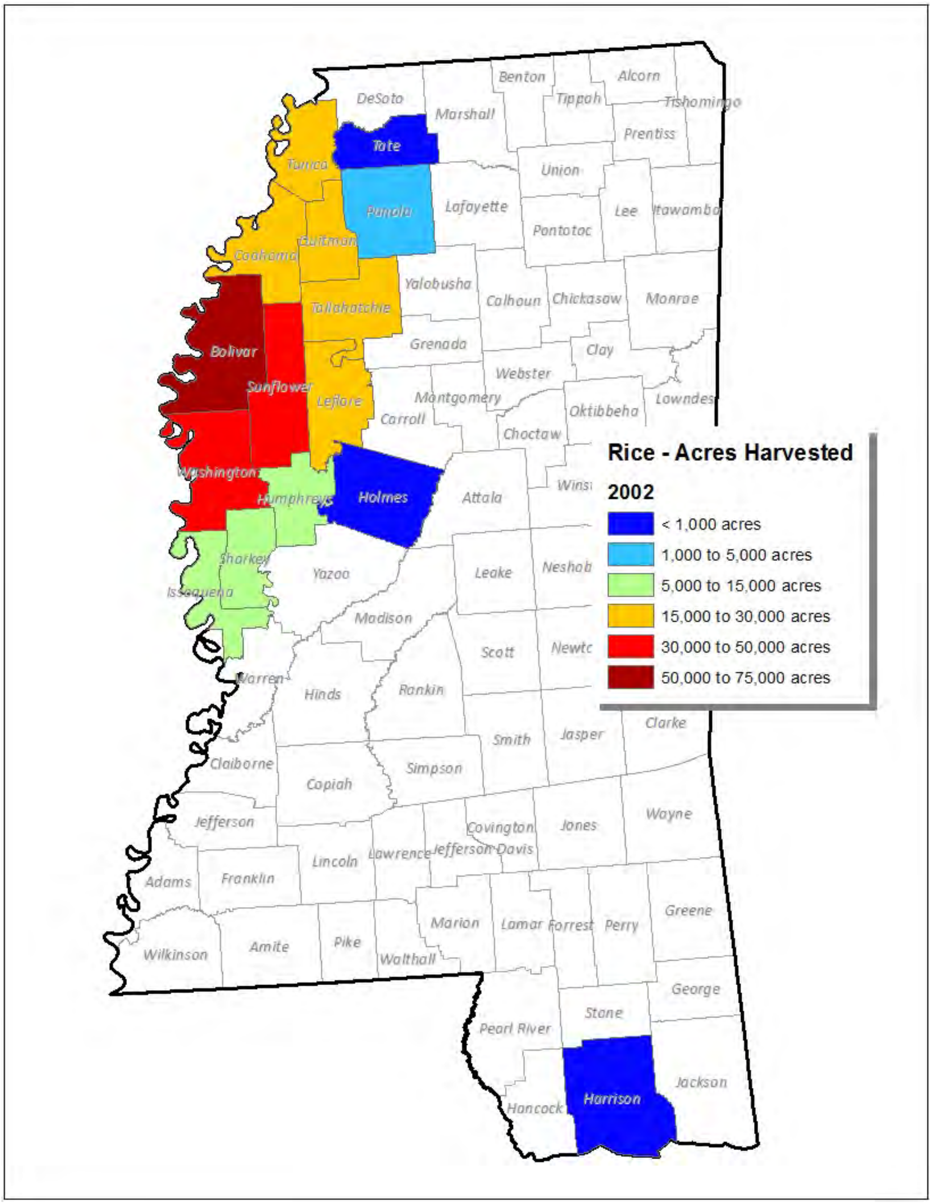

Figure 2-10. Mississippi rice production areas (2002 NASS Agricultural Census data)

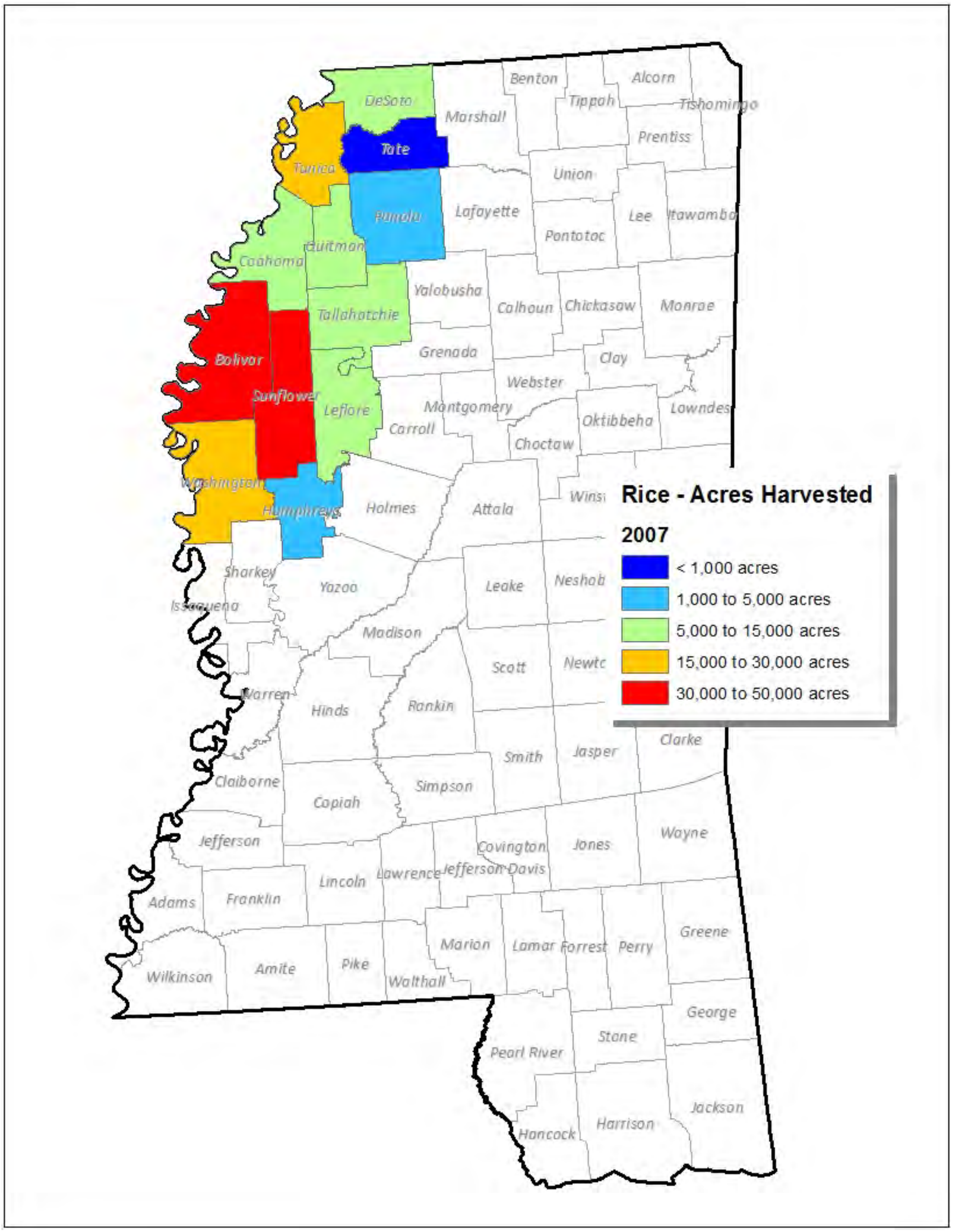

Figure 2-11. Mississippi rice production areas (2007 NASS Agricultural Census data)

2.7 Texas

Most of the state's rice production and milling industry is along the upper Texas coast. Rice is grown in 21 counties in Texas (Austin, Bowie, Brazoria, Calhoun, Chambers, Colorado, Fort Bend, Galveston, Hardin, Harris, Hopkins, Jackson, Jefferson, Lavaca, Liberty, Matagorda, Orange, Red River, Victoria, Waller, and Wharton, **Figure 2-12** and **2-13**) (USDA, 2016). According to the Texas Almanac (Association, 2008), the soil in these counties is primarily Coastal Prairie. The Coastal Prairie soils are mostly deep, dark-gray, neutral to slightly acid clay loams and clays. Bottomland soils are mostly deep, dark-colored clays and loams along small streams but are greatly varied along the rivers.

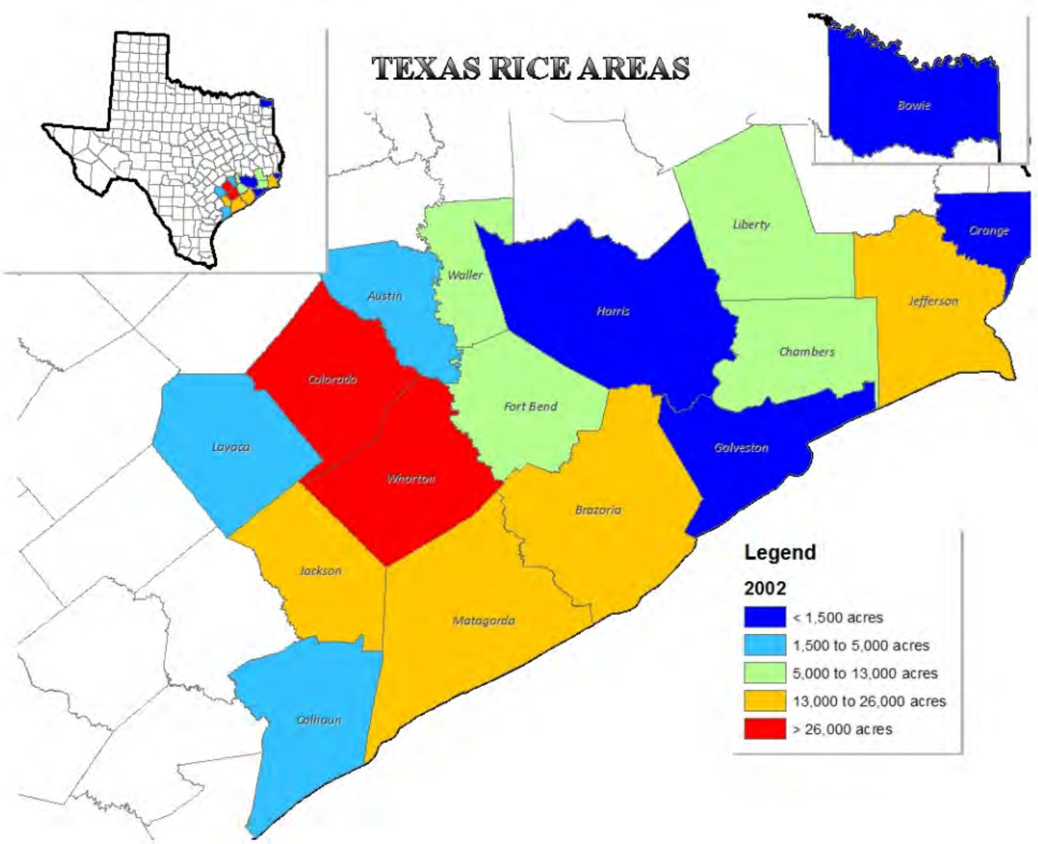

Figure 2-12. Texas rice production areas (2007 NASS Agricultural Census data)

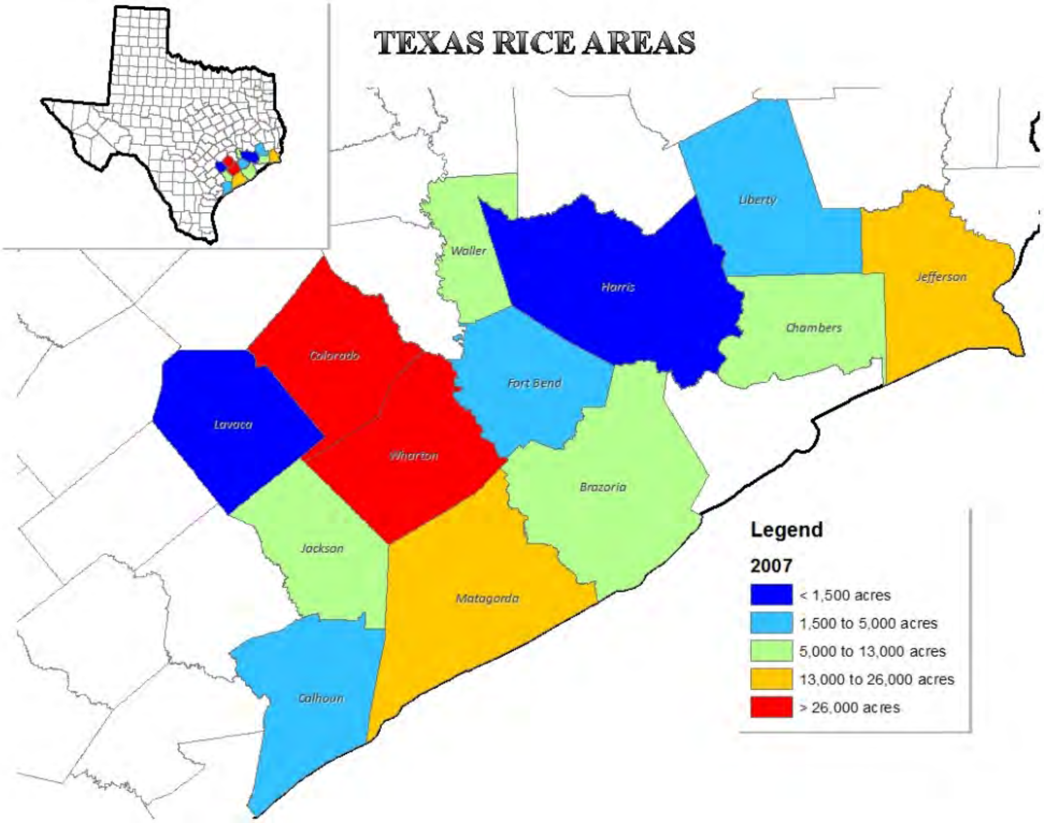

Figure 2-13. Texas rice production areas (2007 NASS Agricultural Census data)

According to the *Texas Rice Production Guidelines* (Way and McCauley, 2012), several seeding methods can be used on fine clay soils, including dry and water-seeding. A well prepared, weed-free seedbed is important when rice is dry-seeded. When dry seeding with a drill on fine clay soils, the field is flushed immediately after planting to ensure uniform emergence. Dry seed can be broadcast on a rough, cloddy seedbed if the planting is followed immediately with a flush. This allows soil clods to disintegrate, cover the seeds, and establish good soil-seed contact, as well as allowing for good germination and uniform emergence. In some areas, dry seed can be broadcast applied on a well prepared seedbed, followed by dragging to cover the seed. This practice also requires immediate flushing of the field so that emergence is uniform. Soil is also flooded immediately after the final seedbed preparation to prevent the establishment of red rice and other weeds. Flushing is normally not used to obtain emergence when rice is drilled into coarse-textured soils because these soils are prone to crusting, which can impede seedling emergence (Way and McCauley, 2012).

If rice is water-seeded, the seedbed may be left in a rough, cloddy condition because the flood breaks up clods and provides some seed coverage. When rice is water-seeded on heavy soils, a 2- to 4-inch flood is established as soon as possible after land preparation. The field is seeded as soon as possible after flood establishment and stabilization to minimize damage from rice seed midge and maintain proper water oxygen content levels, as these levels tend to decrease each day after flood establishment (Way and McCauley, 2012).

In a continuous flood system, dry or sprouted seed are dropped into a flooded field and the flood is maintained until near harvest (Way and McCauley, 2012).

In the pinpoint flood system, dry or sprouted seed are dropped into floodwater. The field is drained after 24 hours and left dry for 3 to 5 days to provide oxygen and allow the roots to anchor or "peg" to the soil. Then the flood is reestablished and maintained until near harvest (Way and McCauley, 2012).

A uniform flood depth of less than 4 inches (1 or 2 inches) is maintained before the rice emerges through the water. The water level is increased to 4 inches as the rice gets taller (Way and McCauley, 2012).

2.8 Ratoon Production

Several factors are critical to successful ratoon crop production, or second/stubble rice production. The earlier the ratoon crop matures, the higher its potential yield. Therefore, rapid stimulation of regrowth is an important factor. Soils are kept moist with a shallow flood until regrowth has advanced and re-tillering has occurred. According to the International Rice Research Institute (1988), appearance of first tiller varies from 1 to 10 days after cutting. The field should be moist but not flooded for 2 weeks at the end of the main crop. After re-tillering, a flood is maintained to control weeds. The duration of the ratoon crop can range from 40 to 135 days. This practice results in an average ratoon duration of 88 days (International Rice Research Institute, 1998).

The climatic conditions of southwest Louisiana and the early germination of commonly grown rice varieties combine to create an opportunity for ratoon crop production. The main crop is harvested by August 15 to ensure adequate time for ratoon rice to develop. Ratoon rice is grown during the months of September and October (Saichuk, 2009).

According to the *Texas Rice Production Guidelines* (Way and McCauley, 2012), fields should not be flushed after harvest. Flushing permits the germination of rice grain residue from harvesting, and the germinated rice seeds become weeds that compete for nutrients and light. Time does not permit them to produce panicles. Flooding immediately after harvest prevents the germination of these seeds through the formation of an anaerobic layer near the soil surface (Way and McCauley, 2012).

Research from Eagle Lake on a Nada fine, sandy loam soil indicates that a dry period of 20 days prior to harvesting the first rice crop is required for optimum ratoon crop yields. For these coarse soil types, draining 10 days before harvest (25 days after main crop heading) is recommended for highest yields and quality. It appears that a short dry period after the main crop is harvested does not adversely affect ratoon crop yields on fine, sandy loam soils.

On fine (clay and clay loam) soils such as Beaumont clay, draining 15 days before harvest (20 days after main crop heading) is recommended for highest yields and quality. These fine soil types can be flooded immediately after main crop harvest without reducing ratoon crop yields, in contrast to the coarse soil types.

2.9 Glossary

Leaf stage or period – Early development in rice with earliest point being 1st leaf and latest point being 5th leaf

Pegging – Upon draining of a water-seeded paddy, the process by which sprouted rice seeds attach their roots to the soil

Ratoon crop - The practice of harvesting grain from tillers originating from the stubble of a previously harvested crop (main crop)

Tillering - The stage subsequent to the leaf stages in rice development

3 Guidance for conducting an ecological risk assessment on the use of pesticides in rice production

PFAM simulates the direct application of a pesticide to a flooded or dry field that is later flooded and predicts concentrations of the pesticide in that field or water body (*e.g*., rice paddy, cranberry bog) (**Figure 3-1**). When application of a pesticide occurs for rice, it may be directly applied to the rice paddy and may be transported to adjacent aquatic and terrestrial areas via spray drift, especially as pesticides are often applied via aerial application. Runoff from rice paddies is generally assumed to be minimal. However, rice paddies will have some water loss through seepage (movement of water through dikes into adjacent water), overflow, or intentional releases from rice paddies (*e.g*., through a weir) after the pesticide application occurs. Thus, pesticides may be transported from the rice paddy via movement with water into adjacent canals. Exposure of non-target organisms to pesticides applied to rice paddies may occur in:

1) the rice paddy,
2) canals or waters adjacent to the rice paddy,
3) a waterbody downstream from the canal, and
4) the terrestrial environment (dry rice paddy or adjacent to rice paddy).

Organisms may be present in all of these places as well (**Figure 3-2**). Residues will occur in water whether the pesticide is applied to a dry or flooded field, as after the field is flooded, residues may move from the soil into the water column.

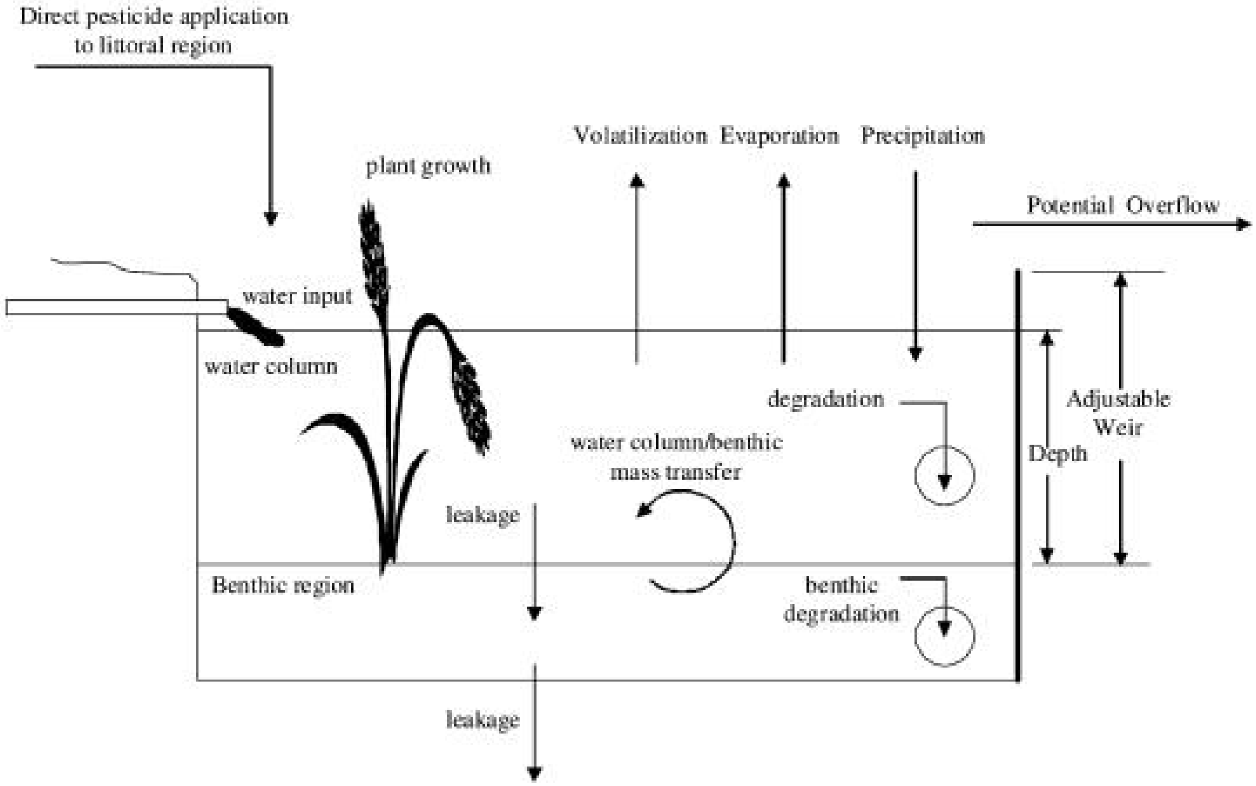

Figure 3-1. The conceptual model for PFAM model

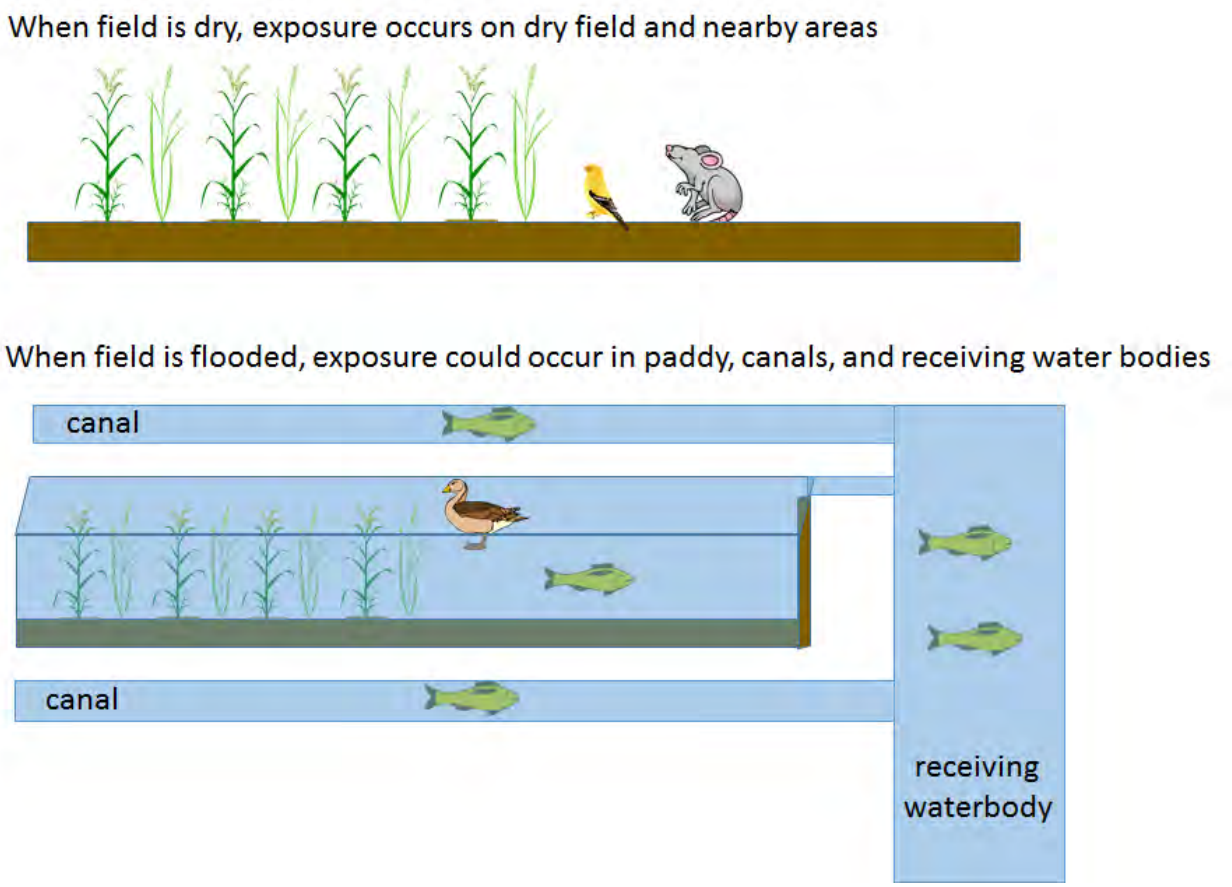

Figure 3-2. Summary of areas where organisms may be exposed to pesticides applied in rice growing areas

Rice paddies and canals associated with rice paddies are promoted as an ecological resource and the water from rice paddies is an important source of water for nearby waters. In the Sacramento Valley, 57% percent of the managed wetlands and 40,000 acres of wetlands use tailwater from the Valley's rice fields (California Rice Commission, 2012b). Wildlife species documented on rice fields include birds (waterfowl, shorebirds, wading birds, raptors, and passerine species), reptiles and amphibians, mammals, and aquatic vertebrates, and invertebrates (Eadie *et al.*, 2008). The document titled, "*Conservation in Ricelands of North America,*" provides details on wildlife using ricelands across the United States including the Mississippi Alluvial Valley, Gulf Coast, and Central California. Typically, fish are not cultivated in rice paddies in the United States; however, in 2013 there was some work on raising salmon in the winter flood in rice grown near the Yolo Bypass of California (Perlman, 2013). While fish are not as abundant as some of other taxa in the rice paddy, fish have been reported to occur in rice paddies and are abundant in canals and ditches next to rice paddies into which paddy water may be released (Eadie *et al.*, 2008; Pearlstine *et al.*, 2007). Therefore, the assumption that fish may occur in rice paddies is conservative. Fish serve as a surrogate for other aquatic vertebrates such as reptiles and amphibians, which are also documented to utilize rice fields. Crawfish are commonly cultivated in rice paddies in the southern United States (Eadie *et al.*, 2008) and aquatic invertebrates serve as an important food resource for other organisms that utilize rice paddies as a resource (Eadie *et al.*, 2008). The density of aquatic invertebrates in rice paddies is reported to be similar to the densities observed in wetlands, reservoirs, naturally flooded forests, and managed moist soil marshes (Eadie *et al.*, 2008).

Terrestrial vertebrates, especially birds, are also abundant on rice fields. It is estimated that 60% of the food resources consumed by wintering waterfowl in the central valley are provided by California rice fields (California Rice Commission, 2012b) and they provide an important resource to 2.5 million of the 5 million ducks using the Pacific Flyway (California Rice Commission, 2012b), 300,000 shorebirds, and 230 species of wildlife overall (California Rice Commission, 2012b). Norling *et al.* (2012) reported that biweekly stratified random surveys of Louisiana and Texas Gulf Coast rice fields estimated over a million birds of 31 species used these rice fields as stopover habitat and that more than 50% of the estimated populations of a number of species used these habitats (Norling *et al.*, 2012). In the Sacramento Valley of California, Elphick and Oring (2003) reported waterbird densities in flooded paddy fields approaching 20 birds per hectare (Elphick and Oring, 2003). These lines of evidence support the need to conduct ecological risk assessments on the use of pesticides on rice for both aquatic and terrestrial organisms.

In EFED, ecological risk is evaluated on the field for terrestrial animals and adjacent to the field for terrestrial plants. For aquatic organisms, risk is typically assessed off the field, as exposure typically occurs through transport in runoff and spray drift; however, when direct applications to water may occur, the potential for adverse effects to aquatic organisms from exposure in that water body is assessed. Current guidance also recommends that risk to terrestrial organisms on the field be evaluated for direct applications to water using T-REX (USEPA, 2013a). Here, residues may occur on plants and insects above the water surface, and exposure at the edge of the field will occur with residues essentially the same as those on the field. Application of pesticides to rice is different compared to other direct applications to water because a crop is raised on the field. For applications of pesticides to rice, risk for terrestrial and aquatic animals is assessed on the rice field where the rice field is considered to be the flooded rice paddy and the berm next to the rice paddy. For applications of pesticides to rice, risk to terrestrial and aquatic plants is assessed adjacent to the rice paddy.

The sections below provide guidance on estimating pesticide exposures following applications to rice and subsequent risks to aquatic organisms, terrestrial animals, and terrestrial plants in adjacent areas.

3.1 Risk to Aquatic Organisms (Plants and Animals)

In assessing risk to aquatic animals (*i.e*., fish, amphibians, invertebrates), exposure is evaluated in the rice paddy for organisms that may move onto the field by comparing toxicity endpoints to estimated exposure in the rice paddy. Exposure estimates are also characterized with concentrations in water that may be released after a specified holding period. These concentrations would represent exposures to organisms located in "receiving waters" (*i.e*., those that are down stream of the rice paddy). The holding period is assumed to be one day if a holding period is not specified on the label. If a minimum water holding period is specified on the label, exposure is estimated in tailwater after that required minimum holding period. PFAM version 2.0 estimates the peak, 90th percentile, and average (over 30 years) exposure in the rice paddy after a specified period from the last day of application. When water is held in the paddy, pesticide residues degrade according to pesticide-specific half-lives. Unlike the human health drinking water assessment where many fields are simulated, in the ecological risk assessment for rice, a single paddy is simulated. Therefore, maximum application rates on the label are simulated, and applications are not spread out over time, unless multiple applications are allowed on the label.

As exposure is estimated in the rice paddy for ecological risk assessment, releases of water after an application could reduce exposure in the paddy. It is uncertain to what extent residues in the water would be diluted after the water leaves the rice paddy as some canals that received water from the rice paddies may have little water in them or the water may be coming from releases from rice paddies upstream. It is expected that at least in some areas pesticide concentrations in canals and waters adjacent to the rice paddy are very similar to the pesticide concentrations in the rice paddy. Therefore, to follow the residues in the water and to provide a protective bound for risk to ecological organisms, water should be held on the rice paddy after the application and until harvest. Reports of humans using the canals right next to rice paddies for fishing are common and the canals are often promoted to be a resource for wildlife (Eadie *et al.*, 2008). It should also be noted that in some areas, water moves from one rice paddy to the next and there have been some cases where residues are applied in one paddy, the water is moved to another paddy, and more pesticide is applied resulting in residues in the water increasing as the water moves from rice paddy to rice paddy.

3.2 Risk to Terrestrial Animals

Terrestrial animals (*i.e.*, birds, terrestrial-phase amphibians, reptiles, mammals, invertebrates) may be exposed to pesticide residues on plants and insects in the rice paddy and in areas next to the rice paddy due to transport of pesticides in spray drift. They may also be exposed to pesticide residues in the rice paddy water, if the rice paddy is used as a drinking water source. For applications of liquid formulations, the standard considerations of the Terrestrial Residue Exposure Model (TREX; *e.g.*, exposure to residues on plants, seeds, and insects) are evaluated for exposures on field and off-field due to spray drift. This applies to both applications to flooded and non-flooded applications. If it is a preplant application, residues on all food items are still evaluated because residues on all dietary items may occur on dietary items at the edge of the field or located on a berm. For any application preplant that involves application to the non-leveled field, all items should be considered. Fields may have plants with foliage at the time of application where all potential food items are likely directly sprayed. For applications of granules, risk is also evaluated in the standard procedure used in TREX[4], whether the application is to a flooded or dry field, as the berm is considered part of the rice field. If the granule is applied directly to a flooded rice paddy, risk is characterized for granules that are inadvertently applied to non-target areas as the granules directly applied to water will dissolve over time and ingestion of the granule is less likely to occur. In general, it is assumed that "spray drift" will be minimal for applications of granules. However, as many applications of pesticides to rice paddies are aerial applications, there is a higher potential for offsite movement of at least some of the applied granules. Additionally, for some granules it takes time for granules to fully dissolve in water and they could be ingested before they fully dissolve. For seed treatments, the TREX analysis is completed for dry seeded rice; however, wet-seeded rice may have already sprouted and similar calculations are not made. Finally, the Kow (based) Aquatic Bioaccumulation Model (KABAM) may be run if the log K_{OW} of the chemical triggers a concern for bioconcentration, bioaccumulation, or biomagnification[5]. Because larger fish are not expected to be

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[4] The standard analysis recommended in the TREX user guide for applications of granular pesticides is an LD_{50} /ft^2 analysis and the calculation of the number of granules that need to be consumed to achieve a dose that would exceed the LD_{50} and trigger an LOC of 0.1 or 0.5. Generally, when an LD50/ft^2 analysis results in an LOC exceedance, additional analysis considering specific exposure pathways is conducted to better characterize risk with a pre-flood application.

[5] KABAM is completed when it is triggered whether the application occurs to a flooded or dry field because residues may move from the soil to water after flooding.

associated with the rice paddy[6,7]; modifications need to be made to the KABAM conceptual model. Tissue concentrations in aquatic organisms can be considered for all of the trophic levels, except the large fish (1.0 kg). The diets of piscivorus birds and mammals (*i.e.*, the large river otter and white pelican) on tables 8 and 9 of the KABAM tool (Ecosystem inputs worksheet) should be altered so that they consume 100% medium fish (instead of 100% large fish). In addition, as noted in the KABAM guidance, the water column and benthic EECs should be reflective of the time to steady state of the pesticide of interest. If the water holding period is shorter than the time to steady state, the risk assessor should characterize potential uncertainties associated with overestimating tissue concentrations in aquatic organisms and associated risks to piscivorus wildlife that may be feeding in the rice paddy. The earthworm fugacity model[8] may be run if LD_{50}/ft^2 screening methods identify a concern for seed treatment (dry seeded) or with a pre-flood application. When running the earthworm fugacity model for applications of pesticides to dry fields, the amount of time it would take to reach equilibrium compares to the amount of time the pesticide is on the dry field before flooding must be considered to determine whether running the earthworm fugacity model is appropriate. The earthworm fugacity model is not utilized for applications to a flooded field.

3.3 Risk to Terrestrial and Semi-Aquatic Plants

For applications of pesticides to rice, there is potential exposure to terrestrial plants. Exposure via spray drift only is evaluated as runoff from rice paddies is assumed to be minimal. The distance from the edge of the field to where LOCs would no longer be exceeded is calculated using standard procedures and as recommended in *Guidance on Modeling Offsite Deposition of Pesticides Via Spray Drift for Ecological and Drinking Water Assessment* (USEPA, 2013a).

3.4 Risk to Pollinators

Assessing pesticide risks to bees is conducted according to the current *Guidance for Assessing Pesticide Risks to Bees* (USEPA *et al.*, 2014). According to the USDA's pollinator attractive crop list (USDA, 2015), rice is not pollinated by bees, but rather by wind. Rice is not considered attractive to bees. Therefore, risk of pesticides to bees should not be assessed on the treated rice paddy.

For pesticides that are applied via foliar spray, spray drift transport onto adjacent areas with blooming crops or weeds may present a relevant exposure to bees. Risks may be assessed using the AgDRIFT model in combination with BeeREX and expressed as the distance from the edge of the field to which risks extend (*i.e.*, where the RQ equals the LOC).

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[6] Duration of flooding in rice fields is similar to that of short-hydroperiod marshes which will be dominated by small pioneering fish species (Pearlstine *et al.*, 2007).

[7] In three years of fish surveys in rice fields of the Everglades Agricultural Area , 22 fish species were observed, including the eastern mosquitofish (*Gambusia holbrooki*), flagfish (Jordanella Floridae), Bluefin killifish (*Lucania goodei*), least killifish (*Heterandria Formosa*) and sailfin molly (*Poecilia latipinna*) (Pearlstine *et al.*, 2007).

[8] Experience with carbofuran incidents of rice field bird mortality involving granules during the interval pre-flood indicated a large number of soil gleaning invertivores killed, including species such as western sandpiper, pectoral sandpiper, buff breasted sandpiper, least sandpiper. There are a variety of soil/sediment probing birds in Rice paddy systems in the United states according to *Birds of Rice Fields in the Americas* (Acosta *et al.*, 2010).

Risks can be precluded for bees for seed treatments and granular formulations of pesticides applied to rice since on-field and off-field exposure is considered negligible.

4 Human Health Drinking Water Conceptual Models

For human health drinking water assessments, PFAM simulates applications to several thousands of acres of rice. It simulates what happens in the rice paddy, as simulated for ecological risk assessment, but it also simulates release of water from rice paddies that eventually goes into a section of a flowing water body where a drinking water intake is located (**Figure 4-1)**. Spray drift is simulated as a mass going into the flowing water or base flow through the flowing water body. Flow from runoff coming from the surrounding watershed also flows through the flowing water body.

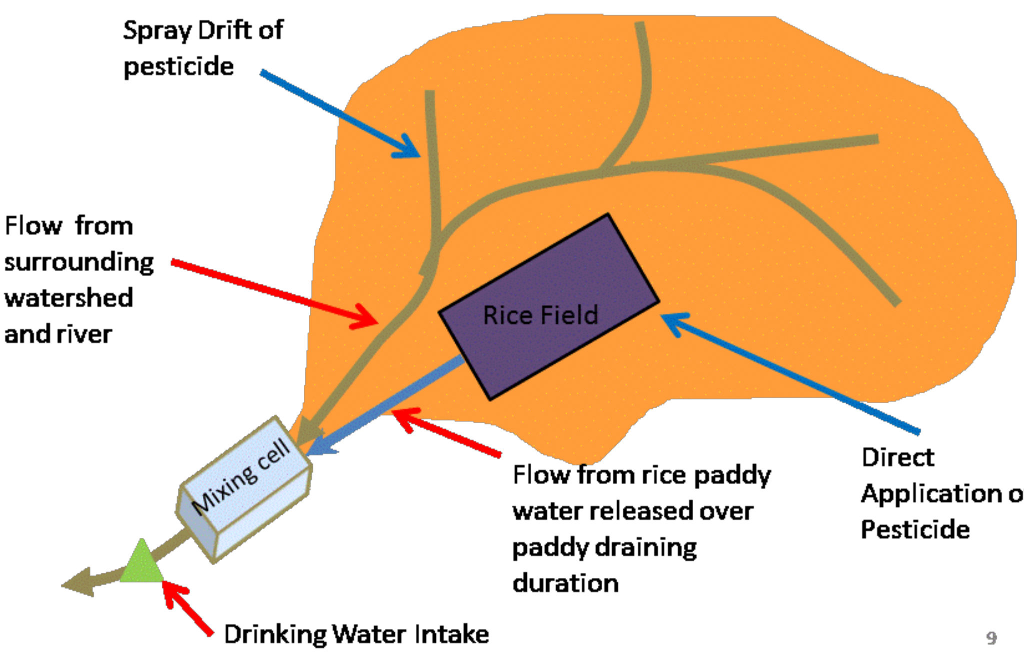

Figure 4-1. The conceptual model for simulating drinking water concentrations from applications of pesticides to rice

4.1 California Drinking Water Conceptual Model

4.1.1 Determination of Watershed and Drinking Water Intake

Most rice in CA is grown in the Sacramento Valley (**Figure 4-1**), while much lesser amounts are grown in the northeast and central coast.

Some wild rice is grown in the northeast (*i.e.*, Modoc and Shasta counties). Based on the Drinking Water Intake (DWI) watershed dataset, Version 1.0 (USEPA, 2014), DWI exist in these counties and the water quality at these intakes may be influenced by rice production. However, the amount of rice grown in the northeast is much smaller (9,018 acres) than that in the Sacramento Valley (518,337 acres), and the 2012 and 2015 Cropland Data Layers (USDA, 2012) do not show any rice grown in the northern counties.

Therefore, we focused on the Sacramento Valley area for development of a CA conceptual model. **Table 4-1** provides the results of the 2007 NASS Agricultural Census Acres Harvested for CA (USDA, 2009). The total acres harvested of rice and wild rice in CA in 2007 was 549,357 acres. The table is sorted from highest to lowest acres rice harvested. Colusa, Sutter, Butte, and Glen counties are the counties with the highest levels of rice grown.

Table 4-1. NASS 2007 Agricultural Census rice and wild rice acres harvested in California counties

County	Rice Acres	Wild Rice Acres	Ag District
COLUSA	147,817	D	SACRAMENTO VALLEY
SUTTER	99,284	3,750	SACRAMENTO VALLEY
BUTTE	97,845	1,050	SACRAMENTO VALLEY
GLENN	93,817	--	SACRAMENTO VALLEY
YUBA	33,399	1,428	SACRAMENTO VALLEY
YOLO	29,675	4,243	SACRAMENTO VALLEY
PLACER	9,313	--	SIERRA MOUNTAINS
SACRAMENTO	5,114	--	SACRAMENTO VALLEY
FRESNO	5,036	--	SAN JOAQUIN VALLEY
SHASTA	--	5,097	NORTHEAST
SAN JOAQUIN	4,323	--	SAN JOAQUIN VALLEY
MODOC	--	3,921	NORTHEAST
MERCED	2,958	--	SAN JOAQUIN VALLEY
TEHAMA	915	--	SACRAMENTO VALLEY
STANISLAUS	372	--	SAN JOAQUIN VALLEY
MADERA	D	--	SAN JOAQUIN VALLEY
NAPA	D	--	CENTRAL COAST
SOLANO	D	--	SACRAMENTO VALLEY
LASSEN	--	D	NORTHEAST
Sum	529,668	19,489	--

D=data withheld to avoid disclosing data for individual farms

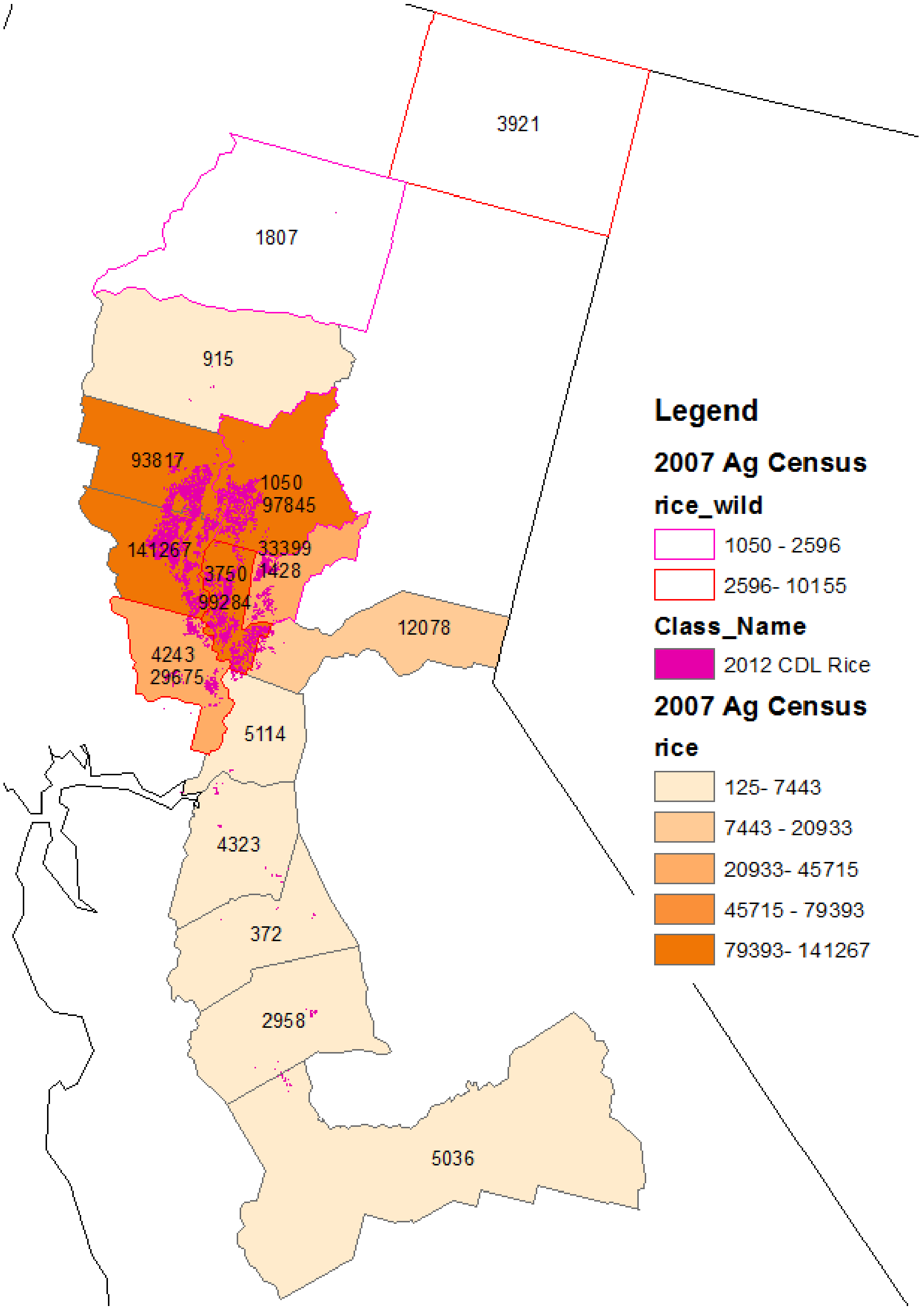

Figure 4-2. NASS 2007 Agricultural Census acres rice and wild rice harvested
The numbers listed are the acres harvested for rice, wild rice, or both.

There are four surface water DWI located in Yolo and Sacramento Counties in CA that would receive the greatest influence from rice.[9] The DWI chosen as the representative intake for the conceptual model is

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[9] The source of the drinking water intakes and associated watersheds is the Drinking Water Intake (DWI) watershed dataset, version 1.0 (DWI_Basins.mdb, 09/08/2011) developed by the Environmental Fate and Effects Division. The mapped drinking water intakes include 6550 intakes and associated watersheds. Not all of the DWI have associated watersheds delineated.

near Sacramento. The closest United States Geological Survey (USGS) gage station is on the Sacramento River at Verona, CA.

This large watershed (58,460 km^2 or 14, 445,978 acres) encompasses most of the rice in the area that has a potential to influence the DWI, and for this reason was chosen as the watershed of interest (**Figure 4-3**). While it appears that there are many smaller watershed sets that would encompass the 2012 CDL rice or the DWI separately, no single smaller watershed encompasses both the 2012 rice CDL that could impact the DWI and the DWI of interest. Counties overlapping the selected watershed include the following: Alpine, Amador, Butte, Colusa, El Dorado, Glenn, Lake, Lassen, Mendocino, Modoc, Nevada, Placer, Plumas, Sacramento, Shasta, Sierra, Tehama, Trinity, Yolo, and Yuba. Many of these counties do not grow rice. The NASS acres in these counties sum to 536,668, as shown in **Table 4-2** and is only 12,689 acres less than the total NASS acres for rice reported for CA.

Table 4-2. NASS 2007 Agricultural Census rice and wild rice acres harvested in California counties that overlap with watershed used for the conceptual model

County	Rice Acres	Wild Rice Acres	Ag District
COLUSA	147,817	D	SACRAMENTO VALLEY
SUTTER	99,284	3,750	SACRAMENTO VALLEY
BUTTE	97,845	1,050	SACRAMENTO VALLEY
GLENN	93,817	--	SACRAMENTO VALLEY
YUBA	33,399	1,428	SACRAMENTO VALLEY
YOLO	29,675	4,243	SACRAMENTO VALLEY
PLACER	9,313	--	SIERRA MOUNTAINS
SACRAMENTO	5,114	--	SACRAMENTO VALLEY
SHASTA	--	5,097	NORTHEAST
MODOC	--	3,921	NORTHEAST
TEHAMA	915	--	SACRAMENTO VALLEY
LASSEN	--	D	NORTHEAST
Sum	517,179	19,489	--

D=data withheld to avoid disclosing data for individual farms

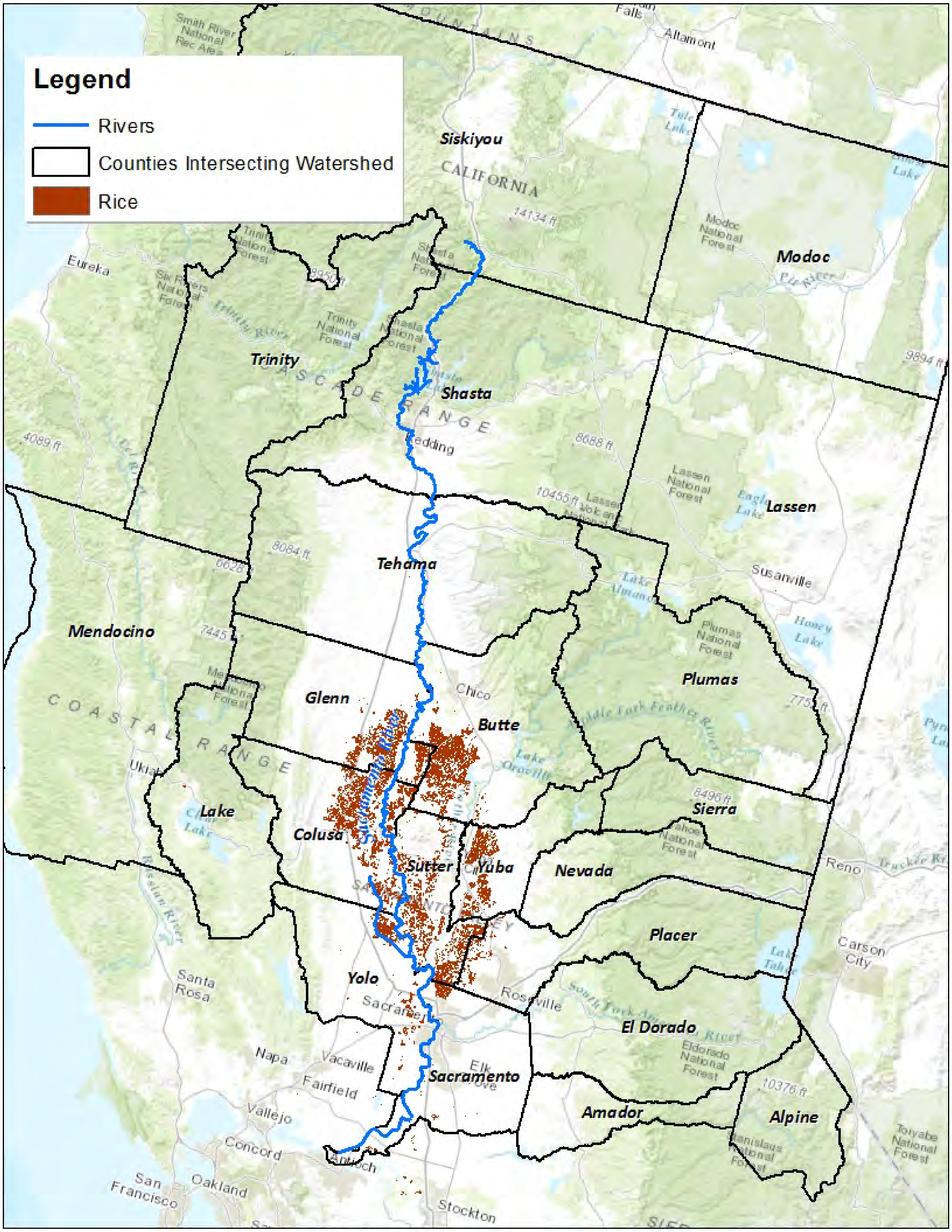

Figure 4-3. Counties that overlap with the drinking water intake watershed and rice growing areas in California used to develop the California conceptual model

The DWI of interest is just north of Sacramento in the city of West Sacramento, CA (USGS, 2013). The Sacramento River flows south through an intensive rice-growing area north of Sacramento and then into Sacramento. A few DWIs are located near Sacramento. Personal communications with California stakeholders in 2012 revealed that a new diversion from the Sacramento River will be coming online a short distance north of the representative DWI chosen for the conceptual model, which was the DWI located the farthest north near Sacramento. This DW conceptual model is expected to be representative or protective of the DWI in and near Sacramento.

4.1.2 Area of Rice in the Watershed

The area of rice was calculated using the standard methodology for calculation of percent cropped areas adjustment factors (except using 2012 CDL data in place of NLCD data) commonly used in OPP to calculate the area of rice in a watershed (USEPA, 2014). In this methodology, the 2007 NASS rice acres in a county are distributed evenly over rice 2012 CDL pixels in a county[10]. This results in a NASS rice acres per rice CDL pixel for each county. Then the watershed area is shown, and a NASS rice acres for the watershed is calculated based on how many rice CDL pixels for each county are inside the watershed and how many NASS rice acres per rice pixel (see **Appendix A**). CDL data were used in place of NLCD because rice is not evenly distributed throughout the county and across agricultural land.

4.1.3 Base Flow, Width, Depth, and Length of Mixing Cell

The relevant water body of interest for concentration estimates is assumed to be a mixing cell located at the DWI. For this mixing cell, base flow, width, depth, and length are needed for characterization of its physical behavior. Width , flow and depth was obtained from the United States Geological Survey (USGS) National Water Information System (NWIS) (USGS, 2013). Length was assumed to be 40 meters, which allows representation simulation of typical dispersion in natural rivers in the U.S. (USEPA, 2015).

One USGS site (USGS 11425500 Sacrament River at Verona, CA[11]) is north of the West Sacramento DWI (**Figure 4-5**). **Figure 4-4** summarizes flow information for the site. The flow rate where 90 percent of the daily flow exceeds the value between 1946 and 2012 was chosen to be representative of the base flow for modeling (7,780 ft^3/second). One concern was that the measured flow includes rice discharge water, and paddy water flowing through the site should not be diluted by itself. Additionally, low flows coincide to when discharges from rice paddies are expected to occur (*e.g.*, May through September; **Figure 4-4)**. Additionally, this value is a low flow value and will be conservative. Gage height (average is 17 ft) for the site are summarized in **Appendix B**. The width was determined by measuring the width at the DWI of interest using ArcMap 10.1, the measure tool, and satellite imagery.

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[10] The area of rice calculations were completed before the 2012 Agricultural Census Data were available. The 2007 Ag Census Acres harvested of rice in 2007 was 90% of the area harvested in 2012. The 2012 data is not expected to substantially change the conceptual model results.

[11] USGS data for the Sacramento River (accessed 06/13/2013)

Table 4-3. Discharge in cubic feet per second at USGS Site 11425500 Sacramento River at Verona, CA*

Parameter	2011	2012	1946-2012
Annual Mean	24,490	14,970	19,750
Highest Daily Mean	67,700 (Mar 26)	46,100 (Mar 18)	95,600 (Jan 3, 1997)
Lowest Daily Mean	9,870 (Nov 11)	7,610 (May 18)	3,59. 0 (June 24, 1992)
Annual 7-day minimum	10,000 (Nov 5)	8,020 (May 15)	3,960 (June 22, 1992)
Maximum peak flow	--	46,900 (Mar 18)	102,000 (Jan 2, 1997)
90 percent exceeds	11,500	10,100	7,780

* Data were calculated by the USGS and reported in Water-Data Report 2012 (USGS, 2012b).

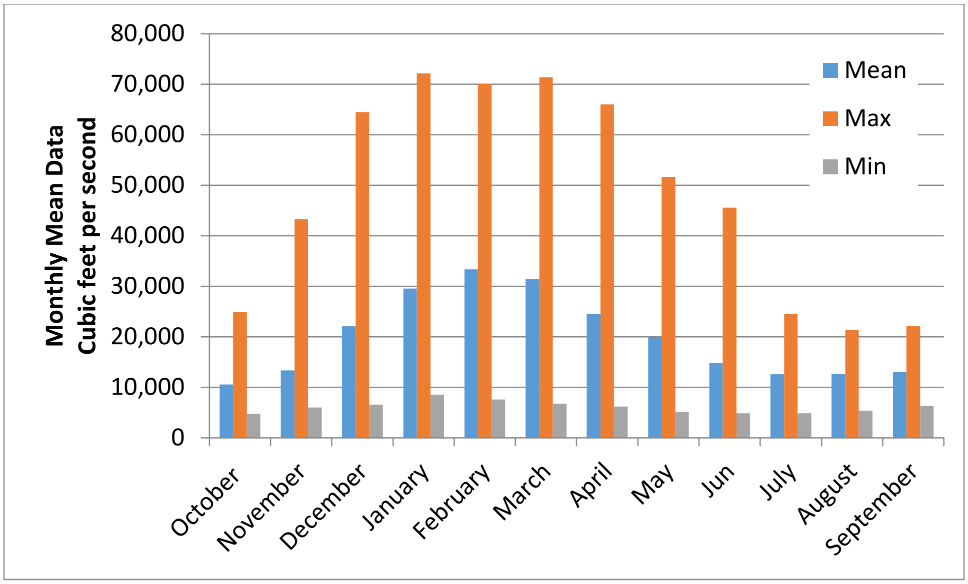

Figure 4-4. Statistics of monthly mean data for water years 1946 – 2012. Data from USGS (USGS, 2012b)

4.1.4 Spread of Application and Flood Events

For DW assessments, applications are simulated for several thousand acres of rice. Therefore, applications are spread out over time. Because of the large area of rice simulated, it is not expected that all acres of rice would be treated with a single pesticide. Therefore, a percent crop treated (PCT) may be used to refine a DW estimate of exposure. The PCT is not used for ecological risk assessment because in ecological risk assessments, the area of interest is the paddy itself, which is entirely treated with pesticide. The application timing recommended in the developed scenarios for simulating EDWC reflects applications that are expected to occur during the rice growing season when rice paddies are flooded. The timing of application should be adjusted to reflect the specific pesticide being simulated, but the applications should be spread out over time for DW assessments. If the number of days over which the pesticide applications is spread out is changed, justification should be provided as to why the change was made because the number of days over which applications are spread out can have a big impact on the estimated drinking water concentrations (EDWC). For DW assessments, applications were spread out over 46 days. This was supported as a reasonable range based on data from the CA Pesticide Use Reporting Database (see **Appendix C**).

For DW assessments, EDWCs are evaluated in a receiving water body outside of the rice paddy. Releases from the rice paddy are adjusted to maximize release from the rice paddy. Therefore, a release of a percentage of water in paddies either the day after or after a minimum holding period is simulated. This practice allows the risk assessment to capture benefits from implementing a holding period. For DW assessments, release of flood water after a holding period was spread out over 33 days. This simulates a drawdown of the water during the rice growing season that may occur with applications of some pesticides. Water is then brought back up to a full flood height as it is the most common practice to maintain the flood height to prevent weeds from growing. The flood release for harvest is spread over the typical harvest dates for the area of interest.

While the dates of applications are important in determining the EDWCs, application dates are primarily chemical parameters and are not saved in the scenario file. Suggested application dates are provided for the different scenarios. The following application and flooding scenarios were developed for DW simulations: mixed, pre-flood, and post-flood. In pre-flood, all applications occur before the flooding of rice paddies begin. For post-flood, all applications occur after the flooding of rice paddies begin. In the mixed scenarios, applications may occur pre- or post-flood of the rice paddy.

Currently in CA, winter flooding is very common (80% of rice fields; personal communication with rice farmers). Less information was available to characterize whether Arkansas and MO use winter floods; however, there is literature describing the use of rice paddies to provide habitat for birds and a place for hunting in the winter, indicating that the practice does occur to some degree. In CA, winter floods were included in the developed scenarios. For Arkansas/MO, scenarios were created with and without a winter flood.

Rice growers in CA have reported that turnover (at a low rate) is maintained in most rice paddies to prevent algae growth. Therefore, turnover at a low rate was applied in modeling. In the absence of data, a turnover rate of once in 60 days was chosen (0.017). For DW assessments, this has a low impact on the EDWCs.

See the *Metadata for Pesticides in Flooded Applications Model Scenarios for Simulating Pesticide Applications to Rice Paddies* (referred to as the Scenario Metadata) document for more specific recommendations on application dates and simulating flood events.

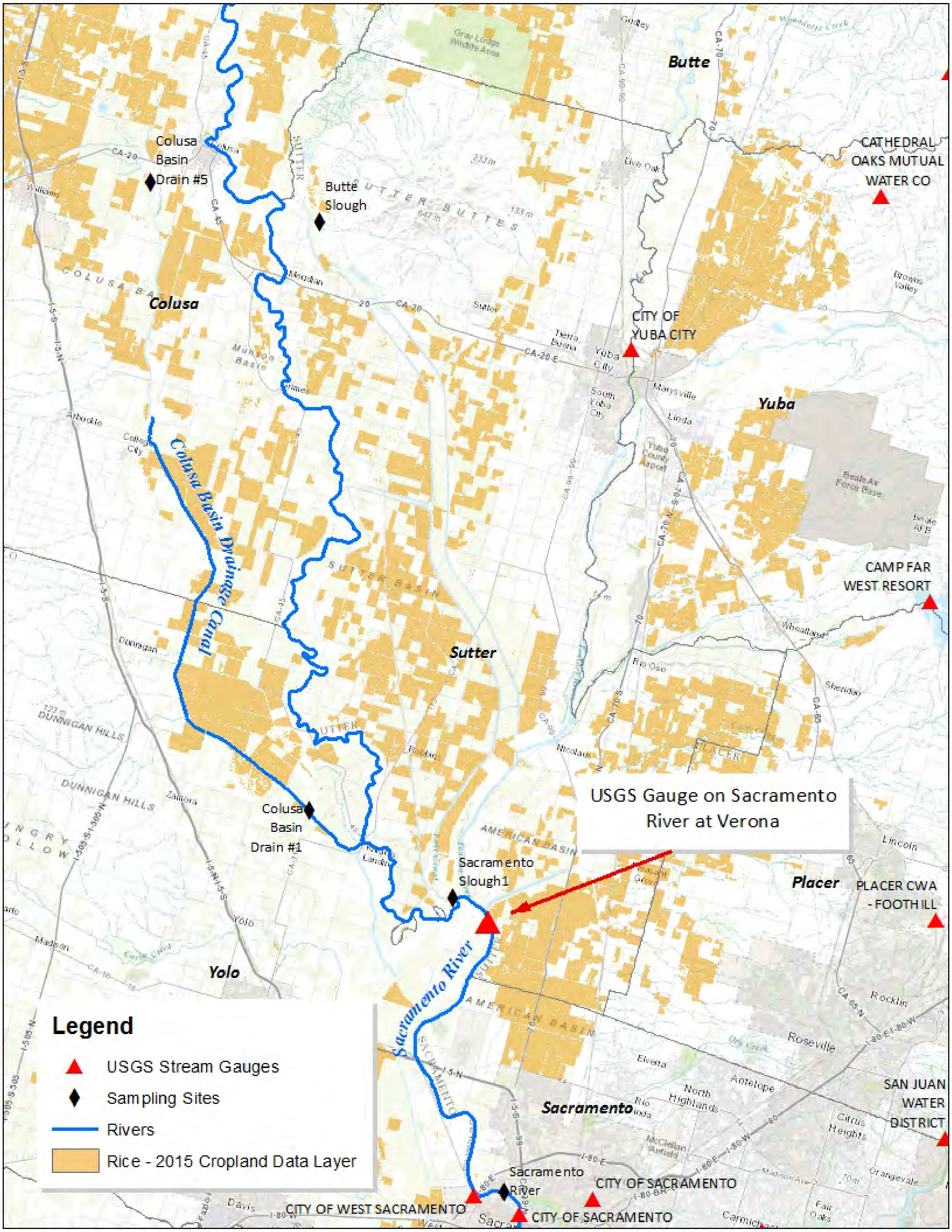

Figure 4-5. USGS gages near Sacramento

Table 4-4. Inputs for the conceptual model for the drinking water intake on the Sacramento River in CA

(a) Physical Tab

Input	Value	Notes
Weather station	W23232	Metfile located closest to drinking water intake near Sacramento, CA
Area of application/rice (m^2)	2,071,280,629	511,824.59 acres rice in watershed (2,071,280,629.18 m^2), see text for calculation.
Latitude	38.6°	Latitude of DWI according to DWI Watershed Dataset, Version 1

(b) Watershed Tab

Input	Value	Notes
Area of surrounding watershed (m)	56,389,517,946	The actual area of the watershed is 58,460,798,574.9 m^2 or 14,445,977.9 acres. The input is the area of the watershed minus the application area resulting in 56,389,517,945.72 m^2.
Curve Number of surrounding watershed	70	The majority of the watershed is forest. The curve number reflects the curve number for a C soil in a forest with a good condition (Carousel, 2006). Minimizing dilution is the most conservative as water runoff does not carry pesticides mass. This parameter did not significantly influence results in CA.
Base flow (m^3/sec)	220	90 percent exceeds between 1946 and 2012 (7780 ft^3/s or 220 m3/s (USGS, 2012)
Width of mixing cell (m)	194	Measured width of river at intake using measure tool in ArcGIS10.1 and satellite imagery (World Imagery)
Depth of mixing cell (m)	5.1	The mean annual gage height for USGS NWIS site 11425500 on the Sacramento River at Verona is 33 feet (10 m).
Length of mixing cell (m)	40	The Spatial Aquatic Model (SAM) is now using an assumption of a 40 m length for flowing water bodies (Fischer *et al.*, 1979; Rutherford, 1994)

4.2 Arkansas/Missouri Drinking Water Conceptual Model

4.2.1 Determination of Watershed and DWI

Arkansas grows approximately 49% of the rice cultivated in the United States, making it an area of interest for the development of a conceptual model. There is only one surface water DW intake in Arkansas in the rice growing areas (PWSID AR0000474)[12]. Therefore, the watershed that encompasses that intake was chosen as the area of interest for developing a conceptual model for DW for rice (see **Figure 4-6**). The closest USGS gage station to the DWI is on the Black River near Pocahontas, Arkansas (USGS site number 0706900[13]). This watershed of interest is a very large watershed that encompasses the following counties:
MO: Dent, Texas, Shannon, Reynolds, Carter, Wayne, Ripley, Butler, Iron, and Oregon.
AR: Randolph, Greene, and Clay

Only five of these counties grow rice: Clay, Randolph, Butler, Ripley, and Greene. However, this watershed only encompasses a very small portion of the rice grown in Greene County. The total acres of rice harvested in the main counties covered by the watershed is 165,260. This number represents the maximum amount of acres of rice that may be grown and that influence the DWI in Arkansas.

Table 4-5. NASS 2007 Agricultural Census acres rice harvested in counties that overlap with the watershed used for the Arkansas/Missouri conceptual model

County	Acres Rice Harvested
CLAY	67,196
RANDOLPH	34,790
RIPLEY	3,400
BUTLER	59,874
GREENE	87,180
Total	252,440

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[12] The source of the drinking water intakes and associated watersheds is the Drinking Water Intake (DWI) watershed dataset, version 1.0 (DWI_Basins.mdb, 09/08/2011) developed by the Environmental Fate and Effects Division. The mapped drinking water intakes include 6550 intakes and associated watersheds. Not all of the DWIs have associated watersheds delineated. The actual watershed and drinking water intake are not shown because they are considered sensitive information.

[13] Click here to go to USGS data for Black River

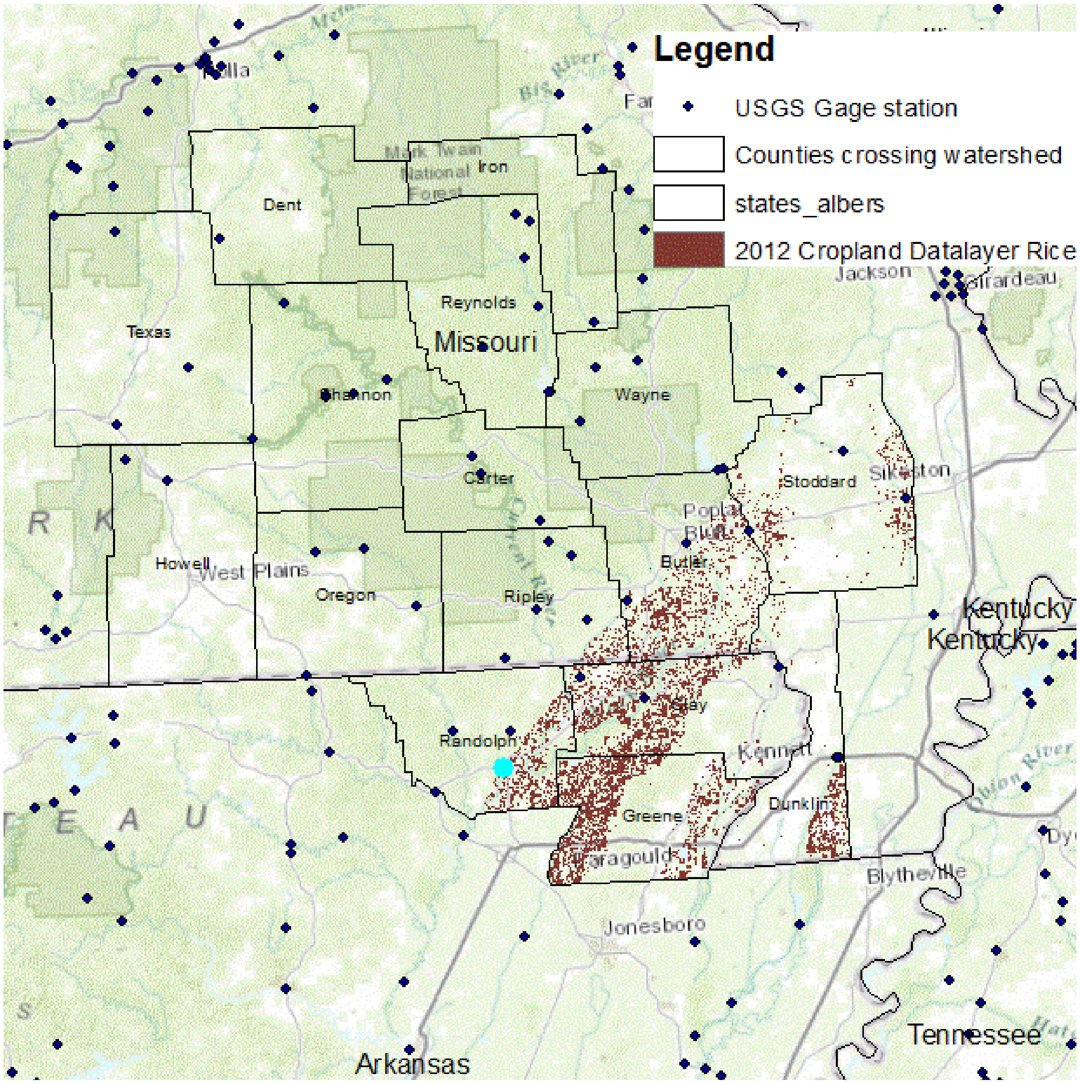

Figure 4-6. Counties intersecting watershed (Basin ID 4026713-1)
The USGS Gage station in light blue is the Gage station near the DWI.

4.2.2 Area of Rice in the Watershed

The area of rice in the watershed was determined using the same methodology used for the CA conceptual model. The total acres of rice in the watershed based on the 2007 NASS Agricultural Census Data, 2012 CDL Rice areas, and the DWI watershed is 102,344.85 acres. This calculation was validated for quality control. The area of the watershed is 3,098,844.77 acres.

4.2.3 Base Flow, Width, Depth, and Length of Mixing Cell

The relevant water body of interest for concentration estimates is assumed to be a mixing cell located at the DWI. For this mixing cell, base flow, width, depth, and length are needed for characterization of its physical behavior. Width , flow and depth was obtained from the United States Geological Survey (USGS) National Water Information System (NWIS) (USGS, 2013). Length was assumed to be 40 meters, which allows representation simulation of typical dispersion in natural rivers in the U.S. (USEPA, 2015).

For the mixing cell in PFAM, the base flow, width, and depth was obtained from the United States Geological Survey (USGS) National Water Information System (NWIS) (USGS, 2013). One USGS site (USGS 07069000 Black River at Pocahontas, AR) is near the DWI of interest. **Table 4-6** summarizes flow information for the site. The flow rate where 90 percent of the daily flow exceeds the value between 1946 and 2012 was chosen to represent the base flow for modeling (1,690 ft^3/second). One concern was that the measured flow includes rice discharge water, and paddy water flowing through the site should not be diluted by itself. In Arkansas, the higher flow rates in the Black River occur during the early to mid-rice growing season (May, June, and July) and then flows decline in August and September (when most releases from rice paddies are expected to occur (**Figure 4-7)**. Additionally, this value is a low flow value and will be conservative. The average gage height between 2002 and 2011 is 2.3 m. The width was determined by measuring the width at the DWI of interest using ArcMap 10.1, the measure tool, and satellite imagery. Inputs for the AR/MO conceptual model are described in **Table 4-6.**

Table 4-6. Discharge in cubic feet per second at USGS Site 07069000 Black River at Pocahontas, AR*

Parameter	2011	2012	1936-2012
Annual Mean	8,734	4,520	5,638
Highest Daily Mean	83,700 (Apr 28)	15,800 (Dec 7)	83,700 (Apr 28, 2011)
Lowest Daily Mean	1,820 (Jan 31)	1,200 (Jul 6)	1,080 (Oct 16, 1956)
Annual 7-day minimum	1,840 (Jan 25)	1,250 (Jul 2)	1,090 (Oct 15, 1956)
Maximum peak flow	--	16,000 (Dec 7)	86,600 (Apr 28, 2011)
10 percent exceeds	15,800	9,540	11,900
50 percent exceeds	5,960	2,800	3,490
90 percent exceeds	2,030	1,500	1,690

* Data were calculated by the USGS and reported in the Water-Data Report 2012 (USGS, 2012a, 2012b).

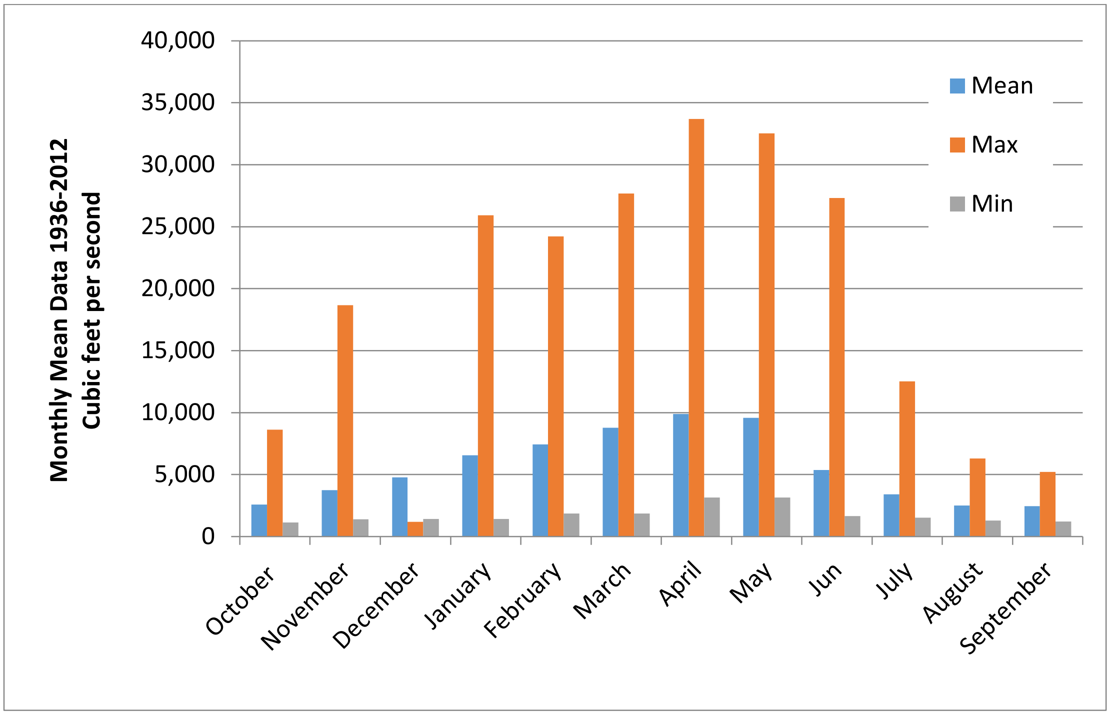

Figure 4-7. Statistics of monthly mean data for water years 1936 – 2012. Data from USGS (USGS, 2012a).

4.2.4 Spread of Application and Flood Events

Specific use data are not available for MO and AR. Therefore, the same general assumptions for spreading applications out over time use in CA were also assumed for Arkansas. However, the actual date of the applications were specific to the MO/AR conceptual model. See the *Scenario metadata* analysis for additional details on these parameters for the conceptual model.

Table 4-7. Inputs for the conceptual model for the drinking water intake on the Black River in Arkansas

(a) Physical Tab

Input	**Value**	**Notes**
Weather station		Metfile located closest to DWI near Sacramento, CA
Area of application/rice (m^2)	414,175,280	102,345 acres, see text for calculation.
Latitude		Latitude of DWI according to DWI Watershed Dataset, Version 1

(b) Watershed Tab

Input	***Value***	***Notes***
Area of surrounding watershed (m)	12,126,415,684	The actual area of the watershed is 12,540,590,964 m^2 (2,996,503 acres), obtained from ArcGIS. The input is the area of the watershed minus the application area.
Curve number of surrounding watershed	70	The majority of the watershed is forest. The curve number reflects the curve number for a C soil in good condition, located in a forest (Carousel, 2006). Minimizing dilution is the most conservative as water runoff does not carry pesticides mass. This parameter did not significantly influence results in CA.
Base flow (m^3/sec)	48	90 percent exceeds between 1936 and 2012 (1690 ft^3/s or 48 m^3/s (USGS, 2012)
Width of mixing cell (m)	98	Measured width of river at intake using ArcGIS10.1 and satellite imagery (World Imagery)
Depth of mixing cell (m)	2.3	In 2013 the range of the depth of a USGS gage station ranged from 0.03 ft to 17.96 ft. The mean annual gage height ranged from 5.7 to 8.8 feet between 2002 and 2011 and is available for five years. The average value of those values is 7.478 feet (2.279 m).
Length of mixing cell (m)	40	The Spatial Aquatic Model (SAM) is now using an assumption of a 40 m length for flowing water bodies (Fischer *et al.*, 1979; Rutherford, 1994)

5 Development of Spray Drift Values for Rice Production

5.1 Introduction

The approach for estimating spray drift into canals that surround rice paddies differs from estimating spray drift to the USEPA standard index reservoir or farm pond. The conceptual models for the index reservoir and farm pond are on a significantly smaller spatial scale than the conceptual model for rice. Aquatic spray drift exposures from the index reservoir and farm pond integrate spray drift from a field application to a single body of water. The conceptual model for rice includes the watershed relevant to the DWI of concern and all rice paddies within the watershed. Spray drift to the canals that are proximate to rice paddies receive more or less drift depending on their distance to a rice paddy and the width of the particular canal. This section explains how spray drift factors are determined to simulate spray drift loading to non-target water bodies from applications of pesticides to rice paddies. Spray drift factors represent spray drift to canals adjacent to rice paddies that flow into the nearby streams and rivers that could impact DW.

5.2 Characterization of Spray Drift to Canals in California

Eight rice paddies (subsequently referred to as "model paddies") were selected from the Colusa Basin in CA to represent the typical canal orientations around rice paddies. The paddies were selected so that they are far enough away from one another that large buffers from each paddy will not overlap with one another. The selected rice paddies can be found at the coordinates listed in **Figure 5-1** within the Albers Equal Area Conic NAD83 coordinate system.

-2,177,401.569 2,128,827.941 Meters	-2,175,284.898 2,122,213.345 Meters
-2,174,755.730 2,128,960.233 Meters	-2,189,909.771 2,074,548.562 Meters
-2,173,300.519 2,126,777.416 Meters	-2,181,654.755 2,066,214.170 Meters
-2,167,479.674 2,123,470.118 Meters	-2,197,212.286 2,059,070.406 Meters

Figure 5-1. Locations of representative California rice paddies used for spray drift analysis

Canals near the model paddies are accounted for based on their distance away from the paddy from directly adjacent to the paddy to 300 meters away. The following process description details the steps taken to categorize the canals based on distance from the model paddies. Using ArcMap v10.1, polygons were created for each selected rice paddy. Using Analysis Tools>Proximity>Buffer, five buffer shapefiles, with distances from the paddy of 10 meters, 50 meters, 100 meters, 200 meters, and 300 meters were created around each selected paddy. Using Analysis Tools>Overlay>Intersect, each buffer was intersected with the National Hydrography Dataset (NHDPlus version 2). Five of the eight selected rice paddies, with intersected NHDPlus flowlines (high resolution), are displayed below in **Figure 5-2**.

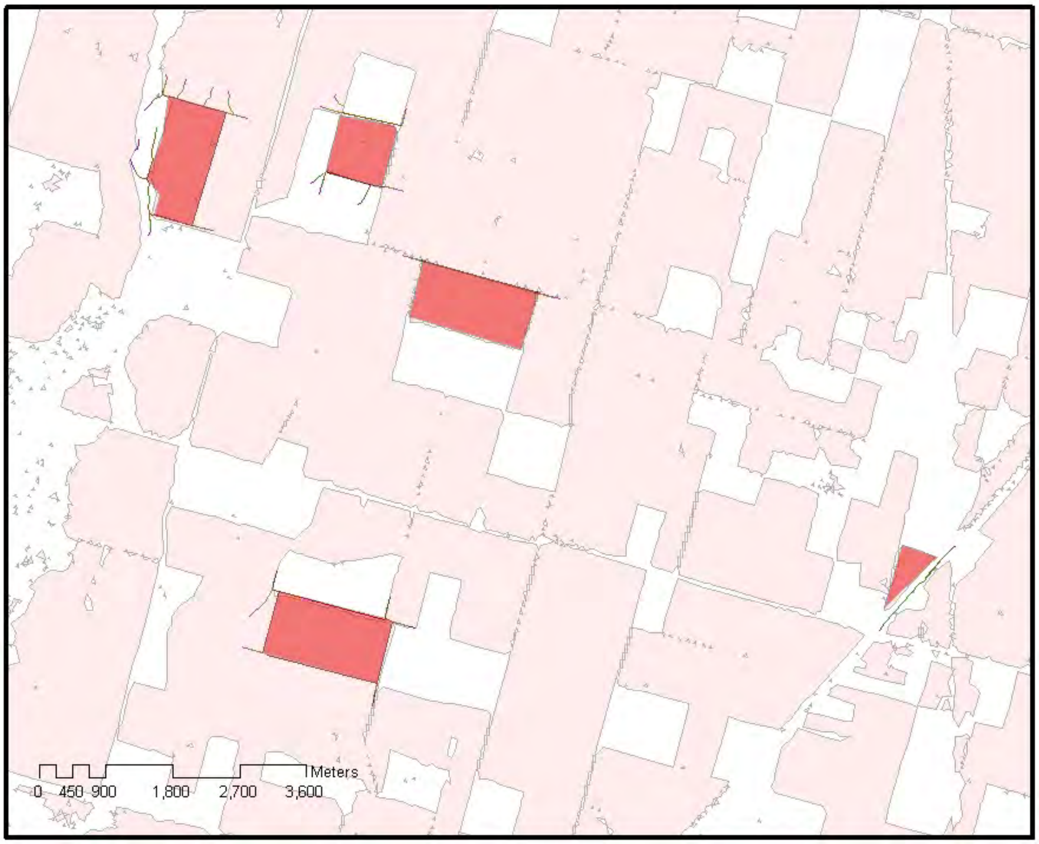

Figure 5-2. Five rice paddies in California used to calculate spray drift factors

Using AgDRIFT version 2.1.1, spray drift deposition curves, average spray drift deposition was derived for each of five buffer widths. Furthermore, length of canal captured within each of five buffers around the eight selected paddies was totaled and factored with the corresponding spray drift fraction. Finally, all canals were assumed to be three meters wide based on aerial photography analysis and site visits to CA rice paddies as seen in **Figure 5-3**.

Figure 5-3. A typical canal adjacent to a rice paddy (photo: A. Shelby)

Buffer widths with corresponding buffer areas and spray drift values are presented in **Table 5-1**. The buffer distance capturing the largest area of canal is zero to ten meters away from the model paddies because canals are typically directly adjacent to rice paddies. The drift fractions presented below are the average depositions within the buffer distances. For instance, the average deposition from the edge-of-field to ten meters from the application site for an aerial application with a very fine to fine droplet spectrum, as defined by American Society of Agricultural Engineers (ASAE), is 40% of the given application rate.

Table 5-1. Canal area receiving drift from representative paddies and average spray drift as the fraction of application rate within each buffer area

(a) Aerial Drift Fractions[2]

Buffer distance from edge of paddy (m)	Canal area receiving drift from 8 selected paddies within each buffer range[1] (m^2)	Very Fine to Fine	Fine to Medium	Medium to Coarse	Coarse to Very Coarse
0-10	56,170	0.40	0.31	0.27	0.25
10-50	32,549	0.23	0.11	0.065	0.043
50-100	19,081	0.12	0.039	0.020	0.012
100-200	23,918	0.07	0.020	0.0094	0.0058
200-300	23,599	0.05	0.013	0.0062	0.0034

(b) Ground Drift Fractions[2]

Buffer distance from edge of paddy (m)	Canal area receiving drift from 8 selected paddies within each buffer range[1] (m^2)	Fine to Medium/ Coarse	Fine/ Very Fine
0-10	56,170	0.26	0.40

Buffer distance from edge of paddy (m)	Canal area receiving drift from 8 selected paddies within each buffer range[1] (m^2)	Fine to Medium/ Coarse	Fine/ Very Fine
10-50	32,549	0.0049	0.011
50-100	19,081	0.0023	0.0043
100-200	23,918	0.0013	0.0022
200-300	23,599	0.00075	0.0012

1 Canal width is assumed to be three meters

2 Deposition curves were derived from field tests in which the aircraft (for aerial deposition curves) made 20 flight lines with a flight line width of 60 feet. Assuming a square field, this represents a 33-acre field. Considering a typical rice paddy is 50 to 100 acres, the data is not overly conservative, as at least 20 flight lines would be made in a typical paddy area.

Beyond accounting for the spatial orientation of water bodies receiving drift from applications to rice, wind direction and orientation in other rice production regions must also be accounted. The spray drift deposition curves from AgDRIFT only account for wind blowing from one direction. However, the methods used here for deriving spray drift assume drift from all directions dispersing from the rice paddy. This may overestimate deposition because wind blowing away from the canal would not contribute to deposition. Therefore , spray drift values were halved to better account for relevant wind directions. Conceptually, canals upwind from a given paddy are not considered to receive drift, while those canals downwind receive drift. This concept can be seen below in **Figure 5-4**.

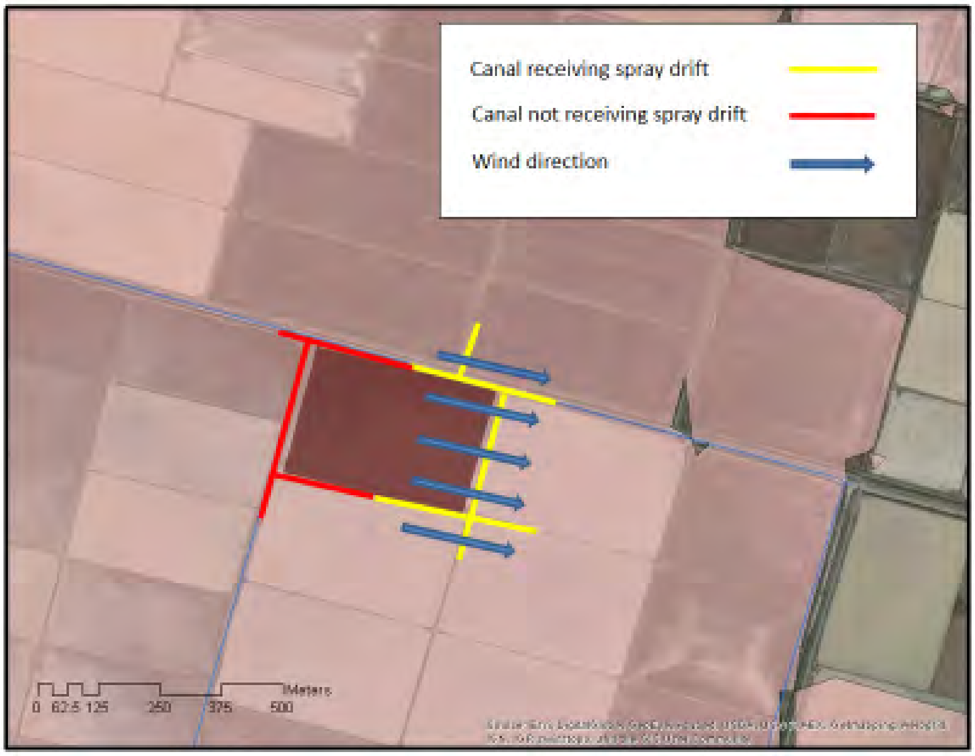

Figure 5-4. Demonstration of wind direction effect on spray drift

The method estimates spray drift to canals in proximity to rice in CA. The proximity and abundance of water in relation to rice differs in other rice growing regions; however, spray drift values calculated for CA can be scaled to estimate spray drift values in other areas. Using the same alternate approach and same data sources referenced above, a 10-meter buffer is applied to the rice area polygon in the Mississippi Delta rice growing region. The 10-meter buffer is intersected with NHD Plus version 2 medium-resolution flowlines. The total area of water is estimated from the total length of the flowlines, with an assumed width of three meters, within 10 meters of rice. When the rice-area-to-water-area proportion is compared to the same approach in CA, there is 53.6% as much water in proximity to rice as in CA. This provides a simple means of modifying the CA rice spray drift values to better reflect conditions in Mississippi Delta rice.

5.3 Parameterization of Spray Drift to Canals in California

After accounting for the significant determinants of spray drift exposure in rice, spray drift can be quantified such that it can be used as an input to PFAM. As a model, PFAM operates with respect to the mass that enters the model mixing cell. Accounting of rice area and canal area are made separately. This “Spray Drift Fraction” input in PFAM results in the calculation of a mass of pesticide that will enter the mixing cell or base flow of the mixing cell in the following manner:

Eq. 1: Mass into mixing cell = Application rate × PFAM Input for Spray Drift Fraction × Hectares of mixing cell

Application rate is a mass per area rate that can be substituted with mass of active ingredient going into canals divided by the area of canals receiving drift. Given this substitution, the input for PFAM spray drift fraction is therefore determined using the following equation:

Eq. 2: $\mathrm{PFAM\ Input\ for\ Spray\ Drift\ Factor} = \mathrm{Fraction\ of\ pesticide\ applied\ that\ drifts} \times \frac{\mathrm{Area\ of\ canals\ with\ drift}}{\mathrm{Area\ of\ mixing\ cell}}$

Area of canals with drift, as presented in Equation 2, is solved in Equation 3 below. Further, the PFAM Input for Spray Drift Factor described in Equation 2 is given an algebraic solution in Equation 4 below. For the five canal spray drift buffer areas, Equation 3 is repeated to produce the canal contribution to the spray drift factor. A scaling factor is introduced to extrapolate the spatial relationship between paddies and canals from the model paddies to all rice in CA that influences the Sacramento River DWI. It is derived by dividing the total area of rice ($2{,}071{,}280{,}000\ \mathrm{m}^2$) by the area of the selected paddies ($6{,}135{,}200\ \mathrm{m}^2$).

Eq. 3: $\mathrm{A_T} = \mathrm{A_M}(\mathrm{F_s})$

Where:

A_T = Total Area of Canal receiving drift for each of five canal spray drift ranges (m^2)
A_M = Area of canal from selected paddies for each of five canal spray drift ranges (m^2)
F_s = scaling factor= the area of rice in conceptual model divided by the area of rice in selected paddies to scale from the model canals to an area representing all CA rice canals (338)

Eq. 4: $$\sum_{i=1}^{5}\frac{(A_{Ti})*(SDF_i)*(F_R)*(F_w)}{(A_{MC})} = \text{PFAM Input for Spray Drift Factor}$$

Where:

SDF = Spray drift fraction for each of five canal spray drift ranges (unitless)
F_R = Regional adjustment factor (CA = 1; Delta = 0.536)
F_w = Factor accounting for unidirectional wind (0.5)
A_{MC} = Mixing cell area (CA = 5,820 m^2)

Spray drift factors for use in PFAM are presented in **Table 5-2** as produced byEquation 2.

Table 5-2. Spray drift factor for use in PFAM for EDWC calculation in rice

(a) Aerial

Spray drift release and droplet size distribution	Very Fine to Fine	Fine to Medium	Medium to Coarse	Coarse to Very Coarse
California spray drift factor	927	404	300	214
Delta spray drift factor	198	86	64	46

(b) Ground - Low Boom

Spray drift release and droplet size distribution	Fine to Medium/Coarse	Fine/ Very Fine
California spray drift factor	343	559
Delta spray drift factor	73	119

(c) Ground - High Boom

Spray drift release and droplet size distribution	Fine to Medium/ Coarse	Fine/ Very Fine
California spray drift factor	566	941
Delta spray drift factor	121	201

No rivers or streams were included in the buffer areas among the selected rice paddies. Spray drift contribution to rivers and streams is expected to be negligible in comparison to spray drift contributions to canals due to best management practices intended to prevent drift[14] and the greater distance from rice paddies relative to canals.

5.4 Alternate Approach to Spray Drift Method

To check the approach for estimating spray drift, an alternate method of estimation was employed that is more accurate but less flexible. Rather than relying upon a selection of eight model paddies, this approach accounts for all rice in CA. This method removes bias associated with a small sample of rice paddies but does not account for spray drift that occurs more than 10 meters from edge-of-field. Using ArcMap v10.1, a 10-meter buffer was applied to the rice area polygon representing all CA rice acreage. The buffer area was intersected with NHDPlus version 2 flowline (high resolution) data. The resulting shapefile is all NHDPlus flowlines within 10 meters of rice. The total length of all NHDPlus flowlines

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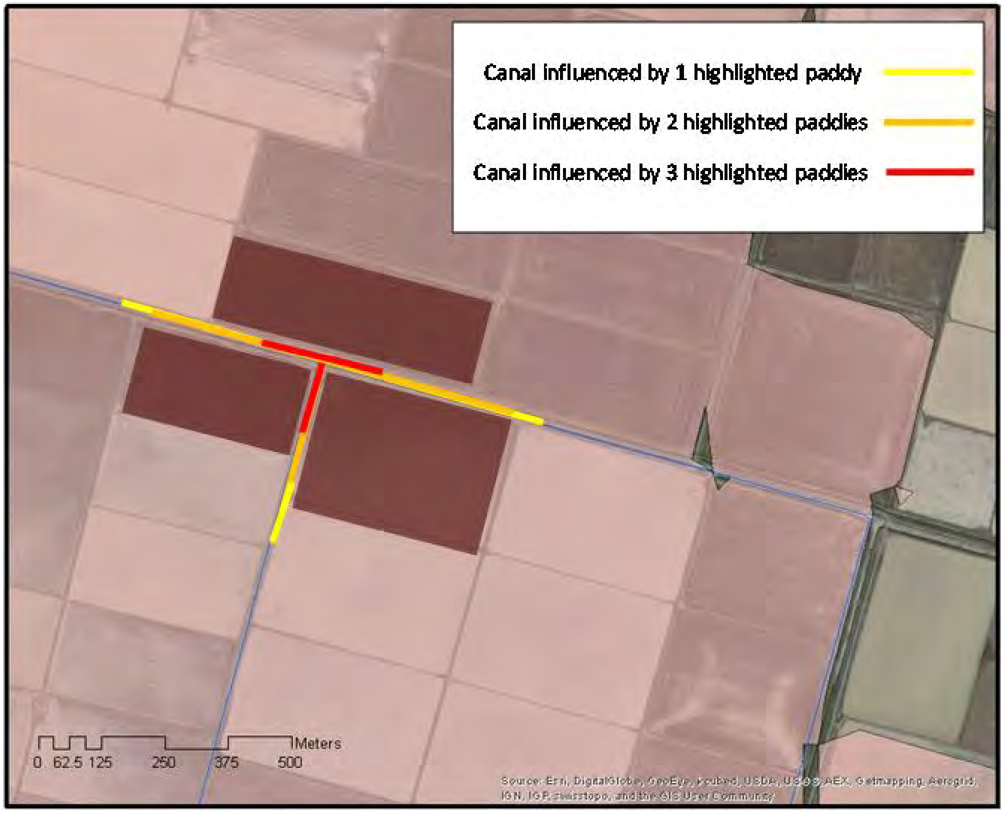
[14] Propanil Rice Herbicide: Stewardship Practices for Protecting Water Quality. Accessed 4/13/2015

within 10 meters of CA rice is 3,813,323 meters. Assuming all flowlines represent canals three meters wide, the water area affected is 11,439,969 m^2. When considering all CA rice, there is one square meter of canal within ten meters of every 181 m^2 of rice ($\frac{\text{Area of rice}}{\text{Area of canals}} = \frac{2{,}071{,}280{,}000\ \text{m2}}{11{,}439{,}969\ \ \text{m2}} = 181$). Comparing this to the area of canals near the model paddies, there is one square meter of canal within ten meters of every 181 m^2 of rice ($\frac{\text{Area of model paddies}}{\text{Area of associated canals}} = \frac{6{,}135{,}200\text{m2}}{54{,}651\ \text{m2}} = 112$). Because more canal area is in proximity to the model paddies than to all rice paddies, the difference between these estimates indicates that the model rice paddies overestimates spray drift and can conservatively represent spray drift to all rice paddies in the CA rice growing region. The validation cannot be carried out further as increasing buffer distances over the full rice area does not account for the multiple sources of drift that may possibly impact a canal adjacent to multiple rice paddies. For instance, a 50 meter buffer over the full rice area will account for drift to a canal from one adjacent rice paddy, but it would not account for drift from other neighboring rice paddies. **Figure 5-5** illustrates that a single canal can be influenced by multiple paddies.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 5-5. Rice paddies and canals in California illustrating that a single canal can be influenced by multiple rice paddies

6 Surface Water Monitoring

6.1 Data selection

Surface water monitoring results from California (CA) and Arkansas (AR) are compiled for evaluating modeled pesticide concentrations. Over the last few decades, pesticides have been detected in CA and AR surface waters near rice fields (Mattice *et al.*, 2000; Ryberg *et al.*, 2014). CA and AR also have the greatest total rice acreage in the US, 15% and 49% respectively. Monitoring data in CA and AR were examined to determine which pesticides had the most robust monitoring data available. The location of the monitoring also needed to be suitable for evaluating the PFAM conceptual models developed near DWIs and the Mississippi River Basin, which has known rice pesticide detections. The pesticides selected for comparison to PFAM-generated EDWCs were monitored over multiple years at a frequency of four samples per year or greater, with high usage on rice (**Table 6-1**).

Table 6-1. Rice pesticides selected for comparison to PFAM modeled concentrations

State	Pesticides	Source
California	Carbofuran Molinate Propanil Thiobencarb	CA Department of Pesticide Regulation[1]
Arkansas	Clomazone Imazethapyr Quinclorac Propanil	Mattice *et al*., 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010

[1] Source: California Department of Pesticide Regulation Surface Water Database (SURF)

6.2 California

The CA Department of Pesticide Regulation (DPR) developed the Surface Water Monitoring Database (SURF), which provides public access to environmental monitoring studies of pesticides in CA surface waters from 1990 to present (most recent release, June 2015) (CADPR, 2016). Data include samples from CA rivers, creeks, agricultural drains, urban streams, and estuaries collected by federal, state, and local agencies, private industry, and environmental groups. There are over 554,000 chemical records currently in the database, each representing an individual analysis of a pesticide active ingredient or degradation product.

SURF data (accessed 13 March 2014) are compiled for four rice pesticides in CA: carbofuran, molinate, propanil, and thiobencarb. These pesticides have high usage on rice and the greatest sampling duration, frequency, and detections in proximity to rice-growing areas and DWIs of Community Water Systems. **Table 6-2** summarizes the selected sampling locations and years available for these four chemicals that were found to have good datasets available that are relevant to California rice. **Figure 6-1** shows the locations of these sampling sites, which are near DWIs within the rice growing areas of the Sacramento River Valley and Glenn Colusa Basin District. The Colusa Basin Drain (CBD) is located in the Sacramento River Valley to the west of the Sacramento River and was originally developed for delivering agricultural water supply. It discharges to the Sacramento River at Knight's Landing. The CBD is considered the primary source of agricultural return flow to the Sacramento River and therefore is an important location for monitoring rice pesticide concentrations (Turek, 1990).

Table 6-2. California sampling locations and years of sampling near DWIs and rice-growing areas in the Sacramento River Valley and Glenn Colusa Basin District

Location	Years Sampled	Latitude (^{o}North)	Longitude (^{o}West)
Sacramento River at Village Marina/Crawdads Cantina	1995-2002, 2006-2008 (Molinate)	38.605	121.525
Colusa Basin Drain #5 (Colusa County)	1995-2001 (Carbofuran); 1995-2002, 2006-2008 (Molinate); 1998, 2001, 2006-2008 (Propanil); 1995-2008 (Thiobencarb)	39.183	122.050
Colusa Basin Drain #1 (Yolo County)	2006-2008 (Molinate) 2006-2008 (Propanil)	38.813	121.773
Sacramento Slough[1]	2001-2003, 2006 (Thiobencarb)	38.7833	121.634
Butte Slough	1994-2001 (Carbofuran); 2006-2009 (Propanil)	39.188	121.900
Colusa Basin Drain above Knights Landing	2006-2008 (Carbofuran) 1994-2002 (Molinate)	38.8125	121.733

[1] Closest location to DWI of all the sites (**Figure 6-1**)

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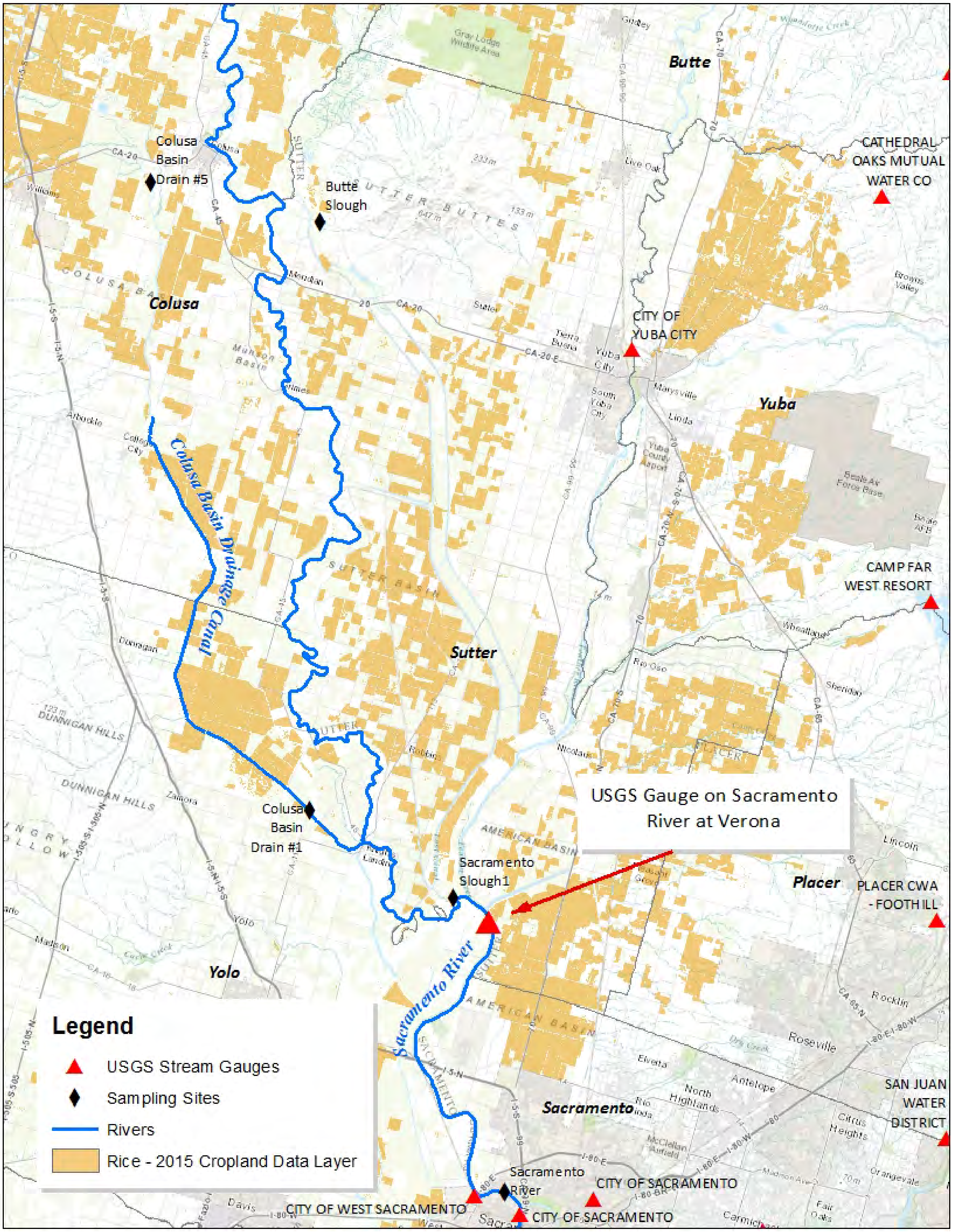


Figure 6-1. California sampling locations near DWIs and rice-growing areas in the Sacramento River Valley and Glenn Colusa Basin District. Nearby USGS stream gauge locations also shown

6.3 Arkansas

AR surface water monitoring data are compiled from a set of research reports on the environmental implications of rice production in AR, including a multi-year monitoring program from 2000 to 2010 (Mattice *et al.*, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009; Mattice *et al.*, 2010). Surface water samples were collected at eight locations during 2000 and 2001, twelve locations in 2002, and sixteen locations in 2003 through 2007 (**Table 6-3**). The original eight locations included four along the L'Anguille River and four along the St. Francis River. Both of these rivers were expected to have a higher frequency of detection due to their smaller volumes in comparison to larger rivers, such as the Black River; however, data are not available to evaluate this. In 2002, four additional sites on La Grue Bayou were added, and in 2003 four more sites were added along the Cache River (**Figure 6-2**).

In most years, the two most frequently detected pesticides were clomazone and quinclorac. While most detections are at low levels and intermittent, quinclorac was detected frequently at low concentrations, and in particular during the middle of the rice season. The Cache and L'Anguille Rivers show the greatest number of detections over time with 74% of detections occurring in these two rivers from 2003 to 2009.

Four rice pesticides from the AR monitoring program are used for model evaluation: clomazone, imazethapyr, quinclorac, and propanil. As in CA, these four pesticides had the greatest sampling frequency (sampling intervals between 7 and 28 days) and duration (between 2000 and 2012), greatest number of detections, and sampling locations in proximity to DW sources.

Table 6-3. AR ambient sampling locations and years of sampling[1]

(a) L'Anguille River

Location	Abbreviation	Years Sampled	Latitude (^{o}North)	Longitude (^{o}West)
Near Claypool reservoir north of Harrisburg	A	2000-2009	35.66536	90.72913
State 14 near Harrisburg	B	2000-2009	35.4746	90.78899
U.S. 64 near Wynne	C	2000-2009	35.20112	90.8891
Crossing of U.S. 79 near Mariana	D	2000-2009	34.79018	90.75191

(b) St. Francis River

Location	Abbreviation	Years Sampled	Latitude (^{o}North)	Longitude (^{o}West)
State 18 E. of Jonesboro	E	2000-2009	35.8208	90.43256
State 75 near Marked Tree	F	2000-2009	35.53255	90.42408
U.S. 64 near Parkin	G	2000-2009	35.27403	90.55951
U.S. 79 near Mariana	H	2000-2009	34.84496	90.63721

(c) Cache River

Location	Abbreviation	Years Sampled	Latitude (°North)	Longitude (°West)
State 91 W. of Jonesboro	QM	2003-2011	35.85781	90.93317
Dirt road off County 37 at Algoa	RM	2003-2011	35.50380	91.12443
State 260 near Patterson	SM	2003-2011	35.24139	91.25301
U.S. 70 S. of I-40	TM	2003-2011	34.83118	91.37646

(d) La Grue Bayou

Location	Abbreviation	Years Sampled	Latitude (°North)	Longitude (°West)
County Rd. ¼ mile below Peckerwood Lake	K	2002-2009	34.65489	91.48708
2nd bridge on Hwy. 146 W. of Hwy. 33 junction	L	2002-2009	34.53221	91.35622
Near town of Lagrue at Hwy. 33 before junction with Hwy. 153	M	2002-2009	34.45437	91.32117
Where Bayou Lagrue crosses Hwy. 1 outside DeWitt.	N	2002-2009	34.31671	91.28261

[1] Courtesy of John Mattice, University of Arkansas, Fayetteville, Arkansas

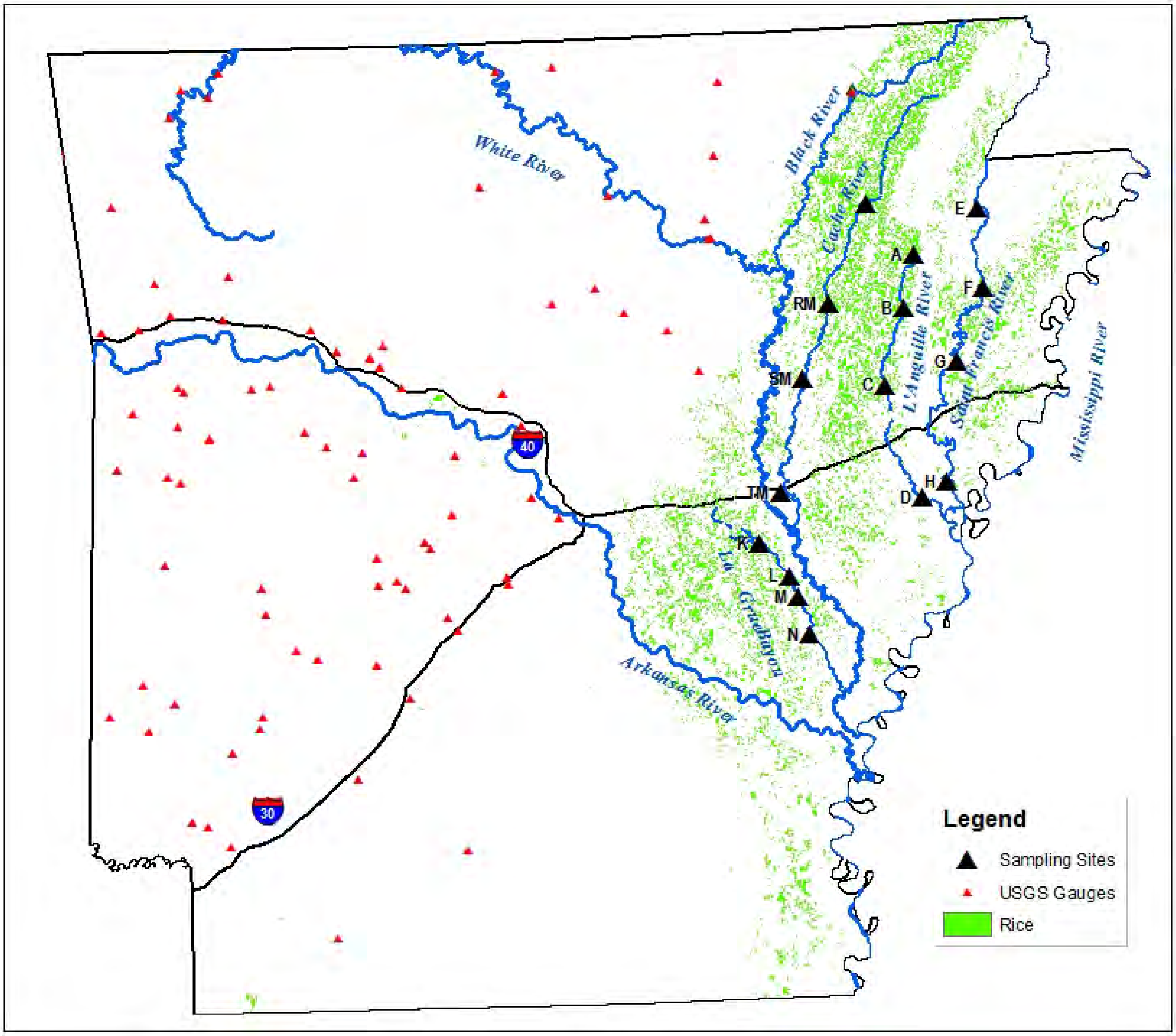


Figure 6-2. Arkansas monitoring locations (2000-2010) along St. Francis River, L'Anguille River, La Grue Bayou, and Cache River

6.4 Use of bias factors in monitoring analyses

The vast majority of pesticide monitoring data in the United States have limited sampling frequencies due to the cost associated with sampling and analysis. Additionally, pesticide use, as well as hydrologic patterns, are spatially and temporally variable. The net effect is a complex set of variables controlling pesticide occurrence in surface water. Because there is uncertainty in determining the exact pesticide occurrence pattern in any specific watershed, there is an inherent bias to underestimate actual pesticide concentrations because of the inability to capture peak or upper-bound concentrations through monitoring. Low detection frequencies are expected to exaggerate the potential bias for underestimation of actual concentrations.

There have been several FIFRA SAP meetings discussing the uncertainty in deriving human health and ecological exposure to atrazine from the monitoring data (USEPA, 2010a, 2010b, 2011, 2012a). These SAP meetings have provided an opportunity to vet different statistical approaches to account for uncertainty due to low sampling frequency, including the use of bias factors (BF) and kriging/sequential stochastic simulation. The SAP recommended that OPP consider using sampling BF for a quantitative estimate of uncertainty in predicting upper bound atrazine concentrations from monitoring data. This analysis will present an estimation of BFs for propanil, thiobencarb, molinate, and carbofuran. The BF serves as a protective multiplier of the actual concentration from monitoring data to account for uncertainty associated with sampling frequency. The general BF equation is as follows:

$\hat{Y}$=X*Bias Factor

Where:
$\hat{Y}$ = Estimated pesticide concentration
X= pesticide concentration obtained from monitoring data
Bias Factor=True pesticide conc./Estimated 5th percentile pesticide concentration estimated from 10,000 simulated chemographs

The statistical implication of the BF is that 95% of the time the BF adjusted pesticide concentrations from monitoring data will be equal to or greater than the true maximum value. As such, it provides, an upper bound estimate on actual exposure.

For stratified random sampling, each constructed chemograph was randomly subsampled 10,000 times using subsampling intervals of 4 days, 7 days, 14 days, and 28 days. The sampling simulation was conducted using a custom Python script software program (Chemograph Generator version 2), starting with a random seed. For each sampling realization, a random value from the custom distribution of values within the designated time interval was selected to represent a value at each sampling interval within the chemograph. These selected concentrations were then used to construct simulated daily chemographs of pesticide concentrations using a linear interpolation. From a distribution of the 10,000 simulated chemographs, the 5th percentile maximum daily, 4-day average, 7-day average, 14-day average, 21-day average, 28-day average, 60-day average, and 90-day average pesticide concentrations were selected to derive the BFs. Selection of the 5th percentile exposure pesticide concentration provides development of conservative BFs. The BFs are calculated by dividing the true maximum value from the original chemograph by the 5th percentile maximum exposure pesticide concentration from the Monte Carlo simulation.

The development of BFs are based on selected monitoring data from state monitoring data for the Colusa Drain #5, Sacramento River, and Butt Slough at Lower Pass. These monitoring data were selected because they generally have high sampling frequency (median 3.5 to 7 day sampling) and represent monitoring sites impacted by rice paddy drainage water (**Table 6-7**).

Table 6-4. Description of monitoring data used for bias factor estimation (collected at Colusa Basin Drain #5)

Pesticide	Range of Median Sampling Interval (Days)	Number of Years	Number of Sites	Observed Concentrations (µg/L): Daily	Observed Concentrations (µg/L:): 21-day	Observed Concentrations (µg/L): 60-day
Propanil	3.5-7	5	1	1.34-31.20	0.54-10.53	0.23-3.73
Carbofuran	2-7	9	2	0.03-3.6	0.03-1.34	0.016-0.68
Molinate	2-3.5	15	2	0.01-44.1	0.01-31.7	0.01-17.3
Thiobencarb	2-27	11	1	0.3-16.9	0.3-8.2	0.3-4.2

The grand mean and standard deviation for BFs were calculated across the various sampling intervals and sites for each pesticide (**Table 6-5**). This analysis approach was conducted because there was generally no notable difference in the BFs as a function of sampling interval and monitoring sites. Although there were little differences of BFs across sampling intervals and monitoring sites for each pesticide, there was high temporal variation of BFs among monitoring years. The coefficient of variation (CV) ranges from 105 to 132% for daily peaks, 77 to 126% for 21-day averages, and 48 to 132% for 60-day averages. The high CV's illustrate a high degree of uncertainty in the estimation of BFs across different years at a site. Additionally, the BFs for propanil are approximately an order of magnitude higher than BFs for carbofuran, molinate, and thiobencarb. The BFs for propanil are likely substantially higher because the occurrence patterns are very sporadic with low temporal duration. This situation results in the BF being equivalent to the peak propanil concentration divided by the detection limit. Additionally, the propanil monitoring data generally had lower sampling frequencies compared to the other monitoring data.

Table 6-5. Statistical description of bias factors among monitoring sites-years

Pesticide	Site-Years	4-day Bias Factor Mean (SD)	21-day Bias Factor Mean (SD)	60-day Bias Factor Mean (SD)
Carbofuran	16	2.88 (3.12)	1.72 (1.17)	1.40 (0.54)
Molinate	15	2.36 (1.29)	1.83 (0.83)	1.52 (0.56)
Thiobencarb	11	2.65 (1.48)	1.98 (0.87)	1.58 (0.49)
Propanil	5	42.98 (95.00)	20.24 (40.08)	10.67 (17.66)

Further analysis on the impact of the site location was conducted to ensure BFs were comparable among monitoring sites. Descriptive statistics indicate substantially similar BFs for the Colusa Drain#5 and Sacramento River (**Table 6-6**) for molinate and carbofuran. Although there is considerable temporal variation (52 to 104%) across various years at each sampling site, the BFs for molinate in the Colusa Drain#5 are very similar to the BFs for molinate in the Sacramento River. Despite hydrological differences between the two sites, bias factors are similar.

Table 6-6. Statistical description of 7-day bias factors for the different molinate monitoring sites

Concentration	Colusa Drain #5 Mean Bias Factor (SD)	Sacramento River Mean Bias Factor (SD)
Daily	1.78 (1.22)	1.52
21-day Average	1.26 (0.24)	1.24
60-day Average	1.15 (0.09)	1.17

SD= standard deviation

The BF data provide some evidence on the potential extent of underestimation for capturing peaks, 21-day average concentrations, and 60 day average concentrations of propanil, carbofuran, molinate, and thiobencarb at monitoring sites impacted by rice paddy drainage water. Although the BFs for the different pesticides provide a general idea on the extent of underestimation, they should be used with caution because of high temporal variation of BFs between monitoring years.

6.5 Monitoring summary

The selected monitoring results for CA and AR, which depict recent trends in rice pesticide concentrations in surface waters, provide a valuable dataset for comparison to modeled concentrations (**Tables 6-7** and **6-8**). Peaks in monitored concentrations typically occur near the time of application. **Figures 6-3** and **6-10** show comparisons of the total molinate applied to rice in the Sacramento River Basin (based on CA DPR Pesticide Use Reports 2002 and 1991) to the daily measured concentrations at two nearby sampling sites. An offset of one to two weeks between the time of application and measured peak concentrations of molinate is observed, possibly due to the transport time of applied pesticide loads to surface water bodies. Since significant water releases from rice paddies are not expected during this time frame, peaks may be caused by spray drift or leakage through weirs or dikes separating the rice paddies from canals. Spray drift is currently simulated in the PFAM conceptual model, and a low level of turnover of water (*e.g.*, loss of water from rice paddies) is also simulated throughout the growing season in CA.

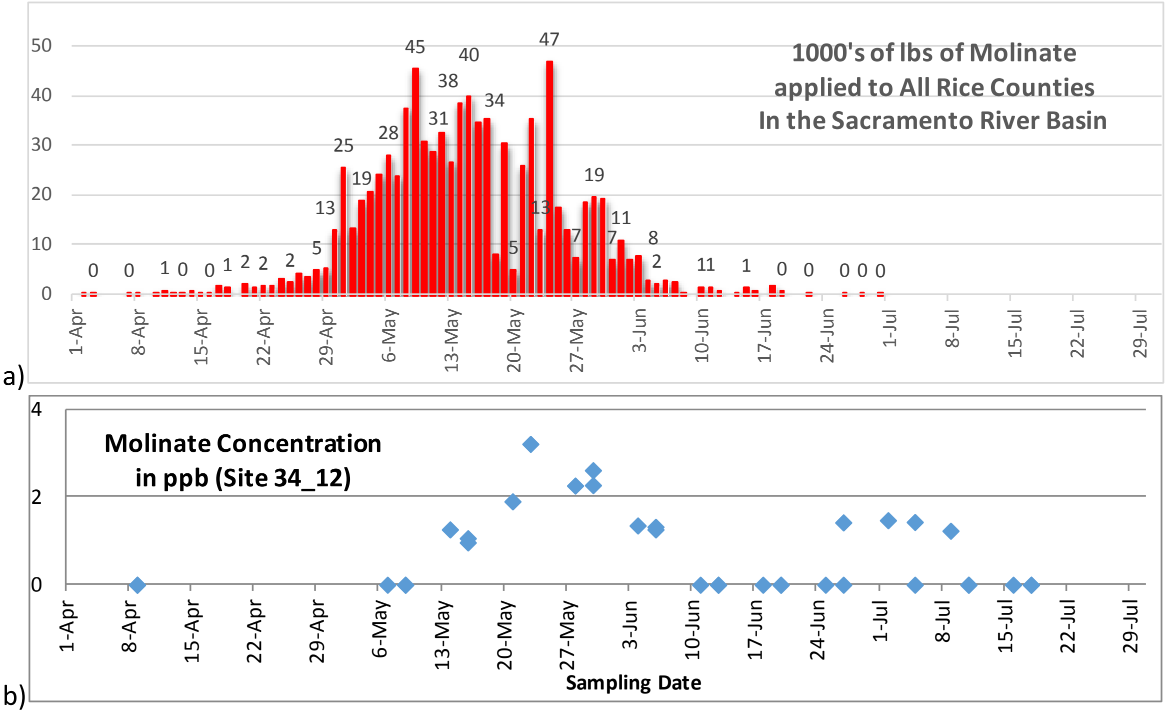


Figure 6-3. a) Daily total molinate applied (lbs) to rice in the Sacramento River Basin in 2002, b) Daily measured molinate concentrations (µg/L) in 2002 at the CA DPR site on the Sacramento River at Village Marina (38.605⁰N, 121.525⁰W).

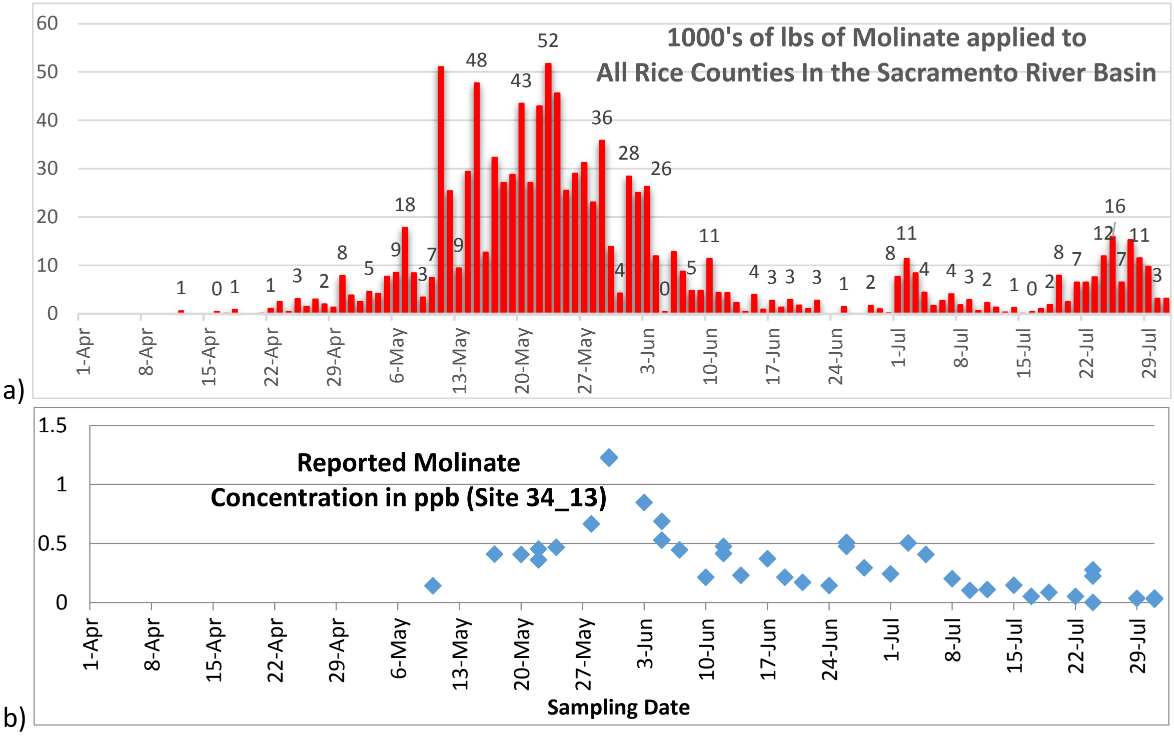


Figure 6-4. a) Daily total molinate applied (lbs) to rice in the Sacramento River Basin in 1991, b) Daily measured molinate concentrations (µg/L) in 1991 at the CA DPR site on the Sacramento River at I Street Bridge (38.586^{o}N, 121.505^{o}W).

Table 6-7. Summary of CA surface water monitoring results*

(a) Sacramento River at Village Marina/Crawdads Cantina

Pesticide	Year (Range Median Sampling Interval)	Peak	Max 21-day Avg	Max 90-day Avg
Carbofuran	1995 – 2001 (5 – 7 days)	ND	--	--
Molinate	1995-2002, 2006-2008 (5 days)	3.2	2.2	1.2
Propanil	2006, 2008 (6 – 7 days)	0.23	0.09	0.03
Thiobencarb	1990 -2008, 2012, 2013 (3 – 7 days)	0.9	0.53	0.32

(b) Colusa Basin Drain #5 (Colusa County)

Pesticide	Year (Range Median Sampling Interval)	Peak	Max 21-day Avg	Max 90-day Avg
Carbofuran*	1995-2001 (2 - 3.5 days)	3.6	1.3	0.51
Molinate	1995-2002, 2006-2008 (3.5 days)	44.1	30.2	15.0
Propanil	1998, 2001, 2006-2008 (7 days)	31.2	10.5	2.5
Thiobencarb	1990 -2008, 2012, 2013 (2 – 7 days)	37.4	7.2	1.9

(c) Colusa Basin Drain # 1 (Yolo County)

Pesticide	Year (Range Median Sampling Interval)	Peak	Max 21-day Avg	Max 90-day Avg
Propanil	2006-2008 (7 days)	3.3	1.6	0.4

(d) Butte Slough

Pesticide	Year (Range Median Sampling Interval)	Peak	Max 21-day Avg	Max 90-day Avg
Carbofuran	1994-2001 (5 days)	1.0	0.6	0.3
Propanil	2006-2009 (7 - 35 days)	1.9	0.8	0.4

ND-Non detects

*Maximum concentrations are derived using either stair interpolation. Original source of monitoring data is the CA Department of Pesticide Regulation Surface Water Database (SURF). Carbofuran in the Colusa Basin Drain #5 (Colusa County) excludes monitoring results from 28-day sampling intervals.

Table 6-8. AR surface water monitoring results across all 16 sampling locations from 2000 to 2012 (Table 7-3. Source of monitoring data is Mattice *et al*. (2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010)

Pesticide	Year	Sampling Interval	Maximum Concentration (µg/L)[1]	Annual Average Concentration (µg/L)	Detection frequency (detects/samples)
Clomazone	2000-2012	7 to 27.7 days	Peak: 38.3 4-day: 38.3 21-day: 37.1	15.9	60.5% (319/527)
Imazethepyr	2006-2012	7 to 27.7 days	Peak: 8.4 4-day: 8.4 21-day: 8.4	5.2	25.4% (97/382)
Quinclorac	2000-2012	7 to 28 days	Peak: 77.9 4-day: 77.9 21-day: 52.2	25.1	65.7% (342/531)
Propanil	2000-2012	7 to 27.7 days	Peak: 42.4 4-day: 42.4 21-day: 42.4 Peak: 9.5* 4-day: 7.6* 21-day: 7.6*	2.0	14.3% (70/490)

*These monitoring results exclude the maximum values in 2012 at Site Q.

[1] The 4-day and 21-day average maximum concentrations were based on chemograph and a linear interpolation between data points.

6.6 Additional National Water Quality Monitoring

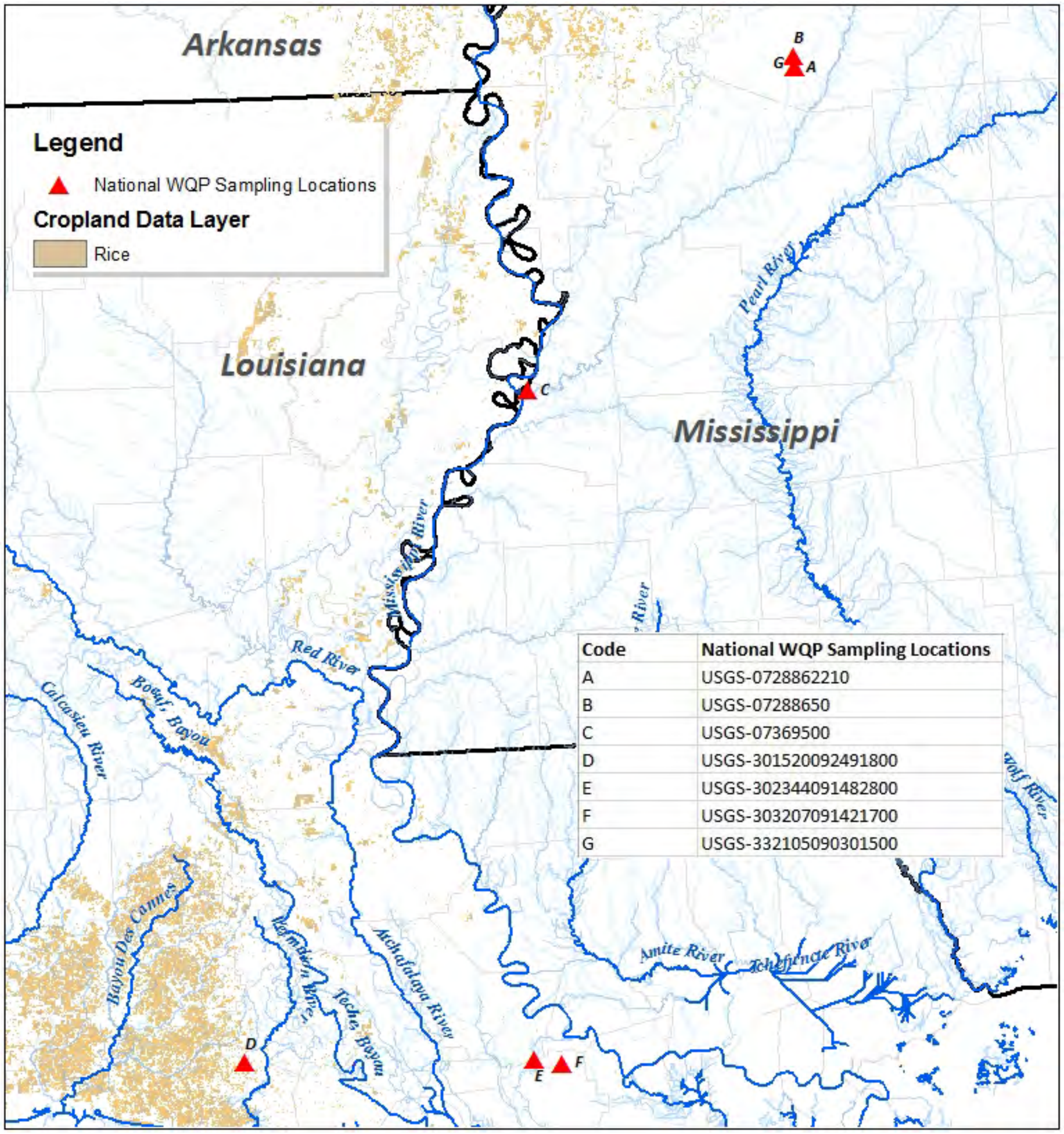
Using the National Water Quality Monitoring Council's Water Quality Portal (WQP) (accessed on 24 February 2016), a short review of additional surface water monitoring data is conducted for rice chemicals in Arkansas, Louisiana, and Mississippi River region. Peak measured concentrations are summarized for additional comparison and to ensure modeled concentrations are protective of DW sources, apart from those included in the AR conceptual model (**Table 6-9, Figure 6-5**). The greatest differences between the peak monitoring results targeted to rice growing areas are seen for molinate, where the National WQP concentrations (**Table 6-9**) are 3 to 3.5 times greater than the peak molinate concentrations from CA DPR for the CBD #5 (Colusa County) (**Table 6-7**). For example, at location D (USGS-301520092491800) in **Figure 6-5**, within a rice-growing area, molinate has a peak concentration of 154 µg/L in comparison to 44 µg/L at CBD #5 (**Table 6-7**). These differences in concentrations may be due to varying application rates, sampling frequency, and flow rates between the two locations.

Table 6-9. National Water Quality Portal measured peak concentrations for rice pesticides in Arkansas, Louisiana, and Mississippi River regions

Pesticide	Peak concentration, dissolved (µg/L)	Sampling date	Sampling location ID	Map ID
Carbofuran	4.1	8/5/1995	USGS-332105090301500	G
	2.82	7/1/1997	USGS-07369500	C
Clomazone	2.88	4/13/2010	USGS-302344091482800	E
	0.17	6/15/2010	USGS-303207091421700	F

Pesticide	Peak concentration, dissolved (µg/L)	Sampling date	Sampling location ID	Map ID
Imazethapyr	0.96	5/21/2014	USGS-07288650	B
	0.74	5/31/2005	USGS-07288650	B
Molinate	154	5/31/2000	USGS-301520092491800	D
	140	6/18/1996	USGS-07288650	B
Propanil	2.73	8/4/1997	USGS-07288650	B
	1.81	7/13/1998	USGS-0728862210	A
Thiobencarb	4.00	6/3/1996	USGS-07288650	B
	3.66	5/21/1997	USGS-07288650	B

Source: National Water Quality Portal http://waterqualitydata.us/portal/



Code	National WQP Sampling Locations
A	USGS-0728862210
B	USGS-07288650
C	USGS-07369500
D	USGS-301520092491800
E	USGS-302344091482800
F	USGS-303207091421700
G	USGS-332105090301500

Figure 6-5. National Water Quality Portal sampling locations for rice pesticides in Arkansas, Louisiana, and Mississippi River regions

7 Comparison of Modeled Results with Monitoring Results

To evaluate whether the DWI conceptual models would produce reasonable and conservative EDWC, measured pesticide concentrations near DWIs were compared to modeled values. The objective of this evaluation is to determine whether the developed DW conceptual models produce EDWCs that are protective of DW that may be downstream from rice-growing areas. Simulated pesticide concentrations are not expected to exactly match measured pesticide concentrations as the model simulations only approximate field conditions. Instead, the PFAM evaluation focuses on how well the magnitude and range in estimated pesticide concentrations compare to measured concentrations. The following criteria are used to compare estimated concentrations to measured concentrations, while acknowledging potential bias errors from sampling frequency:

- Minimal model underestimates compared to monitoring (type II errors);
- Peak concentrations generally within 1 to 5X greater than measured peak concentrations;
- Minimal model overestimates by factor of 10 or greater for longer duration exposure estimates. Lower measured concentrations may relate to limited sampling frequency, resulting in model overestimates of 5-10X greater.

This evaluation focuses on the scenarios and conceptual models developed for DW. An evaluation of PFAM simulating concentrations in rice paddies was completed and described in the PFAM User Guide (Young, 2012, 2013) in Chapter 3.

7.1 Monitoring Data

For evaluating the CA Conceptual Model, four pesticides with high usage on rice, limited usage on other crops, and robust monitoring data in the rice growing area were chosen to compare the monitoring and modeled results. Monitoring data are available in the Sacramento River where the DWI of interest is located; however, there are many non-detects. Robust monitoring data are available for the CBD Site number 5 (see **Figure 6-1** for a map of CA sampling sites) for multiple chemicals, over multiple years. The median sampling frequency for some chemicals is 3.5 days. Finally, monitoring results in the CBD#5 resulted in the highest detections in the area. Therefore, the CBD monitoring data are used as a surrogate for the Sacramento River and are compared to the modeling results simulated using the developed CA Conceptual model.

To explore whether the use of monitoring data from the CBD#5 is a valid surrogate for the Sacramento River the following items were considered: monitoring data available for CBD#5 and Sacramento River, available information on flow, and rice paddies that could flow into the different waters. The CBD's flow is lower than the flow in the Sacramento River and the site of monitoring has some rice downstream from it. Additionally, the Sacramento River has some flow from rice paddies that do not influence the CBD. The average measured flow in the CBD based on available data was 33 m^3/s (USGS, 2016a). In comparison, the average measured flow in the Sacramento River is 424 m^3/s (USGS, 2016b). Concentrations in the Sacramento River were speculated to be lower than those measured at CBD#5 because of its higher flow rate. Monitoring data available for CBD#5 and Sacramento River are shown in **Figure 7-1**. Pesticide concentrations at CBD#5 were generally 6 to 30 times the pesticide concentration measured in the Sacramento River in the same year. There is an outlier for propanil where the measured concentration at CBD#5 is 173 times the concentration in the Sacramento River. This may be due to the rapid degradation rate of propanil or the samples were not collected at similar times and the peak may have been missed in the Sacramento River. It is uncertain whether the differences in pesticide concentrations observed is due to the differences in location, pesticide use, or flow. Pesticide concentrations in the CBD and Sacramento River occur in the same general time frame. The CBD data are the most reliable and robust dataset available near the CA DWI and are used in the comparison to modeled concentrations. Comparing the results of the conceptual model to the CBD monitoring data provides evidence on whether the modeled concentrations are protective and reasonable.

Table 7-1. Maximum concentrations in µg/L observed in the Sacramento River and the Colusa Basin Drain Site 5 in the same year and ratios of those concentrations in the same year

Chemical	Colusa Basin Drain #5	Sacramento River	Ratio of Measured Concentration CBD/Sacramento River
Thiobencarb	37.4 (5/16/1994) 8.2 (5/23/2002)	Not detected (1994) 0.9 (5/23/2002)	-- 9 (2002)
Molinate	44.09 (6/2/1998) 18.8 (5/23/2002)	1.5 (6/2/1998) 3.21 (5/23/2002)	29 (1998) 6 (2002)
Propanil	31.2 (6/20/2006) 1.34 (6/17/2008)	0.18 (6/20/2006) 0.23 (7/15/2008)	173 (2006) 6 (2008)
Carbofuran	3.6 (5/11/1999) Not analyzed (1991)	Not detected (1999) 0.109 (7/3/1991)	--

To be useful for evaluating the conceptual model, monitoring data need to be collected sufficient frequency to capture day-to-day, seasonal, and yearly variations in pesticide concentrations in water (USEPA, 2011). The extent to which monitoring data adequately reflect short-term variability in pesticide concentrations in water depends on how frequently samples are collected and whether the sampling is targeted to pesticide use areas and times of the year in which pesticides have been applied. As the interval between sampling events increases, the likelihood of capturing short-duration or single-day peaks in pesticide concentrations decreases, particularly in fast-flowing waters. Even weekly sampling will often provide a biased (underestimated) perspective on pesticide concentrations in water (USEPA, 2011).

Sampling bias has been discussed in a recent FIFRA Scientific Advisory Panel meetings on atrazine (USEPA, 2011). To evaluate the potential uncertainty in sampling frequency for predicting actual concentrations, USEPA (2011) simulated 4-, 7-, 14-, and 28-day sampling intervals on monitoring datasets that had daily- to near-daily sampling intervals. Median annual peak estimates ranged from 75-78% of the true annual peaks for a 4-day interval, 36-70% for a 7-day interval, and 25-54% for a 14-day interval (USEPA, 2011). These examples of likely underestimations of true peak values, based on infrequent monitoring, leads to the use of BFs to adjust data collected at infrequent intervals.

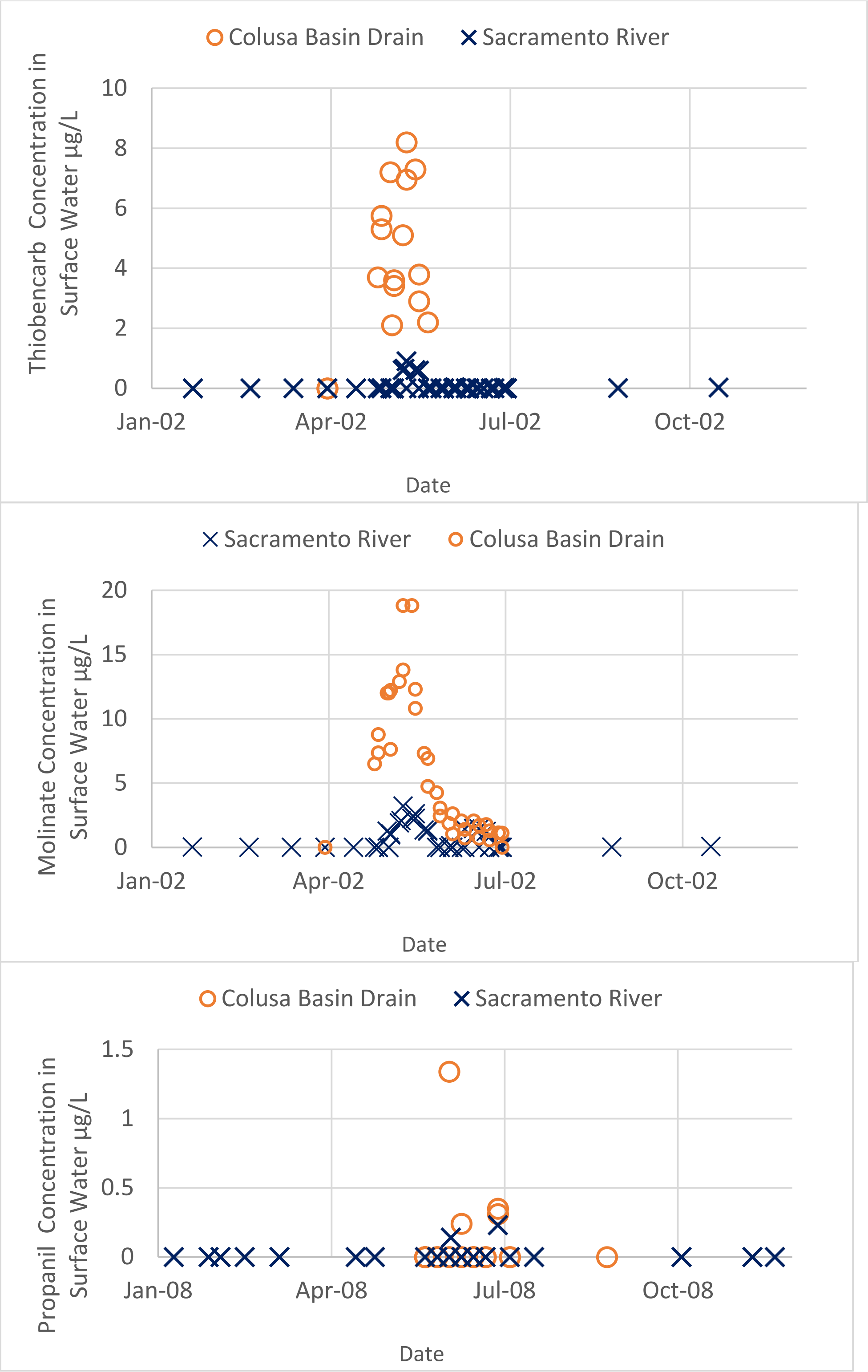


Figure 7-1. Comparison of pesticide concentrations in the Colusa Basin Drain and Sacramento River for thiobencarb, molinate, and propanil

Monitoring data in CA for molinate, thiobencarb, carbofuran, and propanil were frequent enough to calculate BFs at the CBD#5 Site. The BFs calculated from the CBD#5 data were applied to an average pesticide concentration from monitoring results at sites nearby with less frequent sampling frequency and monitoring data available on the same chemicals. These BFs adjusted concentrations were plotted to show the range of possible concentrations that could occur near the Sacramento River DWI area and compared to modeled results for characterization. Additional information on monitoring data and calculation of BFs are described in more detail in **Section 6**.

Robust monitoring data were not available in the Black River (Arkansas) where the DWI of interest is located. There are other sites away from DWIs that are used as surrogate DWI sites; however, the flow in the sites with monitoring results is lower than the flow in the Black River (**Table 7-2**), which impacts the representativeness of these sites. The following uncertainties could result in differences in pesticide concentrations in measured and modeled values for MO/AR:

- Use of pesticides may be different in the different areas and different than the use pattern;
- Data on the amount of rice treated in MO/AR is not available;
- Flows are different in the different areas; and
- The area of rice influencing the area of monitoring and modeling are different.

While there is uncertainty to what degree measured data may reflect concentrations in the Black River, these are the only robust monitoring data available in the area and are used in the evaluation of the Black River Arkansas Conceptual Model. As these monitoring results are not robust enough to calculate BFs, it is likely that the measured concentrations will underestimate true peak concentrations.

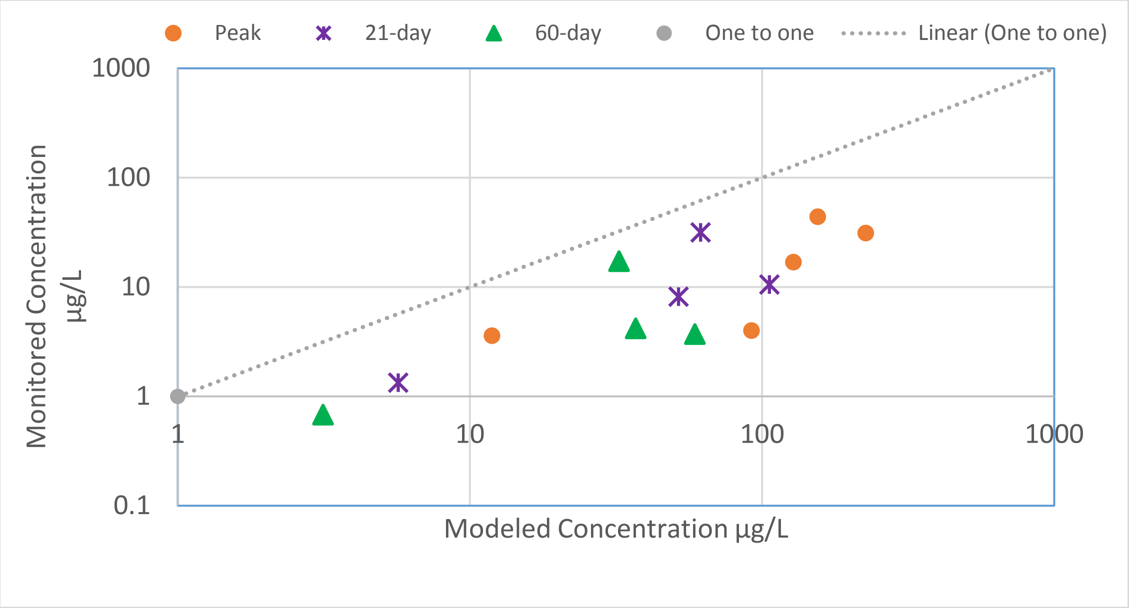
Table 7-2. Discharge statistics in cubic feet per second on the rivers sampled for rice pesticides in Arkansas[1]

Site	10% exceeds	50% exceeds	90% exceeds
Black River near Pocahontas (1936-2012)	11,900	3,490	1,690
St. Francis River at St. Francis AR (1930-2010)	5510	940	190
Cache River at Egypt, AR (1965-2012)	2840	290	30
L' Anguille near Colt, AR (1971-2012)	1830	352	28

[1] Data were collected from water year summary reports available at the USGS National Water Information System, Streamflow Measurements for the Nation

7.2 Results

Figures 7-2 and **Tables 7-2** and **7-3** provide a comparison between measured and modeled estimated pesticide concentrations for CA DW. Model simulations used the default assumptions for simulating DW concentrations in CA along with specific use information averaged over the years of monitoring data available for the chemical simulated. A summary of model inputs is available in **Appendix C.** Monitoring results are shown for measured pesticide concentrations in the CBD Site Number 5 and for nearby sites with adjustment with a BF. Modeled concentrations were higher than measured concentrations in all cases. The ratios of modeled to measured without a BF ranged from 1.94 to 15.8 and were less than 9 for three of four chemicals. The ratios of modeled to measured adjusted with a BF ranged from 3.73 to 80.17. Thiobencarb ratios ranged from 11 to 13 and carbofuran ratios range from 51 to 80. Both carbofuran and thiobencarb had a low detection frequency in the Sacramento River. The sampling frequency for thiobencarb was 28 days, which could be one source of the much lower monitoring results. Carbofuran was being phased out over the sampling period and likely had additional management practices being utilized to reduce carbofuran residues associated with rice paddies that would not be captured in the simulations.



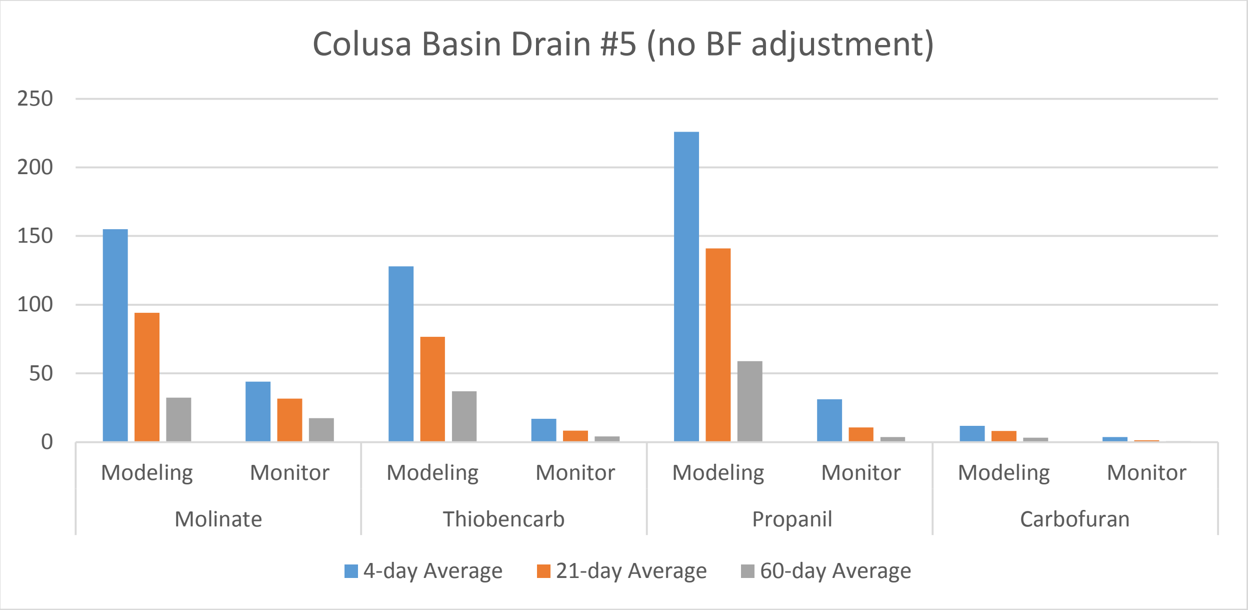


Figure 7-2. Comparison of modeled pesticide concentrations to measured concentrations in the CBD#5 (California Drinking Water Results)

Table 7-3. Comparison of modeled pesticide concentrations for California drinking water and maximum measured pesticide concentrations in the Colusa Basin Drain Number 5[1]

(a) Peak

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	155	44.1	3.51
Thiobencarb	128	16.9	7.57
Propanil	226	31.2	7.24
Carbofuran	11.9	3.6	3.31

(b) 21-day

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	61.6	31.7	1.94
Thiobencarb	51.7	8.2	6.30
Propanil	106	10.53	10.0
Carbofuran	5.68	1.34	4.24

(c) 60-day

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	32.4	17.3	1.87
Thiobencarb	36.9	4.2	8.79
Propanil	58.9	3.73	15.8
Carbofuran	3.14	0.68	4.62

(d) Annual Average Modeling Only

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	0.18	--	--
Thiobencarb	1.07	--	--
Propanil	0.38	--	--
Carbofuran	2.72	--	--

Table 7-4. Comparison of modeled pesticide concentrations for California drinking water and average max measured pesticide concentration across all sites but the Colusa Basin Drain #5 (adjusted with bias factor)

(a) Peak or 4-day Average

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	155	31.1	5.0
Thiobencarb	128	12.1	10.6
Propanil	226	104	2.2
Carbofuran	11.9	1.7	7.0

(b) 21-day

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	61.6	19.1	3.2
Thiobencarb	51.7	8.4	6.2
Propanil	106	6.1	17.4
Carbofuran	5.68	0.64	8.9

(c) 60-day

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	32.4	9.9	3.3
Thiobencarb	36.9	4.7	7.9
Propanil	58.9	3.5	16.8
Carbofuran	3.14	0.42	7.5

(d) Annual Average Modeling

Chemical	Modeled Pesticide Concentrations in Surface Water (µg/L)	Monitoring (CBD #5) Pesticide Concentrations in Surface Water (µg/L)	Modeled ÷ Monitoring
Molinate	0.18	--	--
Thiobencarb	1.07	--	--
Propanil	0.38	--	--
Carbofuran	2.72	--	--

Figure 7- and **Table 7-5** provide a comparison between measured and model estimated pesticide concentrations for MO/AR drinking water. Model simulations used the default assumptions for simulating DW concentrations in Arkansas (see the S*cenario Metadata Document*). Specific use information was not available for MO/AR; therefore, application amounts were adjusted using the

maximum percent crop treated for all herbicides of 84%. A summary of model inputs is available in **Appendix C.**

Monitoring results are shown for measured pesticide concentrations in the Cache, L' Anguille, and St Francis Rivers and in La Grue Bayou. Modeled concentrations are shown for the Black River Arkansas Scenario. Overall peak modeled concentrations were higher than measured concentrations except for the simulation for quinclorac. For quinclorac, the modeled value was slightly lower than the measured concentration (71.7 µg/L modeled versus 77.9 µg/L measured). The ratios of the daily average, modeled to the highest measured pesticide concentration, ranged from 0.92 to 15.0. Propanil modeled concentrations exceeded the measured value by 15x. All other modeled values were very close to measured values. It is possible that the difference in the measured and modeled propanil concentration is due to differences in usage as compared to what was modeled. The high modeled values could be a result of our high estimate of the percent of rice crop that was treated (84%); modeled estimates are directly proportional to this value. Additionally, the sampling frequency for the measured concentrations ranged from 7 to nearly 30 days, and it is unlikely that the measured values capture peak concentrations.

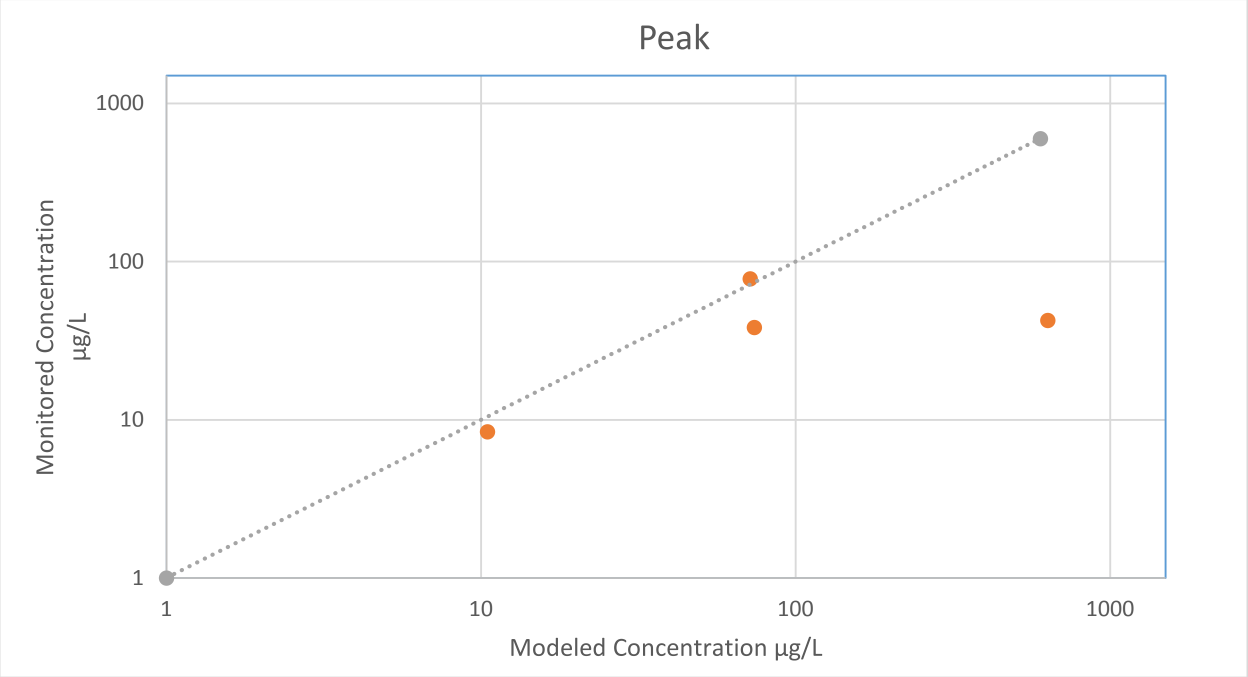


Figure 7-3. Comparison of modeled pesticide concentrations to measured concentrations without a bias factor adjustment (Missouri/Arkansas Drinking Water)

Table 7-5. Comparison of modeled pesticide concentrations for Missouri/Arkansas drinking water and measured pesticide concentrations in Arkansas[1]

(a) Peak

Chemical	Pesticide Concentrations in Surface Water (µg/L): Modeled	: Pesticide Concentrations in Surface Water (µg/L): Monitoring no BF	Ratio of Modeled ÷ Monitoring No BF
Clomazone	73.9	38.3	1.93
Imazethapyr	10.5	8.4	1.25
Quinclorac	71.7	77.9	0.920
Propanil	634	42.4	15.0

(b) Annual Average

Chemical	Pesticide Concentrations in Surface Water (µg/L): Modeled	: Pesticide Concentrations in Surface Water (µg/L): Monitoring no BF	Ratio of Modeled ÷ Monitoring No BF
Clomazone	5.87	--	--
Imazethapyr	0.97	--	--
Quinclorac	8.08	--	--
Propanil	21.6	--	--

BF=Bias Factor

Non-targeted monitoring data were also collected from NAWQA for the pesticides simulated in the MO/AR area. This information was used to ensure that a higher measured concentration in the MO/AR area was not missed. None of the concentrations found in NAWQA data exceeded the measured concentrations in the Mattice data. The maximum measured molinate concentration in the Arkansas/Missouri area examined measured a peak concentration of 154 µg/L, which is very close to the modeled value in CA (155 µg/L). Molinate was not simulated in MO/AR.

7.3 Conservative and Reasonable Results

To be considered conservative, modeled concentrations should exceed measured concentrations, and to be reasonable, the concentrations should not be gross overestimates. Considering that modeled concentrations exceeded measured concentrations provides supporting evidence that the modeled EDWCs are conservative.

For the CA conceptual model, modeled concentrations were typically within a factor of 10 of measured concentrations not adjusted with a BF, providing supporting evidence that the model simulations result in reasonable estimated concentrations. The carbofuran ratio of the modeled to measured bias factor adjusted was rather high (80) for the bias factor adjusted measured values, but the modeled value is based on an average percent crop treated across sites, and it is possible that carbofuran was not used to a high degree in the area where the sampling occurred. For example, the monitoring data covered 1995 to 2001. Usage remained near 100,000-130,000 lbs carbofuran between 1995 and in 1996, but then pounds applied to CA rice declined rapidly to no applications in 2001. Thus, the difference could be a result of a decline in usage for a large portion of the sampling interval.

For the MO/AR conceptual model, modeled concentrations were within a factor of two for three of the four model simulations. For the case where modeled concentrations were 15x the measured values, it is possible that the model simulation overestimated the percent of the rice treated with propanil, and it is also likely that measured concentrations did not capture peak concentrations as the sampling frequency was weekly or greater.

7.4 Comparison of Tier I Rice Model Results to Updated Drinking Water Simulations

The recommended Tier I model for simulating DW concentrations in rice is the Tier I Rice Model (USEPA, 2007). This model can be modified to include aerobic aquatic degradation for developing an annual average concentration and for considering the impact of a holding period on DW. This methodology is described in **Appendix D**. The recommended Tier II rice model for simulating residues in DW is PFAM (USEPA, 2013b). Before the conceptual model was developed, concentrations in the rice paddy were used for both estimates of exposure in DW and ecological risk assessment.

The DW conceptual models developed offer a refinement to the PFAM simulation in the rice paddy. The results from the Tier I Rice Model, modified to account for aerobic aquatic metabolism, were compared with the results from the PFAM simulations in the receiving water body and in the rice paddy to demonstrate this refinement and are presented in **Figure 7-4**. The Tier I Rice Model concentrations are 4 to 684 times larger than PFAM concentrations with a receiving water body. As the Tier I Rice model simulates concentrations in a rice paddy and the PFAM model is simulating concentrations in a receiving water body, these differences are expected. These results illustrate that the new conceptual models will allow for more realistic estimates of DW concentrations as well as refinement of DW concentrations for pesticides used on rice.

Concentrations in the rice paddy estimated using PFAM are sometimes higher than those estimated using the Tier I Rice Model. Many of the simulations do not show this trend because pre-flood applications that are simulated in PFAM are not simulated though Tier I Rice Model version 2.0 can simulate pre-flood degradation with the aerobic soil metabolism half-life. This analysis illustrates that PFAM simulations in the rice paddy may result in higher concentrations than those predicted using the Tier I Rice Model.

Table 7-6. Comparison pesticide concentrations estimated using the Tier I Rice Model Modified with aerobic aquatic metabolism, PFAM in the rice paddy, and PFAM in receiving water*

(a) Arkansas/Missouri

Chemical	KOC (L/kg)	Aerobic Aquatic Half-life	PFAM EDWC Daily Ave	PFAM EDWC Annual Ave	Tier I Daily Ave	Tier I Annual Ave	PFAM Paddy Daily Ave	PFAM Paddy Annual Ave	Ratio of Tier I to PFAM EDWC Daily Ave	Ratio: Tier I to PFAM EDWC Annual Ave
Clomazone	300	44	73.9	4.94	622	187	113	19.2	8.42	37.9
Imazethapyr	62	584	0.97	0.97	97.1	78.8	108	3.29	100	81.2
Quinclorac	36	1295	8.08	8.08	511	464	160	38	63.2	57.4
Propanil	489	6	21.6	21.6	3323	83.5	5090	94.3	154	3.87

(b) California

Chemical	KOC (L/kg)	Aerobic Aquatic Half-life	PFAM EDWC Daily Ave	PFAM EDWC Annual Ave	Tier I Daily Ave	Tier I Annual Ave	PFAM Paddy Daily Ave	PFAM Paddy Annual Ave	Ratio of Tier I to PFAM EDWC Daily Ave	Ratio: Tier I to PFAM EDWC Annual Ave
Molinate	186	1.00E+08	155	6.82	6937	6937	4270	187	44.8	1017
Thiobencarb	1628	1.00E+08	128	18.7	1416	1416	4030	128	11.1	75.7
Propanil	489	6	226	9.88	3323	83.5	5130	360	14.7	8.45
Carbofuran	36	642	11.9	0.617	511	422	5130	115	42.9	684
Clomazone	300	44	92.0	8.56	622	187	161	46.4	6.76	21.8

*Modeling for the receiving waterbody included refinements based on use information while modeling in the rice paddy did not.

8 Literature Cited

Acosta, M., Mugica, L., Blanco, D., López-Lanús, B., Dias, R., Doodnath, L. W., et al. 2010. Special Publication 1: Ecology and Conservation of Birds in Rice Fields: A Global Review. *Waterbirds: The International Journal of Waterbird Biology, 33*, 102-122.

Ahrens, W. H. (Ed.). (1994). *Herbicide Handbook* (7th ed.). Champaign, Ill: Weed Science Society of America.

Association, T. S. H. 2008. *Texas Almanac*. Texas State Historical Association. Accessed April 30, 2016.

CADPR. 2016. *Surface Water Database (SURF)*. California Department of Pesticide Regulation. Accessed April 27, 2016.

California Rice Commission. 2012a. *Califonria Rice Environmental Sustainability Report*. May 2012. Accessed May 5, 2016.

California Rice Commission. 2012b. *Environmental Sustaintability Report.* May 2012. California Rice Commission. Accessed May 22, 2016.

California Rice Commission. 2013. *Balance Sheet: Environmental & Conservation Balance Sheet for the California Rice Industry*. California Rice Commission.

Dickey, D. 2015. *Rice Production Workshop Manual v15.* University of California. California Rice Research Board. Accessed April 29, 2016.

Eadie, J. M., Elphick, C. S., & Reinecke, K. J. 2008. Wildlife Values of North American Ricelands. In S. Manley (Ed.), *Conservation in Ricelands of North America*. Woodland, CA: Star Canyon Books. Accessed May 2, 2016.

Elphick, C. S., & Oring, L. W. 2003. Conservation implications of flooding rice fields on winter waterbird communities. *Agriculture, Ecosystems, and Environment, 94*, 17-29.

Federoff, N. E., & Orrick, G. 2011.D391181. *EFED Registration Review Problem Formulation for Thiobencarb*. D391181. November 8, 2011. Environmental Fate and Effects Division. Office of Pesticide Programs. Office of Chemical Safety and Pollution Prevention. United States Environmental Protection Agency.

Fischer, H. B., List, J. E., Koh, R., Imberger, J., & Brooks, N. H. 1979. *Mixing in Inlnad and Coastal Waters*. London: Academic Press Inc.

Hardke, J. T. 2006. *Arkansas Rice Production Handbook.* M192. University of Arkansas Division of Agriculture Cooperative Extension Service. Accessed April 29, 2016.

Hardke, J. T. 2013. *Arkansas Rice Production Handbook*. MP192. University of Arkansas, Division of Agriculture, Cooperative Extension Service. Accessed April 28, 2016.

International Rice Research Institute. 1998. *Rice Ratooning.* Accessed April 30, 2016.

Kaminski, R., Manly, S., Schoenholtz, S., & Dewey, J. 1999. Winter-flooded Rice Fields Provide Habitat and Agricultural Values. *Forest & Wildlife Research Center. Research Advances. , 4*(1).

Mastrota, F. N., Breithaupt, J., & Syslo, S. 1999. *EFED RED Chapter for Molinate*. D249852+. July 16, 1999. Environmental Fate and Effects Division. Office of Pesticide Programs. Office of Prevention, Pesticides, and Toxic Substances. United States Environmental Protection Agency.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2000. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 485*, 80-85.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2001. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 495*, 70-75.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2002. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 504*, 135-141.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2003. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 517*, 122-131.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2004. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 529*, 210-218.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2005. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 540*, 190-206.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2006. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 550*, 197-204.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2007. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 560*, 103-112.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2008. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 571*, 165-174.

Mattice, J. D., Skulman, B. W., & Norman, R. J. 2009. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 581*, 123-132.

Mattice, J. D., Smartt, A., Teubl, S., Scott, T., & Norman, R. J. 2010. Environmental implications of pesticides in rice production. *B.R. Wells Research Series, Arkansas Agricultural Experimental Stations Research Series, 591*, 141-153.

Miller, T., Street, J., Buehring, N., Kanter, D., Walker, T., Bond, J., et al. 2008. *Missippi's Rice Growers' Guide.* Publication 2255. Missippi State University. U.S. Department of Agriculture. Accessed April 29, 2016.

Norling, W., Jeske, C. W., Thigpen, T. F., & Chadwick, P. C. 2012. Estimating shorebird populations during spring stopover in rice fields of the Louisiana and Texas Gulf Coastal Plain. *Waterbirds, 35*(3), 361-370.

Norman, R. J., & Moldenhauer, K. A. K. 2009. B.R. Wells Rice Research Studies. *Research Series 581, 581*.

Pearlstine, E., Bear, W. M., Mazzotti, F. J., & Rice, K. G. 2007. Checklist of fish in rice and sugarcane fields of the everglades agricultural area. *Florida Scientist, 70*(2), 113-119.

Perlman, D. 2013. *Salmon raised in a rice field thrive.* April 3, 2013. San Francisco Chronicle. Accessed May 21, 2016.

Pringle, H. C.-. 1992. *Rice levee construction and seepage losses on Sharkey clay*. In J. E. Street, A. Mississippi, S. Forestry Experiment, F. Mississippi State University. Division of Agriculture & S. Veterinary Medicine. Dept. of Information (Eds.). Mississippi State, MS: Dept. of Information Services, Division of Agriculture, Forestry, and Veterinary Medicine, Mississippi State University.

Rutherford, J. C. 1994. *River Mixing*. Chichester: John Wiley and Sons.

Ryberg, K. R., Vecchia, A. V., Gilliom, R. J., & Martin, J. D. 2014. *Pesticide trends in major rivers of the United States, 1992-2010.* Scientific Investigations Report 2014-5135. Accessed April 27, 2016.

Saichuk, J. 2009. *Louisiana Rice Production Handbook.* Louisiana State University Agricultural Center. Accessed April 29, 2016.

Turek, S. M. 1990. *Colusa Basin Drain Water Quality Literature Review.* April 1990. Northern District, Department of Water Resources. State of California. Accessed April 27, 2016.

USDA. 2000. *Crop Profile for Rice In Missouri.* April 2000. University of Missouri. U.S. Department of Agriculture. Accessed May 5, 2016.

USDA. 2002. *Crop Profile for Rice In Louisiana.* September 2002. Louisiana State University Ag Center. Accessed April 29, 2016.

USDA. 2005. *Crop Profile for Rice In Mississippi.* August 2005. Mississippi State University Pesticide Education Program. U.S. Department of Agriculture. Accessed April 29, 2016.

USDA. 2009. *2007 Census of Agriculture. United States. Summary and State Data. AC-07-A-51.* Geographic and Area Series Part 51. National Agricultural Statistics Service. United States Department of Agriculture. Accessed June 11, 2011.

USDA. 2010. *Field Crops. Usual Planting and Harvesting Dates.* Agricultural Handbook Number 628. October 2010. National Agricultural Statistics Service. U.S. Department of Agriculture. Accessed April 29, 2016.

USDA. 2012. *CropScape and Cropland Data Layer.* Accessed April 21, 2016.

USDA. 2015. *Attractiveness of Agricultural Crops to Pollinating Bees for the Collection of Nectar and/or Pollen.* U.S. Department of Agriculture. Accessed May 2, 2016.

USDA. 2016. *National Agricultural Statistics Service Quick Stats Census Data.* Accessed Arpil 30, 2016.

USEPA. 2007. *Tier I Rice Model - Version 1.0 - Guidance for Estimating Pesticide Concentrations in Rice Paddies.* May 8, 2007. Environmental Fate and Effects Division. Office of Pesticide Programs. U.S. Environmental Protection Agency. Accessed April 25, 2016.

USEPA. 2010a. *FIFRA Scientific Advisory Panel: A Set of Scientific Issues Being Considered by the Environmental Protection Agency Regarding: Re- Evaluation of Human Health Effects of Atrazine: Review of Experimental Animal and In Vitro Studies and Drinking Water Monitoring Frequency.* Docket Number EPA-HQ-OPP-2010-0125-0008. April 26-29, 2010. U.S. Environmental Protection Agency. Accessed April 26, 2016.

USEPA. 2010b. *FIFRA Scientific Advisory Panel: A Set of Scientific Issues Being Considered by the Environmental Protection Agency Regarding: Re- Evaluation of Human Health Effects of Atrazine: Review of Non-cancer Effects and Drinking Water Monitoring Frequency*. Docket Number EPA-HQ-OPP-2010-0481. September 14-17, 2010. U.S. Environmental Protection Agency. Accessed April 26, 2016.

USEPA. 2011. *FIFRA Scientific Advisory Panel: A Set of Scientific Issues Being Considered by the Environmental Protection Agency Regarding: Re- Evaluation of Human Health Effects of Atrazine: Review of Cancer Epidemiology, Non-cancer Experimental Animal and In vitro Studies and Drinking Water and Monitoring Frequency*. Docket Number EPA-HQ-OPP-2011-0399. U.S. Environmental Protection Agency. Accessed April 26, 2016.

USEPA. 2012a. *FIFRA Scientific Advisory Panel: Problem Formulation for the Reassessment of Ecological Risks from the Use of Atrazine*. Docket Number EPA-HQ-OPP-2012-0230. September 11-14, 2012. U.S. Environmental Protection Agency. Accessed April 26, 2016.

USEPA. 2012b. *Usage Metrics for Row Crops Estimated from Survey Data*. July 31, 2012. Biological and Economic Analysis Division. Office of Pesticide Programs. Office of Chemical Safety and Pollution Prevention. U.S. Enviornmental Protection Agency.

USEPA. 2013a. *Guidance on Modeling Offsite Deposition of Pesticides Via Spray Drift for Ecological and Drinking Water Assessment*. Environmental Fate and Effects Division. Office of Pesticide Programs. Office of Chemical Safety and Pollution Prevention. U.S. Environmental Protection Agency. Accessed April 11, 2014.

USEPA. 2013b. *Implementation of the Pesticides in Flooded Applications Model (PFAM)*. January 23, 2013. Environmental Fate and Effects Division. Office of Pesticide Programs. U.S. Environmental Protection Agency.

USEPA. 2014. *Development of Community Water System Drinking Water Intake Percent Cropped Area Adjustment Factors for use in Drinking Water Exposure Assessments: 2014 Update.* 9/9/14. Environmental Fate and Effects Division. Office of Chemical Safety and Pollution Prevention. U.S. Environmental Protection Agency. Accessed February 9, 2014.

USEPA. 2015. *Meeting of the FIFRA Scientific Advisory Panel on The Development of a Spatial Aquatic Model SAM) for Pesticide Assessments. September 15-18, 2015*. Docket Number EPA-HQ-OPP-2015-0424-0004. Environmental Fate and Effects Division. Office of Pesticide Programs. U.S. Environmental Protection Agency. Accessed April 21, 2015.

USEPA, Health Canada PMRA, & California Department of Pesticide Regulation. 2014. *Guidance for Assessing Pesticide Risks to Bees*. June 23, 2014. U.S. Environmental Protection Agency. Health Canada Pest Management Regulatory Agency. California Department of Pesticide Regulation. Accessed April 10, 2015.

USFWS. 2016. *About Sacramento National Wildlife Refuge*. U.S. Fish & Wildlife Service. Accessed April 30, 2016.

USGS. 2012a. *Water-Data Report 2012: 07069000 Black River at Pocahontas, AR.* Accessed February 14, 2014.

USGS. 2012b. *Water-Data Report 2012: 11425500 Sacramento River at Verona, CA*. United States Geological Survey. Accessed November 8, 2013.

USGS. 2013. National Water Information System. United States Geological Survey. Accessed June 6, 2013.

USGS. 2016a. *National Water Information System. Streamflow Measurements for the Nation. USGS 11390890 Colusa Basin Drain Dr A RD 99E NR Knights Landing, CA*. Accessed April 21, 2016.

USGS. 2016b. *National Water Information System. Streamflow Measurements for the Nation. USGS 38464912181101 Sacramento Slough NR Verona, CA.* Accessed April 22, 2016.

van Groenigen, J. W., Burns, E. G., Eadie, J. M., Horwarth, W. R., & van Kessel, C. 2003. Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. *Agriculture, Ecosystems & Environment, 95*(2003), 289-296.

Way, M. O., & McCauley, G. N. 2012. *2012 Texas Rice Production Guidelines.* B-6131 12/11. Texas AgriLife Research and Extension Center. Accessed April 29, 2016.

Young, D. 2012. Development and Evaluation of a Regulatory Model for Pesticides in Flooded Applications. *Environmental Modeling & Assessment, 15*, 515-525.

Young, D. 2013. *Pesticides in Flooded Applications Model (PFAM): Conceptualization, Development, Evaluation, and User Guide.* EPA-734-R-13-001. July 18, 2013. Environmental Fate and Effects Division. Office of Pesticide Programs. U.S. Environmental Protection Agency. Accessed April 25, 2016.

Appendix A. Calculating the Area of Rice

1. Create a generalized Cropland Layer from the 2012 CDL dataset for the counties that intersect with the watershed of interest.
   a. Create Mask: For Arkansas, created a shape file of the counties (counties_albers) that intersected with watershed FID number 3378 (DWI_watersheds)
      - Load watersheds (DWI_watersheds.shp) or county file (counties_albers) or state file
      - Select watershed/county/state. For watersheds, select by attribute (selection>select by attribute, *etc.*) and for counties select by location (selection>select by location> select those counties that intersect with watershed).
      - Export data for selected areas and save to use as a mask in the next step (after data is selected in table of contents>right click on DWI_watersheds layer or counties_albers >data>export data>shapefile (XX.shp)
   b. Load cdl file (2012_30m_cdls.img) and Extract by mask (arctoolbox>spatial analyst tools>extraction>extract by mask[15]) for the appropriate county or watershed shape file
         - Input Raster: 2012_30m_cdls.img
         - Input raster or feature mask data: XX.shp (county shape file created in 1a.)
         - Output raster:XXcdl.shp (E:arkansas)
   - Reclass cdl for area of interest so it only contains rice (value=3) data using the reclassify feature (arctoolbox>spatial analyst tools>reclass>reclassify). This tends to time out. Load only the shape file reclassifying and build pyramids before reclassifying if it does not run without building pyramids. Wait a few minutes for the tool to load and come back to it before giving up.
      - Input raster: XXcdl.shp
      - Reclass field: value
      - Reclassification

Old Values	New Values
1-2	NoData
3	1
4-255	NoData
NoData	NoData

Save File as C:/GIS/rice/stcdlri/rXXcdl

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a) [15] Before beginning the spatial analysis in this step, make sure that the Spatial Analyst extension is checked.
   i) Click on the "Customize" option in the menu at the top of ArcGIS.
   ii) Select "Extensions"
   iii) Check "Spatial Analyst" and then close the Extension box.

2. Open the attribute file of the generalized data layer for the watershed/county/state. The count is the number of rice cdl pixels per watershed or counties in watershed. Note that a pixel is equivalent to 90 m^2. You can check this layer to make sure it is correct by comparing it to the rice cdl layer.
3. Calculate the number of agricultural pixels per county using the *zonestats at table* command (this calculates the number of rice cdl pixels per county)
    a. Load file with rice cropland data (containing only no data or 1), e.g., file created in step one for area of interest
    b. Run the zonestats at table (arctoolbox>spatial analyst tools>zonal>zonal statistics at table)
        i. Feature zone data: counties_albers
        ii. Zone field :FIPS
        iii. Input value raster: 2012 rice CDL layer with only 1s and 0s (layer created in step 1):rcdlXXpix
        iv. Ignore no data
        v. Statistics: all

The sum field is the number of rice CDL pixels per county. Create a new field and call it numbpix, this will show the number of rice CDL pixels per county. Set it equal to the sum field.

4. Combine NASS county-level crop acreage information with the ag pixel information to derive acre per pixel value by crop
    a. Join the file created in step 3 with the NASS county data (NASS2007rice.csv) using the FIPS code. If fields are not available to join, add fields and format them the same in each table, export the file and join the new files.
    b. Calculate acrepix field=total NASS acres/numbpix. Add it as a float field.
    c. Export to a shape file and label as acrepix
5. Join acrepix to county shapefile, and export to a new shapefile labeled with acremap. Then use “polygon to raster tool’ (ArcToolbox>conversion tools>to raster>polygon to raster)
    a. Input features: acremap.shp joined to counties (in acremap folder)
    b. Value field:acrepix
    c. Output raster dataset:XXacremapras
    d. Cell assignment type (optional):cell center
    e. Priority field: acrepix
    f. Cell size:30
6. Use math time tool (spatial analyst) to multiply acremap x rice cdl (arctoolbox>math>times)
    a. Input raster 1:acremapras
    b. Input raster 2:rice cdl pixels in relevant counties
    c. Output raster: camappxcdl
7. Run zonestats at table on object ID of watershed and select sum summary statistics
        i. Feature zone data: watershed file
        ii. Zone field :objectid
        iii. 2012 rice CDL layer with only 1s and 0s (filed created in step 6):camappxcdl
        iv. Ignore no data
        v. Statistics: all

vi. Export:Camaster
vii. Sum field will be the acres rice in the watershed, convert to m2

Acres in watershed: Convert the shape area from m^2 to acres.

Overview or procedure

Rcdlpix	Acrepix	Acremap	camapxcdl	Zonestats with watershed
Pixels/county	NASSacres/pixels for each county	Map of NASSacres/pixels	Multiply by map of cdl pixels	Acres in map area

Appendix B. Peak Flow, Mean Annual, Flow, and Gage Height at USGS 11426000 NWIS site

Data from: USGS. 2013. National Water Information System. United States Geological Survey. Accessed June 6, 2013.

Table B1. Gage Height

Date	Gage Height ft
9/10/1987	12.88
10/29/1987	9.86
12/2/1987	10.99
1/8/1988 10:30	23.08
2/10/1988 9:30	12.6
3/17/1988	11.54
4/21/1988 9:00	16.84
5/24/1988 9:00	10.81
7/20/1988	13.29
8/30/1988	12.36
10/13/1988	12.21
11/22/1988	11.31
1/4/1989 11:30	13.45
2/17/1989 9:25	12.79
3/9/1989 11:15	19.66
3/20/1989	26.24
3/20/1989	26.2
4/27/1989	14.05
6/1/1989 11:15	12.99
8/1/1989 10:50	16.54
8/28/1989	13.79
10/12/1989	12.67
12/8/1989	14.71
12/8/1989	14.71
1/19/1990	17.96
1/24/1990	13.18
3/6/1990 10:45	15.25
4/11/1990 9:45	14.78
5/24/1990	13.34
6/26/1990	10.68
9/19/1990	11.25
10/18/1990	10.14
11/16/1990	10.31
1/11/1991	11.93
2/25/1991	9.91
3/29/1991 9:30	23.92

Date	Gage Height ft
5/16/1991 9:45	11.08
7/15/1991	10.26
8/26/1991 9:45	10.86
11/1/1991	9.65
11/1/1991	9.6
12/6/1991	10.14
1/24/1992 9:15	10.65
2/15/1992	25.73
4/28/1992	8.68
6/15/1992	9.35
6/15/1992	9.35
9/21/1992 9:50	11.7
10/16/1992	8.95
12/14/1992	18.25
1/16/1993 9:45	28.37
2/22/1993	32.26
6/2/1993 10:25	21.57
7/12/1993	15.01
8/25/1993	16.05
10/5/1993	13.89
11/15/1993	12.61
1/10/1994	12.81
3/1/1994 9:00	15.37
4/8/1994 9:30	10.7
5/31/1994 9:45	10.18
7/14/1994 9:00	13.82
9/12/1994 9:30	14.67
10/4/1994 9:30	12.21
12/5/1994	20.65
1/13/1995	35.92
2/22/1995	24.12
3/14/1995 9:30	37.7
4/27/1995	22
7/20/1995	18.42
8/1/1995	15.74
9/7/1995	17.12
10/3/1995	16.53
11/30/1995	12.68
1/4/1996	17.54
2/22/1996	35.46
4/4/1996	25.58
5/14/1996	14.1
6/26/1996	14.58

Date	Gage Height ft
8/7/1996	16.26
9/26/1996	13.82
11/19/1996	13.2
Average	16.82

Table B2. Annual Daily Mean Flow

Year	Annual Daily Mean Flow
1946	18,260
1947	11,230
1948	17,100
1949	13,420
1950	14,430
1951	23,320
1952	31,210
1953	21,780
1954	20,890
1955	12,580
1956	25,860
1957	15,430
1958	29,820
1959	14,550
1960	12,910
1961	14,340
1962	15,100
1963	23,850
1964	13,360
1965	23,080
1966	16,940
1967	28,140
1968	15,750
1969	26,610
1970	23,710
1971	27,760
1972	15,050
1973	24,580
1974	36,630
1975	23,630
1976	13,470
1977	7,178
1978	20,890
1979	14,810
1980	22,660
1981	13,960
1982	33,990

Year	Annual Daily Mean Flow
1983	39,150
1984	26,510
1985	14,440
1986	20,680
1987	12,440
1988	12,060
1989	14,800
1990	11,820
1991	9,229
1992	9,506
1993	22,550
1994	11,250
1995	32,110
1996	25,940
1997	23,740
1998	33,280
1999	24,900
2000	21,500
2001	12,810
2002	15,850
2003	22,160
2004	20,940
2005	18,660
2006	32,130
2007	13,830
2008	12,890
2009	12,660
2010	16,040
2011	26,190
2012	14,970
Average	14970

Appendix C. Test Chemical Supporting Information

C1. Comparison of Properties of Tested Chemicals

Chemicals were chosen to be used in the validation model based on the availability of monitoring data in a relevant area.

Table C1. Comparison of properties of tested chemicals

(a) Scenario Description

Scenario→	**Stable, K_{OC} 1628, spray drift, mixed**	**Stable, K_{OC} 186, no spray drift**	**Degrades, K_{OC} 489, spray drift**	**Stable, K_{OC} 36, no spray drift**	**Degrades, K_{OC} 300, spray drift**	**Stable, K_{OC} 62, spray drift**	**Stable, K_{OC} 36, spray drift**

(b) Chemical Tab

Input Parameter↓	**Thiobencarb-Herbicide**	**Molinate-Herbicide**	**Propanil - Herbicide**	**Carbofuran-Insecticide**	**Clomazone-Herbicide**	**Imazethapyr - Herbicide**	**Quinclorac-Herbicide**
Organic Carbon Partition Coefficient (mL/g_{OC}) (K_{OC})	1628	186	489	36	300	62	36
Water Column Half-life (days)	1×10^{8} at 20^{o}C	1×10^{8}	6 (25°C)	642 (25°C)	79(25°C)	584 (25°C)	1295
Benthic Compartment Half-Life (days)	1×10^{8} at 20^{o}C	1×10^{8} at 20^{o}C	9 (25°C)	189 (25°C)	44 (25°C)	$1\text{x}10^{8}$ (25°C)	$1\text{x}10^{8}$
Un-flooded Soil Half-life (days)	246 at 25^{o}C	1×10^{8} at 23^{o}C	1.5 (25°C)	321 (25°C)	80 (25°C)	$1\text{x}10^{8}$ (25°C)	622
Aqueous Near Surface Half-life (days)	190 at 40^{o} Latitude	1×10^{8} at 40^{o} Latitude	103 at 40^{o} Latitude	5.6 at 40^{o} Latitude	87 at 40^{o} Latitude	2.1 at 40^{o} Latitude	16
Hydrolysis Half-life (days)	$1\text{x}10^{8}$	1×10^{8}	1×10^{8}	28	$1\text{x}10^{8}$	$1\text{x}10^{8}$	$1\text{x}10^{8}$
Molecular Weight (g/mol)	257.78	221	218.08	221.25	239.7	289.93	242
Vapor Pressure (torr)	$2.2 \text{ x } 10^{-5}$	5.3×10^{-3}	9.1×10^{-7}	5.2×10^{-7}	$1.44\text{x}10^{-4}$	$5.3\text{x}10^{-8}$	$7.5\text{x}10^{-8}$
Solubility (mg/L)	27.5	970	152	351	1100	1380	64
Heat of Henry (J/mol)	45727	48780	55000	54000	49884	58198	58198
Henry Reference Temperature (^{o}C)	20	25	25	25	25	25	25

(c) Applications Tab for Ecological Risk Assessment

Input Parameter	**Thiobencarb-Herbicide**	**Molinate-Herbicide**	**Propanil - Herbicide**	**Carbofuran-Insecticide**	**Clomazone-Herbicide**	**Imazethapyr - Herbicide**	**Quinclorac-Herbicide**
Application Rate	4.0 lbs a.i./A 4.5 kg a.i./ha	4.0 lbs a.i./A 4.5 kg a.i./ha	5.0 lbs a.i./A 5.6 kg a.i./ha	0.5 lbs a.i./A 0.56 kg a.i./ha	0.67 lbs a.i./A 0.75 kg a.i./ha	0.094 lbs a.i./A 0.11 kg a.i./ha	0.5 lbs a.i./A 0.56 kg a.i./ha
Number of Applications	1	2	1	1	1	2	1
Application Dates	5/24	5/24, 6/24	6/2	4/24	4/26		
Slow Release 1/day	0.017	0.017	0.017	0.017	0.017	0.017	0.017

(d) Scenario for Drinking Water Assessment

Input Parameter	**Thiobencarb-Herbicide**	**Molinate-Herbicide**	**Propanil - Herbicide**	**Carbofuran-Insecticide**	**Clomazone-Herbicide**	**Imazethapyr - Herbicide**	**Quinclorac-Herbicide**
Apply over a Distribution	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular	Triangular
First Application Date	05/09	05/09 (CA) 4/25 (AR)	6/2 (CA) 4/30 (AR)	4/24	4/24 (CA) 03/15 (AR)	3/15	3/15
Last Application Date	06/24	06/24 (CA) 6/10 (AR)	7/17 (CA) 6/15 (AR)	6/9	06/09 (CA) 04/30 (AR)	4/30	4/30
Total Mass Applied (kg/ha)	1.3	1.6	2.5 (CA) 4.7 (AR)	0.095	0.75	0.11	0.56
Drift Application	15% flowable, aerial fine to medium (60.6)	0% spray drift also assumed, granular	Ground, high, fine to medium/ coarse DSD and flowable 566 (CA) 121 (AR)	0% drift, granular formulation typically aerially applied	Ground, high, fine to medium/ coarse DSD and flowable (566)	Ground, high, fine to medium/ coarse DSD and flowable (566)	15% Ground, high, fine to medium/ coarse DSD and flowable (566)
Percent Crop Treated over Monitoring Years	30%	35%	48% (CA) 84% (AR)	17%	84%	84%	84%
Scenario	Mixed	Mixed	Postflood	Preflood	Preflood	Preflood	Preflood
Holding Period (day)	14	14	7 (CA) 0 (AR)	28	0	0	0

C2. Model Inputs for Thiobencarb

Fate data for thiobencarb were taken from the most recently completed review (Federoff and Orrick, 2011, D391181).

The CA mixed scenario with a 14-day holding period was used to estimate drinking water concentrations as molinate can be applied pre- or post-flood. The specified holding period has changed over the years; however, as molinate is very stable, the holding period had little impact on the EDWCs. For ecological risk assessment, the scenario for water-seeded rice in California was used in modeling. Other state ecological risk assessment scenarios were simulated with turnover and without a winter flood.

Table C2. PFAM inputs specific to thiobencarb

(a) Chemical Tab

Input Parameter	Value	Source	Comment
Water Column Half-life (days)	1×10^8 at 20°C	MRID 42015301	Essentially stable
Benthic Compartment Half-Life (days)	$1x10^8$ at 20°C	MRID 42015301	Essentially stable
Un-flooded Soil Half-life (days)	246 at 25°C	MRID 00040925, 43300401, 43121201	90th percentile confidence bound on the mean half-life value: 3 values are available: 23, 84, 249 days; mean = 119 days; std. dev. = 117 days, n = 3, $t_{90,n-1}$ = 246.
Aqueous Near Surface Half-life (days)	190 at 40° Latitude	42257801	--
Hydrolysis Half-life (days)	$1x10^8$	41609012	No evidence of degradation (pH range 5 to 9).
Organic Carbon Partition Coefficient (mL/g_{OC}) (K_{OC})	1628	41215313	EPIWeb v4.4, MIC method. (426 using KOW method)
Molecular Weight (g/mol)	257.78	--	---
Vapor Pressure (torr)	2.2×10^{-5}	MRID 140158	at 23°C
Solubility (mg/L)	27.5	MRID 140158	---
Heat of Henry (J/mol)	45727	--	Estimated using HENRYWIN program in EPISuite.
Henry Reference Temperature (°C)	20	--	

(b) Applications Tab for Ecological Risk Assessment

Input Parameter	Value	Source	Comment
Apply Pesticide on Specific Days or over a Distribution of Days	Specific Day	--	--
Application Rate	4.0 lbs a.i./A 4.5 kg a.i./ha	Label	Based on information on the label
Number of Applications	1	---	---
Application dates	5/24	---	---
Slow Release 1/day	0	--	
Drift Application	0	--	Risk is assessed in rice paddy

(c) Applications Tab for Drinking Water Assessment

Input Parameter	Value	Source	Comment
Apply Pesticide on Specific Days or over a Distribution of Days	Distribution of Days, ^	--	--
Application Rate	4.0 lbs a.i./A 4.5 kg a.i./ha 1.2 lbs a.i./A 1.3 kg a.i./ha	--	Based on information on the label. Thiobencarb can be applied one time at a max of 4 lbs a.i./A. The average application rate from CAPUR is similar to the max rate. Simulations were run with and without a PCT of 30%. This reflects the average number of acres treated between 1995 and 2008 (years of monitoring) divided by 511000 acres. Acres treated was provided by the CA Rice Commission.
Application Dates	5/9-6/24	--	Applications were spread out over 46 days. This value is supported by the CAPUR data (**Table C3**) for thiobencarb and was assumed in the scenario development.
Drift Factor	60.6 (Aerial, medium to fine DSD and 15% Flowable)	--	Based on CA PUR data (**Table C3**), most thiobencarb is applied via air and in granular form. Approximately 15% of that applied by air is applied in a flowable formulation. The spray drift value was assumed to be 15% of the spray drift factor assumed for a fine to medium spray of a flowable (404 x 0.15).

PCT=Percent Crop Treated

Table C3. California pesticide use reporting data summary in support of test input assumptions

Year	% of Lbs applied by air that is flowable	% of Lbs applied by air that is granule	% of total lbs applied that is air	% of Lbs applied by ground that is flowable	% of Lbs applied by ground that is granule	% of total lbs applied that is ground	Ave app rate[1]	Beginning Date with > 1% applied	Ending Date with > 1% applied	# of days
1995	32%	68%	95%	95%	5%	5%	4.51	9-May	24-Jun	46
1996	12%	88%	92%	84%	16%	8%	4.01	9-May	14-Jun	36
1997	11%	89%	95%	78%	22%	5%	3.99	30-Apr	30-May	30
1998	34%	66%	81%	100%	0%	19%	3.88	29-Apr	28-May	29
1999	7%	93%	96%	86%	14%	4%	3.93	6-May	7-Jun	32
2000	5%	95%	95%	96%	4%	5%	3.99	28-Apr	29-Jun	62
2001	5%	95%	95%	96%	4%	5%	3.82	29-Apr	2-Jun	34
2002	7%	93%	95%	78%	22%	5%	3.79	28--Apr	2-Jun	35
2003	2%	98%	94%	88%	12%	6%	3.79	12-May	17-Jun	36
2004	5%	95%	92%	75%	25%	8%	3.83	30-Apr	30-May	30
2005	8%	92%	97%	53%	47%	3%	3.77	10-May	18-Jun	39
2006	12%	88%	96%	66%	34%	4%	3.92	17-May	17-Jun	31
2007	15%	85%	92%	77%	23%	8%	3.89	30-Apr	6-Jun	37

Year	% of Lbs applied by air that is flowable	% of Lbs applied by air that is granule	% of total lbs applied that is air	% of Lbs applied by ground that is flowable	% of Lbs applied by ground that is granule	% of total lbs applied that is ground	Ave app rate[1]	Beginning Date with > 1% applied	Ending Date with > 1% applied	# of days
2008	49%	51%	98%	80%	20%	2%	3.90	2-May	5-Jun	34
Ave	**15%**	**85%**	**94%**	**82%**	**18%**	**6%**	**3.93**	**--**	**--**	**37**

Ave=Average

[1] Average application rate = total lbs chemical ÷ total acres treated

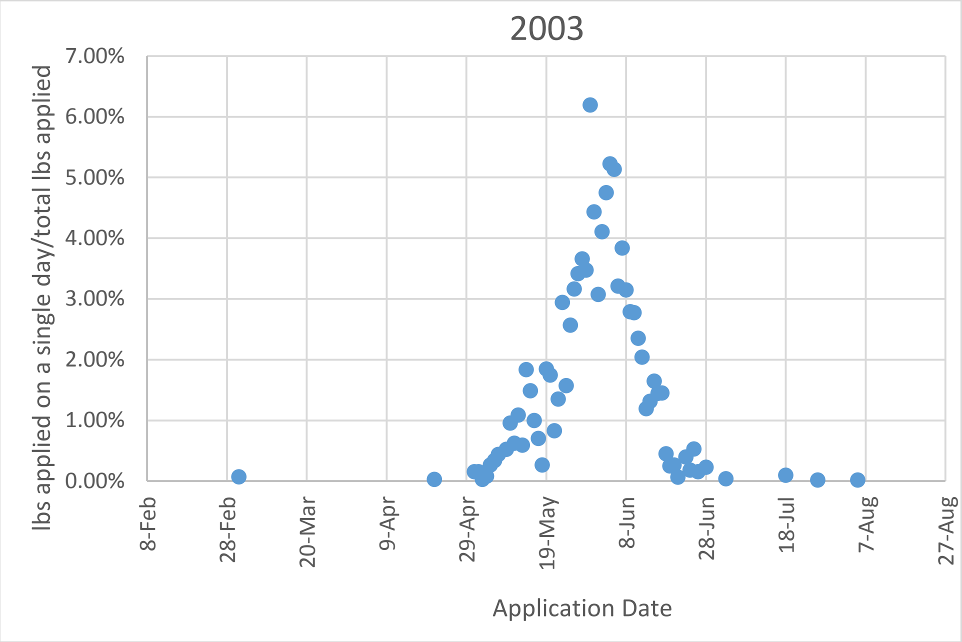

Figure C1. California pesticide use reporting data in support of the pattern of the distribution of pesticide applications

C3. Model Inputs for Molinate

Molinate inputs were obtained from information in the EFED molinate RED chapter (Mastrota *et al.*, 1999).

The only crop that molinate was used on was rice. Maximum single application rates ranged from 3 to 5 lbs a.i./A per season and the maximum seasonal rates ranged from 6 to 9 lbs a.i./A. Products could be applied 2 to 3x per season; however, survey data indicates that greater than 85% of applicators only applied molinate once (USEPA, 2012b). Granular and flowable products were available. Molinate could be applied pre- or post-flood.

The CA mixed scenario with a 14-day holding period was used to estimate drinking water concentrations as molinate can be applied pre- or post-flood. The specified holding period has changed over the years; however, as molinate is very stable, the holding period had little impact on the EDWCs. For ecological risk assessment, the scenario for water-seeded rice in California was used in modeling. Other state ecological risk assessment scenarios were simulated with turnover and without a winter flood.

Table C4. PFAM inputs specific to molinate

(a) Chemical Tab

Input Parameter	Value	Source	Comment
Organic Carbon Partition Coefficient (mL/g_{OC}) (K_{OC})	186	MRID 40749701	Average of 5 values. Calusa canal K_{OC} was 206 L/kg_{OC}.
Water Column Half-life (days)	1×10^8	MRID 41421802	Essentially stable, not enough data to calculate a half-life. Data only available for 30 days.
Benthic Compartment Half-Life (days)	1×10^8 at 20°C	MRID 41421802	Essentially stable, not enough data to calculate a half-life. Did not confirm anaerobic environment.
Un-flooded Soil Half-life (days)	1×10^8 at 23°C	--	Essentially stable, no data available.
Aqueous Near Surface Half-life (days)	1×10^8 at 40° Latitude	MRID 41599301	Essentially stable
Hydrolysis Half-life (days)	1×10^8 at 25°C	MRID 40817901	No evidence of degradation (pH range 5 to 9).
Molecular Weight (g/mol)	221	--	---
Vapor Pressure (torr)	5.3×10^{-3}	MRID 40593304	--
Solubility (mg/L)	970	MRID 00149370	At 25°C
Heat of Henry (J/mol)	48780	--	Estimated using HENRYWIN program in EPISuite.
Henry Reference Temperature (°C)	20	--	--

(b) Applications Tab for Ecological Risk Assessment

Input Parameter	Value	Source	Comment
Application Rate	4.0 lbs a.i./A 4.5 kg a.i./ha	--	Average application rate from CA PUR data.
Number of Applications	2	---	2 to 3 applications of molinate were allowed on labels with a maximum of 9 lbs a.i./A. This allows for 2 applications at 4 lbs a.i/A.
Application Dates	5/24, 6/24	---	Assumed
Slow Release 1/day	0.017	--	--
Drift Application	0	--	Risk is assessed in rice paddy

(c) Applications Tab for Drinking Water Assessment

Input Parameter	Value	Source	Comment
Distribution of Days or Specific Days	Distribution of Days, ^	--	--
First Day of Application (Month-day)	05-09	--	Based on CA PUR usage data
Last Day of Application (Month-day)	06-24	--	Based on CA PUR usage data

Input Parameter	Value	Source	Comment
Total Amount Applied Per Year (lbs a.i./A)	8 for max scenario (9 in kg/ha) 1.4 with 35% PCT and assuming 1 app at 4 lbs a.i./A (1.6 kg/ha)	--	The maximum application rate is 5 lbs a.i./A, and the maximum annual rate is 9 lbs a.i./A. CA pur data yielded an average application rate consistently near 4 lbs a.i./A and across many years. Two applications would be possible with this application rate; however, survey data indicate that most users only apply molinate once per year. The PCT varies over time. The average acres treated per year between 1995 and 2008 was 181,968 acres, assuming 511,824 acres rice planted per year results in an estimated PCT of 35%. Pesticide use data was supplied by the California Rice Commission.
Application Timing	Mixture of pre and post-flood	--	Both pre and post flood applications are allowed on labels
Distribution of Applications	Triangular	--	Based on CA PUR usage data
Application Method for Drift	0 Drift	--	Based on CA PUR data (**Table C5**), most molinate is applied via air and in granular form. The spray drift factor was assumed to be zero.
Holding Period Duration	14	--	The final recommended holding period for molinate in California was 28 days. However, this holding period was not in place since 1995. Therefore, a 14-day holding period was used. This practice has little impact on the result due to the stability of molinate.

PCT=percent crop treated

Table C5. California pesticide use reporting data summary in support of test Input assumptions for molinate

Year	% of Lbs applied by air that is flowable	% of Lbs applied by air that is granule	% of total lbs applied that is air	% of Lbs applied by ground that is flowable	% of Lbs applied by ground that is granule	% of total lbs applied that is ground	Ave app rate[1]	Beginning Date with > 1% applied	Ending Date with > 1% applied	# of days
1995	0%	100%	99%	66%	34%	1%	4.1	10-May	17-Jun	38
1996	0%	100%	98%	55%	45%	2%	4.0	7-May	12-Jun	36
1997	0%	100%	97%	81%	19%	3%	3.7	29-Apr	28-May	29
1998	0%	100%	94%	66%	34%	6%	3.8	18-May	19-Jun	32
1999	0%	100%	96%	78%	22%	4%	3.7	6-May	7-Jun	32
2000	0%	100%	95%	82%	18%	5%	3.7	29-Apr	8-Jun	40
2001	0%	100%	95%	79%	21%	5%	3.9	4-May	2-Jun	29
2002	0%	100%	94%	55%	45%	6%	4.0	30-Apr	1-Jun	32
2003	0%	100%	98%	64%	36%	2%	4.0	13-May	16-Jun	34
2004	0%	100%	96%	70%	30%	4%	4.1	27-Apr	29-May	32

Year	% of Lbs applied by air that is flowable	% of Lbs applied by air that is granule	% of total lbs applied that is air	% of Lbs applied by ground that is flowable	% of Lbs applied by ground that is granule	% of total lbs applied that is ground	Ave app rate[1]	Beginning Date with > 1% applied	Ending Date with > 1% applied	# of days
2005	0%	100%	2%	99%	1%	98%	4.2	10-May	13-Jun	34
2006	0%	100%	97%	100%	0%	3%	4.3	16-May	16-Jun	31
2007	0%	100%	97%	56%	44%	3%	4.3	27-Apr	7-Jun	41
2008	0%	100%	99%	100%	0%	1%	4.3	25-Apr	27-Jun	63
Average	**0%**	**100%**	**90%**	**75%**	**25%**	**10%**	**4.01**			**35.93**

Ave=Average

[1] Average application rate = total lbs chemical ÷ total acres treated

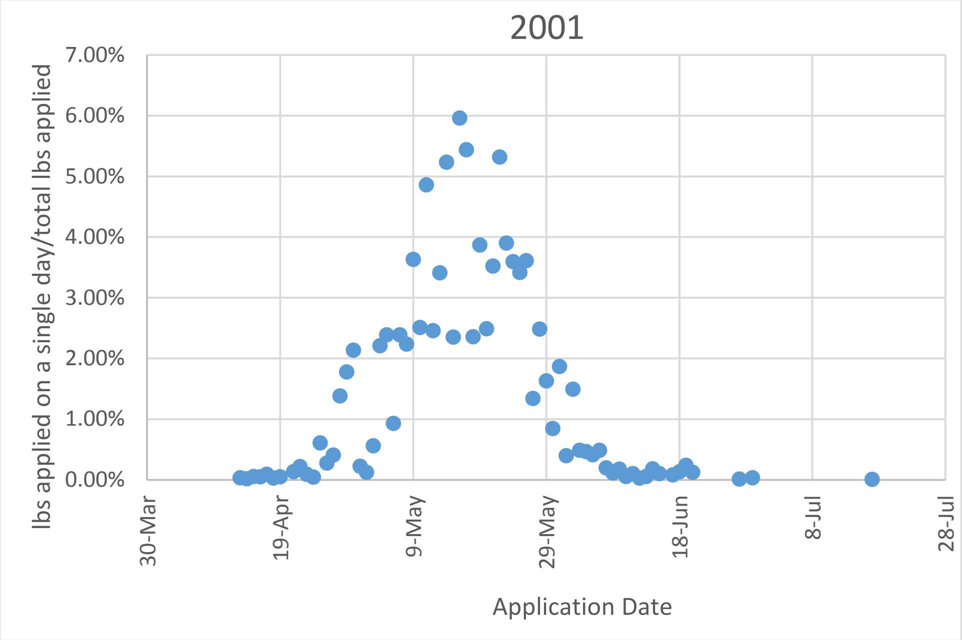

Figure C2. California pesticide use reporting data in support of the pattern of the distribution of pesticide applications for molinate

C4. Model Inputs for Propanil

Propanil is only used on rice. Rice paddies must be fully or partially drained before application. The maximum labeled use rate is 8 lb/acre/yr. The minimum required rice paddy water holding time is 7 days, per the 2003 RED. The average application rate in all counties was approximately 4 lb/acre (applied by aerial equipment) prior to 2004 and approximately 5 lb/acre (applied by ground equipment) afterward (CA PUR, 2014). Only one application appears to have been made per year (CA PUR, 2014), and survey data confirms that one application is commonly made (USEPA, 2012b). Propanil is applied as a flowable in spray applications with both aerial and ground applications occurring (USEPA, 2012b). The CA post-flood scenario (DW CA postflood no holding period.PFS) was used to estimate drinking water concentrations as propanil is normally applied post flood. For ecological risk assessment, the scenario for water-seeded rice in California was used in modeling simulations that were completed with turnover (ECO CA Winter.PFS). The scenario was also simulated with applications beginning after a drawdown of the water prior to application and reflooding after the day after the application. Other state ecological risk assessment scenarios were simulated with turnover and without a winter flood.

Table C6. PFAM inputs specific to propanil

(a) Chemical Tab

Input Parameter	Value	Source	Comment
Organic Carbon Partition Coefficient (mL/g_{OC}) (K_{OC})	489	MRID 42780401	Average of 5 values (306, 239, 703, 800, and 398)
Water Column Half-life (days)	6 at (25°C)	MRID 41848701	One value (2 d) multiplied by 3.
Benthic Compartment Half-Life (days)	9 at (25°C)	MRID 41872601	One value (3 d) multiplied by 3.
Un-flooded Soil Half-life (days)	1.5	MRID 41537801	One value (0.5 d) multiplied by 3.
Aqueous Near Surface Half-life (days)	103 (24°C) and 40 Latitude	MRID 41074701	–
Hydrolysis Half-life (days)	0	MRID 41066601, 00111395	–
Molecular Weight (g/mol)	218.08	(calculated)	–
Vapor Pressure (torr)	9.1×10^{-7} (25°C)	MRID 00143618	–
Solubility (mg/L)	152 (24°C)	MRID 00150488	–
Heat of Henry (J/mol)	55000	HENRYWIN	Estimated using HENRYWIN program in EPISuite.
Henry Reference Temperature (°C)	25	HENRYWIN	Temperature of vapor pressure measurement.

(b) Applications Tab for Ecological Risk Assessment

Input Parameter	Value	Source	Comment
Application Rate	5.0 lbs a.i./A 5.6 kg a.i./ha	CA PUR, 2014	Average application rate for recent years from CA PUR data.
Number of Applications	1	CA PUR, 2014	One application per year appears to be applied in the CA PUR data.
Application Date	June 2	CA PUR, 2014	Median initial date with >1% applied.
Slow Release (1/day)	0	--	--
Drift Application	0	--	Risk is assessed in rice paddy.

(c) Flood Tab for Ecological Risk Assessment

Input Parameter	Value	Source	Comment
Number of Flood Events	4	--	--
Date of Event 1 (Month-Day)	05-01	--	Assumed day of field flooding prior to planting.
Fill Level, Wier Level, and Min.level (m) for Event 1	0.1016	--	Assumed flood depth of 4 inches.
Event 2 (days after)	31	--	Field is drained the day before application (6/1).

Input Parameter	Value	Source	Comment
Fill Level, Wier Level, and Min.level (m) for Event 2	0	--	--
Event 3 (days after)	33	--	Field is flooded the day after application (6/3).
Fill Level, Wier Level, and Min.level (m) for Event 1	0.1016	--	Assumed flood depth of 4 inches.
Event 4 (days after)	40	--	Field is drained after the 7-day holding period.
Fill Level, Wier Level, and Min.level (m) for Event 2	0	--	--

(d) Application Information for Drinking Water Assessment

Input Parameter	Value	Source	Comment
Distribution of Days or Specific Days	Distribution of Days, ^	--	Default
First Day of Application (Month-day)	06-02 (CA) 4-30 (AR)	CA PUR, 2014	Median first date with >1% of annual state total of pounds applied; assumed for Arkansas
Last Day of Application (Month-day)	07/18 6/15 (AR)	CA PUR, 2014	Spreads applications over 46 days.
Total Amount Applied Per Year (lbs a.i./A)	4.6 for max scenario (5.2 in kg/ha) 2.5 kg/ha with 48% PCT and assuming 1 app at 4.6 lbs a.i./A (5.2 kg/ha) for CA 4.7 kg/ha with 84% PCT for AR	Ca Rice Commission Data on acres treated	The average PCT during years of monitoring was 48% based on data received from the CA Rice Commission.
Application Timing	Post-flood	EPA Reg. No. 71085-6	Application is made after paddy is fully or partially drained.
Distribution of Applications	Triangular	Table C8	Default
Application Method for Drift	566 in CA 121 in AR (Ground application, high boom, fine to medium coarse)	EPA Reg. No. 71085-6; CA PUR, 2014	Label directs to apply as a medium or coarser spray. CA PUR data indicate ~2/3 of applications are applied with ground equipment since 1998.
Holding Period Duration	7	Labels	--

PCT=percent crop treated

Table C8. California pesticide use reporting data summary in support of test input assumptions for propanil

Year	% of Lbs applied by air that is flowable	% of Lbs applied by air that is granule	% of total lbs applied that is air	% of Lbs applied by ground that is flowable	% of Lbs applied by ground that is granule	% of total lbs applied that is ground	Ave app rate[1]	Beginning Date with > 1% applied	Ending Date with > 1% applied	# of days
1995	100%	0%	91%	100%	0%	9%	3.8	8-Jun	29-Jul	51
1996	100%	0%	93%	100%	0%	7%	4.2	11-Jun	19-Jul	38
1997	100%	0%	70%	100%	0%	30%	3.9	21-May	10-Jul	50
1998	100%	0%	39%	100%	0%	61%	4.2	18-Jun	22-Jul	34
1999	100%	0%	33%	100%	0%	67%	4.0	9-Jun	8-Jul	29
2000	100%	0%	23%	100%	0%	77%	4.1	1-Jun	7-Jul	36
2001	100%	0%	23%	100%	0%	77%	4.2	31-May	3-Jul	33
2002	100%	0%	21%	100%	0%	79%	4.2	30-May	3-Jul	34
2003	100%	0%	20%	100%	0%	80%	4.4	10-Jun	15-Jul	35
2004	100%	0%	33%	100%	0%	67%	4.5	30-May	1-Jul	32
2005	100%	0%	33%	100%	0%	67%	4.6	3-Jun	18-Jul	45
2006	100%	0%	34%	100%	0%	66%	4.7	14-Jun	15-Jul	31
2007	100%	0%	30%	100%	0%	70%	5.0	31-May	8-Jul	38
2008	100%	0%	32%	100%	0%	68%	5.0	2-Jun	8-Jul	36
2009	100%	0%	30%	100%	0%	70%	5.1	29-May	8-Jul	40
2010	100%	0%	32%	100%	0%	68%	5.0	2-Jun	8-Jul	36
2011	100%	0%	30%	100%	0%	70%	5.1	29-May	8-Jul	40
2012	100%	0%	28%	100%	0%	72%	5.1	13-Jun	16-Jul	33
2013	100%	0%	29%	100%	0%	71%	5.2	15-Jun	19-Jul	34
Average	**100%**	**0%**	**38%**	**100%**	**0%**	**62%**	**4.6**	**4-Jun**	**11-Jul**	**37**

Ave=Average

[1] Average application rate = total lbs chemical ÷ total acres treated

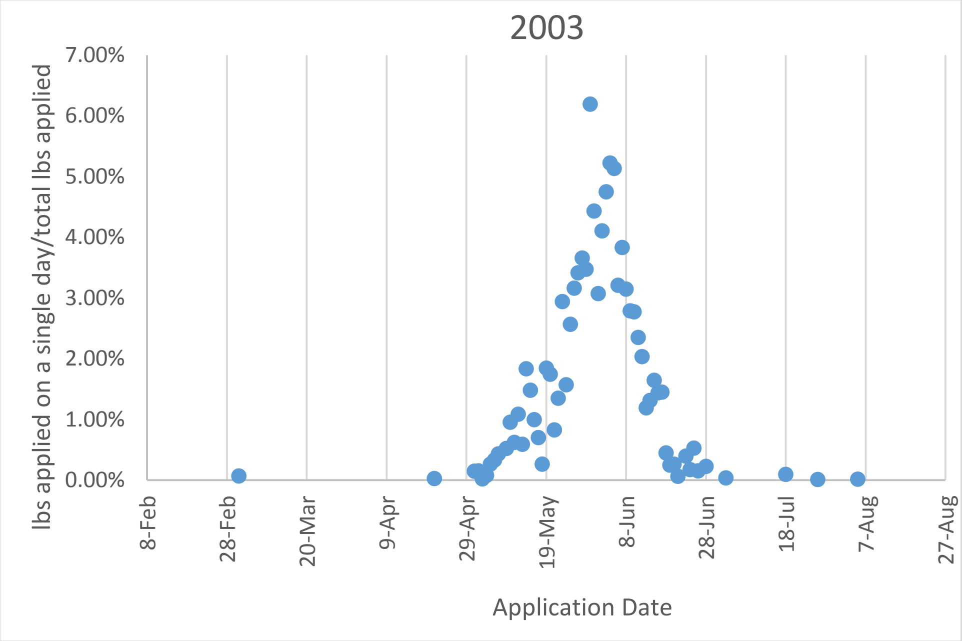

Figure C3. California pesticide use reporting data in support of the pattern of the distribution of pesticide applications

C5. Model Inputs for Carbofuran

Carbofuran was applied as a granular to rice paddies prior to flooding and planting, and incorporated no deeper than 2 inches. The maximum labeled use rate was 0.5 lbs/acre, which was applied once per year. The minimum required rice paddy water holding time was 28 days. Use of carbofuran on rice was cancelled in 1999 with phase out of existing stocks in 2000 (CA DPR, 2003). The typical application rate was 0.5 lbs/acre, with an average of 72% of applications by air (CA PUR, 2014).

The CA post flood scenario (DW CA preflood nohold.PFS) was used to estimate drinking water concentrations as carbofuran is normally applied pre-flood but a 28-day holding period was simulated. For ecological risk assessment, the scenario for water-seeded rice in California was used in modeling simulations that were completed with turnover (ECO CA Winter.PFS). Other state ecological risk assessment scenarios were simulated with turnover and without a winter flood.

Table C8. PFAM inputs specific to carbofuran

(a) Chemical Tab

Input Parameter	Value	Source	Comment
Water Column Half-life (days)	642 at (25°C)	--	2x aerobic soil value, in absence of data.
Benthic Compartment Half-Life (days)	189 at 25°C	MRID 43437101	One value available. Uncertainty factor was not applied due to high value.
Un-flooded Soil Half-life (days)	321 at 25°C	MRID 43437201	One value available. Uncertainty factor was not applied due to high value.
Aqueous Near Surface Half-life (days)	5.6	MRID 00092801	Value at 40°N Latitude.
Hydrolysis Half-life (days)	28	MRID 42117502	Value at 25°C, pH 7.

Input Parameter	Value	Source	Comment
Organic Carbon Partition Coefficient (mL/g$_{OC}$) (K$_{OC}$)	36	MRIDs 42596102, 00093688, 00255057, 00093687	Mean of 23 values.
Molecular Weight (g/mol)	221.25	(calculated)	–
Vapor Pressure (torr)	5.2×10^{-7} (25°C)	MRID 00145190	–
Solubility (mg/L)	351 (25°C)	MRID 44656801	–
Heat of Henry (J/mol)	54000	HENRYWIN	Estimated using HENRYWIN program in EPISuite.
Henry Reference Temperature (^{o}C)	25	HENRYWIN	Temperature of vapor pressure measurement.

(b) Applications Tab for Ecological Risk Assessment

Input Parameter	Value	Source	Comment
Application Rate	0.5 lbs a.i./A 0.56 kg a.i./ha	CA PUR, 2014	Typical application rate from CA PUR data.
Number of Applications	1	CA PUR, 2014	One application per year appears to be applied in the CA PUR data.
Application Date	April 24 (CA) or 1 day before flood	CA PUR, 2014	Median initial date with >1% applied.
Slow Release (1/day)	0	--	--
Drift Application	0	--	Risk is assessed in rice paddy; and formulation is granular.

(c) Applications Tab for Drinking Water Assessment

Input Parameter	Value	Source	Comment
Distribution of Days or Specific Days	Distribution of Days, ^	--	Default
First Day of Application (Month-day)	04-24 (CA) 5-15 (AR)	--	Median first date with >1% of annual state total of pounds applied; assumed for Arkansas
Last Day of Application (Month-day)	6/9 6/30 (AR)	CA PUR, 2014	Spreads applications over 46 days.
Total Amount Applied Per Year (lbs a.i./A)	0.5 lbs a.i./A 0.56 kg a.i./ha 0.095 kg/ha with 17% PCT and assuming 1 app	Ca Rice Commission Data on acres treated	The percent crop treated (PCT) varies over time. The maximum acres treated per year between 1989 and 2000 was 137,297 acres. Assuming 511,824 acres rice planted per year results in an estimated percent crop treated of 27%. When focusing on the monitoring years 1995-2000, the average acres treated divided by 511,824 was 17%. Acres treated was not reported or zero for 2001. Pesticide use data was supplied by the California Rice Commission. Max PCT for insecticides is 48% (copper sulfate).
Application Timing	Pre flood	EPA Reg. No. 279-2874	Application is made prior to flooding paddy.

Input Parameter	Value	Source	Comment
Distribution of Applications	Triangular		
Application Method for Drift	0	EPA Reg. No. 279-2874	Formulation is granular. Granulars are assumed in PFAM to result in zero drift.
Holding Period Duration	28	EPA Reg. No. 279-2874	Label included a 28-day holding period

Table C9. California pesticide use reporting data summary in support of test Input assumptions for carbofuran

Year	% of Lbs applied by air that is flowable	% of Lbs applied by air that is granule	% of total lbs applied that is air	% of Lbs applied by ground that is flowable	% of Lbs applied by ground that is granule	% of total lbs applied that is ground	Ave app rate[1]	Beginning Date with > 1% applied	Ending Date with > 1% applied	# of days
1995	0%	100%	82%	0%	100%	18%	0.5	24-Apr	3-Jun	40
1996	0%	100%	74%	0%	100%	26%	0.5	29-Apr	2-Jun	34
1997	0%	100%	66%	0%	100%	34%	0.5	14-Apr	18-May	34
1998	0%	100%	73%	0%	100%	27%	0.5	1-May	6-Jun	36
1999	1%	99%	69%	1%	99%	31%	0.5	24-Apr	1-Jun	38
2000	4%	96%	66%	2%	98%	34%	0.5	20-Apr	25-May	35
Average	**1%**	**99%**	**72%**	**0%**	**100%**	**28%**	**0.5**	**23-Apr**	**29-May**	**36**

[1] Average application rate = total lbs chemical ÷ total acres treated

C6. Model Inputs for Clomazone

Clomazone was applied as a liquid to rice paddies planting but prior to flooding. The maximum labeled use rate was 0.8 lbs/acre, which was applied once per year. There was no minimum required rice paddy water holding time.

The AR post flood scenario (DW MO preflood nohold.PFS) was used to estimate drinking water concentrations as clomazone was normally applied pre-flood.

Table C10. PFAM inputs specific to clomazone

(a) Chemical Tab

Input Parameter	Value	Source	Comment
Water Column Half-life (days)	79 at (25°C)	MRIDs 44348404	R^2=0.78, F=90, p=5.88e-10 Represents water column half-life
Benthic Compartment Half-Life (days)	44 at 25°C	--	2 times aerobic aquatic value
Unflooded Soil Half-life (days)	80 at 25°C	MRID 00072819	1st order non-linear analysis
Aqueous Near Surface Half-life (days)	87	MRID 44864488	Value at 40°N Latitude.
Hydrolysis Half-life (days)	$1x10^8$	MRID 00248476	Stable
Organic Carbon Partition Coefficient (mL/g_{OC}) (K_{OC})	300	(Ahrens, 1994)	--
Molecular Weight (g/mol)	239.7	(calculated)	–

Input Parameter	Value	Source	Comment
Vapor Pressure (torr)	1.44×10^{-4} (25°C)	Ahrens, 1994	–
Solubility (mg/L)	1100 (25°C)	Ahrens, 1994	–
Heat of Henry (J/mol)	49844	HENRYWIN	Estimated using HENRYWIN program in EPISuite.
Henry Reference Temperature (^{o}C)	25	HENRYWIN	Temperature of vapor pressure measurement.

(b) Applications Tab for Drinking Water Assessment

Input Parameter	Value	Source	Comment
Distribution of Days or Specific Days	Distribution of Days, ^	--	Default
First Day of Application (Month-day)	3/15 (AR)	--	Assumed for Arkansas
Last Day of Application (Month-day)	4/30 (AR)	--	Spreads applications over 46 days.
Total Amount Applied Per Year (lbs a.i./A)	0.80 lbs a.i./A 0.89 kg a.i./ha 0.75 kg/ha with 84% PCT and assuming 1 app	Label	Assumed a percent cropped treated (PCT) of 84% based on maximum use information from CA PUR for herbicides and insecticides.
Application Timing	Pre-flood	Label	Application is made prior to flooding paddy.
Distribution of Applications	Triangular		
Application Method for Drift	566 (Ground application, high boom, fine to medium coarse)	Label	.
Holding Period Duration	0	Label	No holding period

C7. Model Inputs for Imazethapyr

Imazethapyr was applied as a liquid foliar spray preplant, preemergence, or postemergence to dry paddies. The maximum labeled use rate was 0.094 lbs/acre, which was applied once per year. There was no minimum required rice paddy water holding time.

The AR post flood scenario (DW MO preflood nohold.PFS) was used to estimate drinking water concentrations, as imazethapyr is normally applied pre-flood without a holding period.

Table C11. PFAM inputs specific to imazethapyr

(a) Chemical Tab

Input Parameter	Value	Source	Comment
Water Column Half-life (days)	584 at (25^{o}C)	MRID 45161330	
Benthic Compartment Half-Life (days)	1x10^8 at 25^{o}C	MRID 45161329	Considered stable.
Un-flooded Soil Half-life (days)	1x10^8 at 25^{o}C	MRIDs 00159754, 40074201, and 45161328	Considered stable.
Aqueous Near Surface Half-life (days)	2.1	MRID 40429407	Value at 40^{o}N Latitude.
Hydrolysis Half-life (days)	1x10^8	MRIDs 00159752 and 00159753	Considered stable at 25°C, pH 7.
Organic Carbon Partition Coefficient (mL/g$_{OC}$) (K$_{OC}$)	62	MRIDs 00159755 and 45161329	Kd is a mean of 5 values. Converted to Koc by dividing by 0.01, the fraction of organic carbon
Molecular Weight (g/mol)	289.93	(calculated)	–
Vapor Pressure (torr)	5.3 × 10^{-8} (25°C)	MRID 46841305	–
Solubility (mg/L)	1380 (25°C)	MRID 46854502	–
Heat of Henry (J/mol)	58198	HENRYWIN	Estimated using HENRYWIN program in EPISuite.
Henry Reference Temperature (^{o}C)	25	HENRYWIN	Temperature of vapor pressure measurement.

(b) **A**pplications Tab for Drinking Water Assessment

Input Parameter	Value	Source	Comment
Distribution of Days or Specific Days	Distribution of Days, ^	--	Default
First Day of Application (Month-day)	3/15 (AR)	--	Assumed for Arkansas
Last Day of Application (Month-day)	4/30 (AR)	--	Spreads applications over 46 days.
Total Amount Applied Per Year (lbs a.i./A)	0.094 lbs a.i./A 0.11 kg a.i./ha 0.092 kg/ha with 84% PCT and assuming 1 app	EPA Reg. No. 7969-222	Assumed a percent cropped treated (PCT) of 84% based on maximum use information from CA PUR for herbicides and insecticides.
Application Timing	Preflood	EPA Reg. No. 7969-222	Apply product to dry paddy
Distribution of Applications	Triangular		

Input Parameter	Value	Source	Comment
Application Method for Drift	566 (Ground application, high boom, fine to medium coarse)	EPA Reg. No. 7969-222	
Holding Period Duration	0	EPA Reg. No. 7969-222	No holding time specified on label.

C8. Model Inputs for Quinclorac

Quinclorac was applied as a liquid foliar spray preplant, preemergence, or postemergence to dry paddies. The maximum labeled use rate for quinclorac was 0.5 lbs/acre, which was applied once per year. There was no minimum required rice paddy water holding time.

The AR post flood scenario (DW MO preflood nohold.PFS) was used to estimate drinking water concentrations, as quinclorac is normally applied pre-flood without a holding period.

Table C12. PFAM inputs specific to quinclorac

(a) Chemical Tab

Input Parameter	Value	Source	Comment
Water Column Half-life (days)	1295 at (25^oC)	MRIDs 42294102 and 42294103	Upper 90th percentile confidence interval on the mean of two half-lives: 1229 and 393 days
Benthic Compartment Half-Life (days)	1x10^8 at 25^oC	MRIDs 42294104, 41063561, and 42786401	Assumed stable
Unflooded Soil Half-life (days)	622 at 25^oC	MRID 44084503	Upper 90th percentile confidence interval on the mean of two half-lives: 168 and 391 days
Aqueous Near Surface Half-life (days)	1x10^8	MRID 41063560	Value at 40^{o}N Latitude.
Hydrolysis Half-life (days)	1x10^8	MRID 40320816	Assumed stable at pH 7.
Organic Carbon Partition Coefficient (mL/g_{OC}) (K_{OC})	36	MRID 41063562	
Molecular Weight (g/mol)	242	(calculated)	–
Vapor Pressure (torr)	7.5 × 10^{-8} (25°C)	Product chemistry	–
Solubility (mg/L)	64 (25°C)	Product chemistry	–
Heat of Henry (J/mol)	58198	HENRYWIN	Estimated using HENRYWIN program in EPISuite.
Henry Reference Temperature (^oC)	25	HENRYWIN	Temperature of vapor pressure measurement.

(b) Applications Tab for Drinking Water Assessment

Input Parameter	Value	Source	Comment
Distribution of Days or Specific Days	Distribution of Days, ^	--	Default

Input Parameter	Value	Source	Comment
First Day of Application (Month-day)	3/15 (AR)	--	Assumed for Arkansas
Last Day of Application (Month-day)	4/30 (AR)	--	Spreads applications over 46 days.
Total Amount Applied Per Year (lbs a.i./A)	0.5 lbs a.i./A 0.56 kg a.i./ha 0.47 kg/ha with 84% PCT and assuming 1 app	EPA Reg. No. 34704-920	Assumed a percent cropped treated (PCT) of 84% based on maximum use information from CA PUR for herbicides and insecticides.
Application Timing	Pre flood	EPA Reg. No. 34704-920	Application is made to dry paddy.
Distribution of Applications	Triangular		
Application Method for Drift	566 (Ground application, high boom, fine to medium coarse)	EPA Reg. No. 34704-920	
Holding Period Duration	0	EPA Reg. No. 34704-920	No holding period specified

Appendix D. Tier I Rice Model Modified for Aerobic Aquatic Metabolism

The Tier 1 Rice Model is used to estimate aquatic exposures for direct application to water (USEPA, 2007). The Tier 1 Rice Model estimates one concentration that represents both acute and chronic exposures; it was modified to evaluate degradation in water after the time of application.

The Tier 1 Rice model estimates concentrations in a water body holding a 10 cm water depth. When a pesticide is applied to the water, the model assumed that the pesticide instantaneously partitions between water and sediment, as determined by the chemical's sorption coefficient, according to:

$$C_{w0} = \frac{10^2 m_{ai}'}{d_w + d_{sed}\left(\theta_{sed} + 10^{-3}\rho_b K_d\right)}$$

Where,

C_{w0} = initial water concentration [µg/L]
m_{ai}' = mass applied per unit area [kg/ha]
K_d = water-sediment partitioning coefficient [L/kg]
K_{OC} = organic carbon partitioning coefficient [L/kg]
d_w = water column depth = 0.10 m
d_{sed} = sediment depth = 0.01 m
θ_{sed} = porosity of sediment = 0.509
ρ_b = bulk density of sediment = 1300 kg/m^3

This equation simplifies to:

$$C_w = \frac{m_{ai}'}{0.00105 + 0.00013K_d}$$

And, if appropriate:

$K_d = 0.01K_{oc}$

Where:

C_w=water concentration in µg/L
m_{ai}'=mass applied per unit area in kg/ha
K_d=soil-water distribution coefficient (L/kg-soil)
K_{oc}=organic-carbon normalized soil-water distribution coefficient (L/kg-oc)

The concentration in water over time for the modified Tier I Rice Model was based on the following equation:

$C_{w,\,t} = C_{w,\,0}\, e^{(-kt)}$

Where

Cw, t = the concentration in water at time, t

Cw, 0 = the concentration in water at application or time of zero
e = base of natural logarithm
k = first-order rate constant of degradation or dissipation (1/days)
t = time after application (days)

Acute concentrations were reported at the maximum concentration for the given scenario. Annual average concentrations are the average daily concentration over 365 days.