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Water discharge models, seasonal effluent mass loading, and best management practices for crawfish ponds

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WATER DISCHARGE MODELS, SEASONAL EFFLUENT MASS LOADING, AND BEST MANAGEMENT PRACTICES FOR CRAWFISH PONDS

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This thesis is a product of mom’s “persistence” and dad’s “looking for good in all things.”

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Abstract

Nearly 35,000 ha are used to grow crawfish in southwest and south-central Louisiana, and many of these ponds discharge into impaired water bodies. In 2002, proposed guidelines were published by the United States Environmental Protection Agency (USEPA) assigning effluent limitations and standards for some aquaculture production systems and exempting others (e.g. crawfish ponds). This research had three objectives relative to crawfish ponds: develop water discharge models; final drawdown effluent quality and seasonal mass loading of solids and nutrients; and identification of Best Management Practices (BMPs) that could reduce effluent discharge and improve effluent quality. Models for south-central and southwest Louisiana with a 15 cm storage capacity showed that excess precipitation overflow (final drawdown not included) can be decreased by 28% for a high precipitation year, 61% for an average precipitation year, and 100% for a low precipitation year. The major sources of effluent from crawfish ponds are (1) overflow during winter – when precipitation exceeds evaporation, evapotranspiration, and infiltration – and (2) discharge during the summer drawdown period. Pond evaporation and evapotranspiration combined are the greatest sources of water loss (68%) during a crawfish production cycle. During final drawdown, solids were high during the first 5% of pond water discharge due to poorly consolidated sediment in and around the drain and high during the last 20% of pond water discharge due to the poorly consolidated pond bottom sediments. During final drawdown: total suspended solids were reduced over a distance of 268 m by 28% at the Aquaculture Research Station (wide, shallow, non-vegetated ditch); total suspended solids increased over a distance of 268 m by 15% at the Rice Research Station (narrow, non-vegetated ditch); and total suspended solids were reduced over a distance of 268 m by 80% at the University of Louisiana at Lafayette Model Sustainable Agricultural Complex (deep vegetated

ditch). To reduce solid and nutrient mass loading in crawfish pond discharge, ponds should be slowly drained from the top of the water column and avoid draining the last 20% of the pond volume. If that is not possible, then it is recommended to treat the last 20% of the pond volume by sending the discharge through deep vegetated ditches, settling basins, or constructed wetlands with a residence time of 4 d to 14 d.

Chapter 1

Foreword

"Liquid water is a necessity for every form of life known with the possible exception of some plants or fungi that may get by on water vapor (NASA 2002a)." "Amongst the highest priorities in earth science and environmental policy issues confronting society are the potential changes in the Earth's water cycle due to climate change (NASA 2002b)."

The focus of this thesis is water conservation for crawfish ponds. If water is conserved, it follows that less will be required for crawfish ponds, and less will be discharged (i.e. effluent). Aquaculture facilities practicing good "water management practices maintain the pond water quality while minimizing pond overflow and drainage discharge (USEPA 2002)."

Water is a ubiquitous molecule, existing on moons, meteors, asteroids, stars, and planets. On Earth, water is essential to the sustainability of the planet; 2.7% of all the water on Earth is fresh and the remaining 97.3% is marine water found predominantly in the world's oceans. Of that 2.7%, 0.5% is available from freshwater lakes, rivers, and aquifers (Villiers 1999).

Given the importance of water as a resource, it is understandable how federal, state, and local regulatory agencies, environmental groups, and citizens can have concerns regarding the general use of water, and as the population grows, so will the concern.

Aquaculture producers are but one of may stakeholders who have an interest in the use of water. In areas with stressed water resources, water issues can be reduced to a management problem, a matter of allocation and distribution; in other areas, demand simply surpasses supply (Villiers 1999). In 2001, the Louisiana legislature passed a law requiring new water wells to be licensed in response to concerns that rice farmers and new power plants might be depleting the state's groundwater. Levees and other structures along the Mississippi River have blocked

natural pulses of water, nutrients, and sediments from spilling over the land thus allowing water to recharge aquifers and sediment to create wetlands (Schleifstein 2002). In southwest Louisiana, ground water withdrawals are lowering water levels in some areas of the Chicot aquifer (where a significant amount of rice and crawfish production takes place), and the same is happening in southeastern Louisiana aquifer systems. In 2000, approximately 3,107,823 m^3 per day were being removed from the Chicot aquifer, 65% for crop irrigation, 11% for aquaculture, and 24% for other uses (Lovelace 2001). Furthermore, nearly 90% of the crawfish aquaculture area is located in two impaired water basins – Mermentau and Vermilion-Teche river basins – both located in southwest and south-central Louisiana. The impact crawfish pond discharge has on these impaired water bodies is not known, and was one of the underlying reasons for this study.

The use of water for the production of animals has shown that effluent from aquaculture facilities can introduce a variety of pollutants into receiving waters. In the case of crawfish ponds, the terms effluent and pollution are commonly used to define solid and nutrient concentrations that surpass regulatory limits or surpass the ability of the receiving stream to assimilate the solids and nutrients being discharged. The Federal Water Pollution Control Act (FWPCA) of 1972 intended to "restore and maintain the chemical, physical, and biological integrity of the nation's water," by creating what is known as the National Pollutant Discharge Elimination System (NPDES). As is relates to warmwater concentrated aquatic animal production (CAAP) facilities, the NPDES excluded closed ponds (e.g. crawfish ponds) discharging only during periods of excess runoff and facilities that discharge less than 30 days per year. In September 2002, the USEPA issued "Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category; Proposed Rule" that recommends new effluent limitations guidelines and standards for

flow-through systems, recirculating systems, and net pens. Alternatively, other systems have been proposed to be excluded from regulation “because the EPA does not believe the species/production system adds more than trivial amounts of pollutants or because no feasible pollutant control technologies are available to reduce pollutant loads (e.g. solids and nutrients) in more that de minimis amounts.” Examples of such systems are fish ponds, lobster pounds, crawfish ponds, molluscan shellfish production in open waters, aquaria, and alligator ponds (USEPA 2002).

Earthen pond facilities, for example, are excluded because the USEPA believes there are very few pond facilities that meet the definition of a CAAP facility and most of the pond discharges that do occur add only minor pollutant loads because high quality water is needed to produce the aquatic animals. Furthermore, drainage from the surface of the pond – from excess precipitation – discharges minor amounts of solids and nutrients because excess precipitation results in overflow from the top of the water column and not the sediment and nutrient-rich bottom (USEPA 2002).

Figure 1.1. Crawfish pond water being discharged from the Aquaculture Research Station in Baton Rouge Louisiana. Final drawdown usually takes place in spring or summer.

However, regardless of the above proposed exemptions, there is concern regarding the process of rapid-drain discharges from earthen aquaculture ponds (e.g. summer drawdown of crawfish ponds, Fig. 1.1). The USEPA is inviting comments on the proposed rule through 11 December 2002 and considering whether or not it should regulate rapid-drain discharges from ponds because of high solid and nutrient loads in the first 5% and last 20% of the discharge (USEPA 2002).

Also, despite exemption, the USEPA believes that Best Management Practices (BMPs) to control discharge quality and quantity must continue to be developed and implemented by state agencies. Certain BMPs have proven to be effective in controlling and reducing effluents from ponds (USEPA 2002).

The USEPA concluded that its proposed regulation for new and old CAAP facilities – except those that were exempted – would reduce total suspended solids (TSS) by a least 1.9 million kg per year. By controlling TSS the discharge of biochemical oxygen demand (BOD) and nutrients would be reduced by at least 3.9 million kg per year (USEPA 2002).

Some aquaculture facilities have improved effluent quality (i.e. reduced solids and nutrients) with BMPs. It is necessary, from an ecological perspective, for more facilities to employ BMP technologies to improve the quality of discharged water into impaired and unimpaired surface waters in the United States. By implementing cost effective and achievable BMPs that are consistent with the principles of environmental stewardship and by promoting mutually beneficial cooperation among the members of aquaculture industries and other stakeholders, aquaculture will increase its long-term sustainability.

Minimizing water use minimizes discharge. For example, reducing water use by adding storage capacity lessens discharge and thus conserves valuable sediments and nutrients needed for the growth of crops. This is highly applicable for crawfish ponds.

The objectives of this study were to: (1) develop water discharge models for crawfish ponds in south-central and southwest Louisiana to determine seasonal patterns of unintentional and intentional water discharge; (2) characterize seasonal effluent (i.e. solids and nutrients) for crawfish ponds with focus on summer drawdown; and (3) based on the findings of objectives one and two, and reviews of published literature, identify BMPs for crawfish ponds to reduce solid and nutrient discharge.

This document is organized into five Chapters: Forward, Introduction, Water Discharge Models, Effluent Discharge, and Best Management Practices. Chapter 1 (Forward) justifies the research and explains the organization of subsequent chapters. Chapter 2 (Introduction) provides a detailed overview of the genesis of aquaculture effluents. Chapter 3 (Water Discharge Models) discusses water discharge from crawfish ponds and reports water discharge quantity under several different systems from the models used in this study, and Chapter 4 (Effluent Discharge) covers solid and nutrient dynamics in pond and stream environments and presents the results from crawfish ponds and their receiving streams used in this study. Chapter 5 (Best Management Practices) discusses ways for mitigating solid and nutrient discharge from crawfish ponds in Louisiana.

When citations appear at the end of a paragraph that has more than one sentence, that citation will apply to the whole paragraph. Any other citation appearing in the middle of the paragraph will apply to the sentence of which it is part. All chapters of this thesis have been prepared in the format of the Journal of the World Aquaculture Society.

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Chapter 2

Introduction

The growth of aquaculture has led to a corresponding growth in aquaculture effluents. Those associated with the aquaculture industry recognize that in certain situations aquaculture effluents can be detrimental to the environment. This thesis will address issues regarding crawfish pond effluents and how their potential impact on Louisiana's environment can be mitigated by the conservation of water through Best Management Practices (BMPs).

Total global inland aquaculture increased from 12.1 million MT in 1994 to 19.8 million MT in 1999, a 67% increase in less than one decade (FAO 2000). The global value of aquaculture products in 1998 was estimated to be US $41 billion with the People's Republic of China producing 67% of the world aquaculture products and the US producing 1% (Tomasso 2002). The increase in world population is bringing about an increase in aquaculture. The world's population is expected to increase from 5.9 billion to 9.3 billion by the year 2050 (USCB 1998). Population in the US is expected to increase from an estimated 270 million in 1998 to 310 million in 2015 (USDC 1999). By the year 2030, aquaculture will dominate fish supplies and less than half of the fish consumed will come from capture fisheries (FAO 2000).

As the industrial revolution established itself within the US in the early 1900s, so did environmental regulations to curtail the byproducts of industrial growth. Similarly, aquaculture's fast growth in the past few decades has also brought about concern from regulatory agencies and environmental groups on the issue of aquaculture effluents. At the center of these regulations, past and present, is concern for the environment (e.g. water use issues) in the wake of human population expansion.

In the early 20th century, increases in population and waterborne diseases prompted the US government to pass the Federal Water Pollution Control Act of 1948. This act formalized and focused the government's obligation to control the nation's water pollution. State governments were given primary responsibility, and the federal government provided financial assistance and research support to the states through the US Public Health Service. The 1956 and 1965 amendments to this act increased the role of the federal government in controlling water pollution, but primary responsibility of monitoring and enforcement was left to the states. The 1965 amendment – also know as the Water Quality Act – moved federal responsibility from the Public Health Service to the new Federal Water Pollution Control Administration. The 1965 amendment came at a time of deteriorating water quality throughout the nation. The 1965 amendment permitted the federal government to create water quality standards if the states did not establish their own. Standards were neither effective nor enforced and water quality continued to diminish (Kubasek and Silverman 2002).

Seven years later, the Federal Water Pollution Control Act (FWPCA) of 1972, also known as the Clean Water Act (CWA), created major changes in the way water quality would be handled in the US. The core provisions of the FWPCA of 1972 prohibit the discharge of pollutants from a point source into waters of the US except as authorized in the National Pollutant Discharge Elimination System (NPDES) (USEPA 2002a). The USEPA developed the FWPCA of 1972 to address the concerns of "pollution" on water quality in receiving watersheds (LAP 2000), and later amendments to the FWPCA of 1972 required that the nation's streams, rivers, and lakes be sufficiently clean to be fishable and swimable by a target date near the year 2010. Furthermore, under the FWPCA of 1972, discharge from any point source (single, definable outlet such as a discharge line or drain pipe) is prohibited without regulatory

exemption or a NPDES permit (Lutz 2001). Three main acts followed the FWPCA of 1972: the Clean Water Act (CWA) of 1977, the Water Quality Act (WQA) of 1987, and the Oil Pollution Control Act of 1990. These Acts added to the principles established in the FWPCA of 1972 and have resulted in a complex and comprehensive system of water pollution control (Kubasek and Silverman 2002).

Despite the nation's obvious movement over the years toward curtailing water pollution through such programs as the NPDES, national standards were not created for aquaculture until the winter of 2000 when the USEPA decided to develop national effluent limitations guidelines and standards for aquaculture facilities (Clipper 2000). The decision to develop effluent limitations guidelines and standards came about because Natural Resources Defense Council, Inc., and Public Citizens, Inc., filed an action against the USEPA on 30 October 1989 in which they alleged that the USEPA had failed to comply with CWA Section 304 (m). The plaintiffs and the USEPA agreed to a settlement through a court ordered consent decree entered on 31 January 1992. The consent decree required the USEPA to sign a proposed rule for the aquatic animal production industry in the summer of 2002, and take final action on the proposal by 30 June 2004 (USEPA 2002a).

The USEPA's proposed rule, or "Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Source Category; Proposed Rule," was published in the Federal Register on 12 September 2002 (USEPA 2002a). The USEPA stated in this document that flow-through systems, recirculating systems, and net pens would be subjected to new effluent limitations guidelines and standards. Exempt from the new regulations are floating and bottom culture systems for molluscan shellfish and ponds (e.g. catfish, crawfish, etc.) along with a few other systems because of the "trivial" amounts of

pollutants or because no feasible pollutant control technologies are available to reduce the pollutants in more than minuscule amounts (Fig. 2.1). The USEPA must take final action on this proposal by 30 June 2004 (USEPA 2002a).

Figure 2.1. Drain pipe from a crawfish pond at the Aquaculture Research Station during summer drawdown. Crawfish ponds are currently exempt from NPDES permits.

Under existing regulations, the CWA, Appendix C, places certain warmwater aquaculture facilities (i.e. CAAP facilities) in the status of an agricultural facility and as a point source of water pollution, which are subject to NPDES permit requirements and exemptions (USEPA 2002b). Warmwater aquaculture facilities discharging waters at least 30 d per year are placed under the NPDES permit (USEPA 2002b). Aquaculture facilities exempt from the NPDES have the following criteria: (1) production of less than 45,454 kg harvest weight (100,000 lb) of aquatic animals per year, and (2) have closed ponds that discharge only during periods of excess runoff (USEPA 2002b). States may develop more stringent, but not less, regulations relative to the USEPA regulations regarding water quality.

To review, the USEPA summarizes the history behind the recent focus on effluent limitations guidelines and standards as follows:

> "In assessments of surface water quality, states most frequently cite siltation, nutrients, and pathogens as the major cause of water quality impairment. Over the past two years, EPA has directed resources of the Office of Water's Engineering and Analysis Division to address specific sources of these pollutants. Current activities addressing coal mining (remining operations and certain mine land reclamation activities in the arid west) and the

construction and development industry are expected to result in significant reductions of soil and other solids reaching rivers, lakes, and streams. Ongoing activities to control nutrients and pathogens from concentrated animal (pork, poultry, beef, and dairy) feeding operations are expected to improve water quality.

In 1974, EPA issued a summary technical document for use as guidance in developing controls for wastewater discharges from fish hatcheries and farms. At that time a decision was made not to issue final national effluent limitations guidelines and standards. Based on the 1997 agricultural census data, the aquaculture industry includes close to 5,000 land based and marine environment facilities. The aquaculture industry has facilities located in every state and territory, and is currently one of several growing segments of USA agriculture. Given the current growth of the aquaculture industry, and the inconsistent state regulatory oversight, EPA has decided to examine technologies currently available for the control of pollutants, primarily nutrients, from land based and marine environment aquaculture operations. Although the aquaculture industry is currently subject to the permitting system, there are no national technology based standards for aquaculture. New national standards for aquaculture will assist the 43 states that are delegated by EPA to administer the NPDES (National Permit Discharge Elimination System) permitting program.

Some aquaculture facilities can contribute nutrients to environmentally sensitive areas in estuaries, rivers, lakes, and streams throughout the country. Improvements in wastewater treatment within the aquaculture industry have been employed by some facilities to reduce the nutrient pollutant load. It may be possible for more facilities to employ these technologies to reduce pollutant discharge loadings to surface waters and, in some cases, water quality impairment in portions of the USA By examining the cost and performance of pollution control technologies and practices, EPA is committed to developing national effluent limitations guidelines and standards that are consistent with the principles of good environmental stewardship and support the long-term sustainability of the industry.

Throughout this national regulatory effort, EPA will work closely with USDA and other federal agencies, academia, industry trade associations, state and local governments, citizen groups, environmental groups and other stakeholders. EPA's efforts will build on the technical expertise of nationally-recognized leaders, such as members and participants of the Federal Joint Subcommittee on Aquaculture (JSA) and its newly created Aquaculture Effluents Task Force. EPA will regularly provide to the JSA, the industry, and the public, information on its data needs and the status of their efforts throughout the regulatory development period (USEPA 2000)."

Louisiana Climate and Weather

Unintentional effluent discharge is highly correlated with climate and weather patterns, therefore a general discussion of climate and a specific discussion of weather in Louisiana is in order. "Amongst the highest priorities in Earth science and environmental policy issues

confronting society are the potential changes in the Earth's water cycle due to climate change. The science community now generally agrees that the Earth's climate will undergo changes in response to natural variability, including solar variability, and to increasing concentrations of greenhouse gases and aerosols. Furthermore, agreement is widespread that these changes may profoundly affect atmospheric water vapor concentrations, clouds, and precipitation patterns. For example, a warmer climate, directly leading to increased evaporation, may well accelerate the hydrologic cycle, resulting in an increase in the amount of moisture circulating through the atmosphere. Many uncertainties remain, however, as illustrated by the inconsistent results given by current climate models regarding the future distribution of precipitation (NASA 2002)."

Climate is related to the rotation of the Earth, wind patterns, to oceans and their currents, and to solar radiation. The El Niño effect is an example of the planet's ever-changing climate, it brings periodic flooding to otherwise arid regions and can abruptly change an area's food chains and ecology (Villiers 1999).

The El Niño Southern Oscillation (ENSO) happens due to cyclic warming and cooling of the ocean's surface in the central and eastern Pacific. Normally this region of the Pacific is colder than it's equatorial location would suggest, mainly due to the influence of northeasterly trade winds, a cold ocean current flowing up the coast of Chile, and to the upwelling of cold deep water off the coast of Peru. The influence of these cold water sources wane in cycles, causing the surface of the eastern and central Pacific to warm up. This is an El Niño event. This results in cool, wet winters over the southern USA from Texas to Florida (NOAA 2002).

Historically in Louisiana, strong El Niño episodes have been associated with above normal precipitation (110% to 130% of normal or excess precipitation of 2.5 cm to 7.6 cm (1 in to 3 in) throughout the state during November and December and over southern portions of the

state from January to March. During the 1982-1983 El Niño episode excess rainfall of up to 40.6 cm (16 in) occurred from November through December. Excess rainfall was generally from 10.2 cm to 15.2 cm (4 in to 6 in) from January through March. Temperatures across the state during El Niño episodes have averaged about 2^{o}C below normal for late winter and early spring (February through April) (CPC 1997).

At other times, the injection of cold water in the central and eastern Pacific becomes more intense than usual, causing the surface of the eastern Pacific to cool. This is a La Niña event, and the results on Louisiana's climate are usually opposite of El Niño events (CPC 1997).

The National Oceanic and Atmospheric Administration published, in 1982, a modified version of the original 1976 publication "Climatography of the United States, #60, Climate of Louisiana." This document was assigned to specific states (e.g. Louisiana) and was designed to "provide selected climatic information of general interest to a broad spectrum of users." The general climate of Louisiana is best summarized and described in this publication (personal communication, Jay Grymes, Louisiana state climatologist, LSU, Louisiana Office of State Climatology, Baton Rouge, Louisiana, 17 July 2002). Relevant climatic sections are cited below:

> "The principal influences that determine the climate of Louisiana are its subtropical latitude and its proximity to the Gulf of Mexico. The marine tropical influence is evident from the fact that the average water temperatures of the Gulf of Mexico along the Louisiana shore range from 17.8^{o} C (64^{o} F) in February to 28.9 ^{o} C (84^{o} F) in August. Elevation and type of soil is a factor of varying importance.
>
> In summer, the prevailing southerly winds provide moist, semitropical weather often favorable for afternoon thunderstorms. When westerly to northerly winds occur, periods of hotter and drier weather interrupt the prevailing moist condition. In the colder season, the state is subjected alternately to tropical air and cold continental air, in periods of varying length. Although warmed by its southward journey, the cold air occasionally brings large and rather sudden drops in temperature, but conditions are usually not severe.
>
> During the summer months, the rich source of moist tropical air results in almost daily showers in the coastal parishes; however, shower frequency diminishes with distance

from the Gulf Coast toward the northern parishes. In the winter months, the northern portion of the state is invaded by cold air, which tends to stall and become stationary. This sometimes produces prolonged rains over that area, while clear weather continues in the southern parishes. The pattern of spring rains is similar to that of winter, while fall rains are distributed in the same manner as summer rains. However, fall (September, October, and November) is the driest season of the year. Flood producing rains may occur during any month of the year in Louisiana, although they are less likely during September, October, and November, the drier months, and are most frequent during the late winter and early spring (NOAA 2002)."

Crawfish Culture Cycle

The state of Louisiana has a total of 12,697,791 surface ha, and in 2001 crawfish aquaculture was practiced in about 34,251 ha or 0.3% of Louisiana's total surface area (Fig. 2.2). This is the greatest amount of land usage of all aquaculture commodities produced within the state. Over 90% of the state's crawfish aquaculture area is located in the southwest region (45.7%) and the south-central region (49.4%) of Louisiana (Fig. 2.2). Crawfish aquaculture in Louisiana had a farm gate value of $36.8 million in 2001 (LCES 2002). For a detailed overview of crawfish production practices, refer to the Crawfish Production Manual (LCES 1999a).

Red swamp Procambarus clarkii and white river Procambarus zonangulus crawfishes are the two species commercially cultured in Louisiana. P. clarkii is preferred because it produces more consistent yields and is valued more in the market (SRAC 1990).

Crawfish ponds vary in shape and size, typical ponds are 4 ha to 8 ha (10 acres to 20 acres), and most farmers manage less than 40.5 ha (100 acres) (LCES 1999a). Crawfish ponds are shallow water ecosystems usually anywhere from 25 cm to 46 cm when fully flooded. Crawfish are not fed formulated feeds, rather vegetation such as rice, sorghum-sudangrass, or native aquatic plants are established in the summer to serve as food for crawfish (LCES 1999a). This vegetation, along with any crop residue, serves as the base of the detritus food chain that sustains crawfish growth when ponds are permanently flooded in fall.

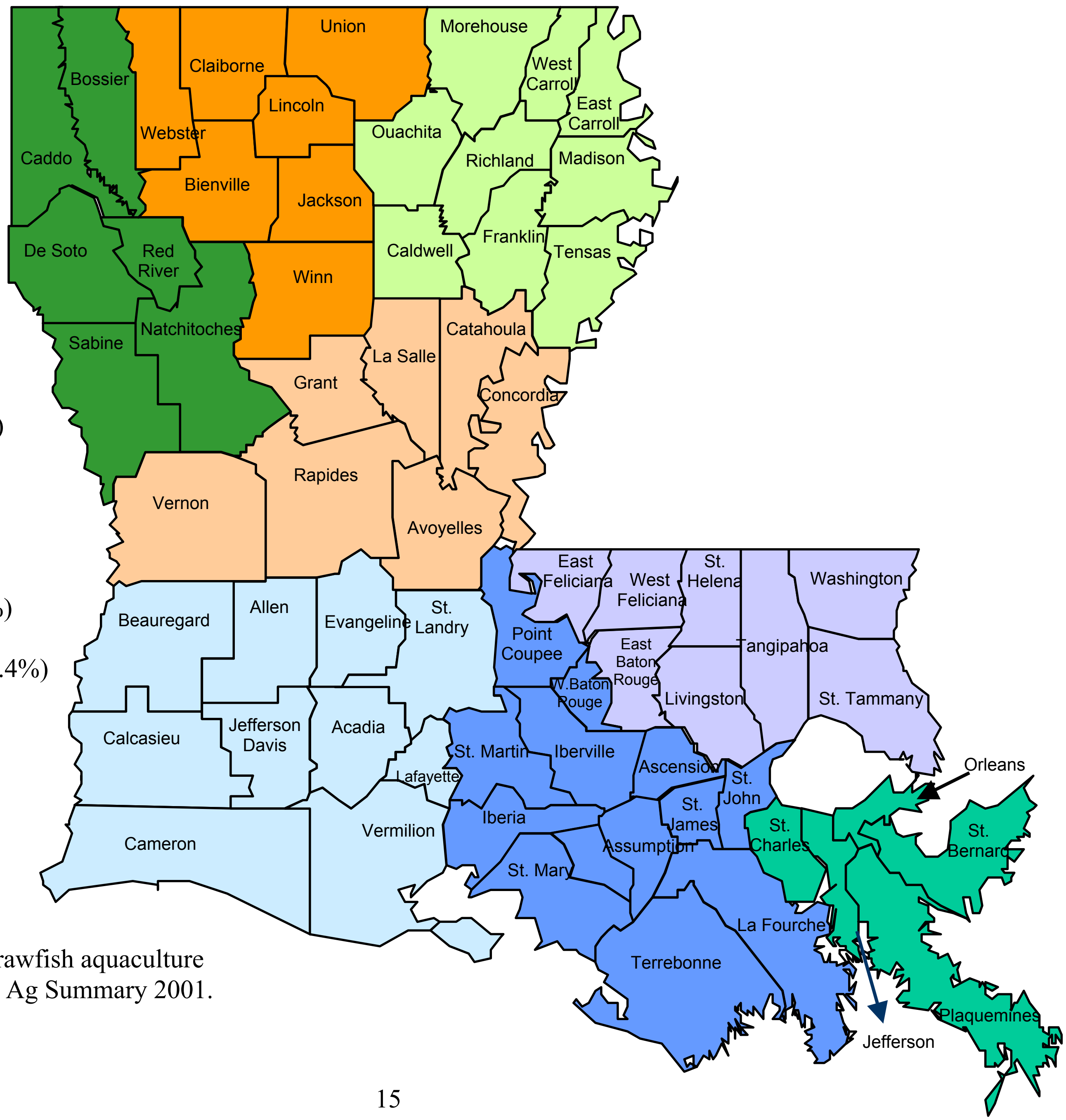

Figure 2.2. Louisiana crawfish aquaculture area. Source: Louisiana Ag Summary 2001.

P. clarkii and P. zonangulus are opportunistic benthic omnivores and feed mainly on wetland invertebrates. The invertebrates feed mainly on the microbially-enriched detritus generated by the decomposition of plants (Huner 2002).

There are two basic types of crawfish production systems in Louisiana, the single-crop crawfish system and the double-crop system, which is further divided into the double-crop rice/crawfish system and the double-crop rice/crawfish rotational system.

Single-Crop Crawfish System

Crawfish is the sole crop harvested in single-crop crawfish sytems (Fig. 2.3), and production occurs in permanent ponds built primarily for crawfish aquaculture. Most of the crawfish production in south-central Louisiana uses this production system, and probably 20% or less in southwest Louisiana. Rice or other cultivated forages (sorghum, sorghum-sudan grass) are planted in the summer (June/July/August) as a forage crop for the crawfish or volunteer vegetation is allowed to colonize. Crawfish are harvested in the fall, winter, and spring (November – May/June). This system is stocked once and then relies on holdover or broodstock from the previous cycle to produce the next year's crop (Eversole and McClain 2000). Average depth during full flood is about 40 cm.

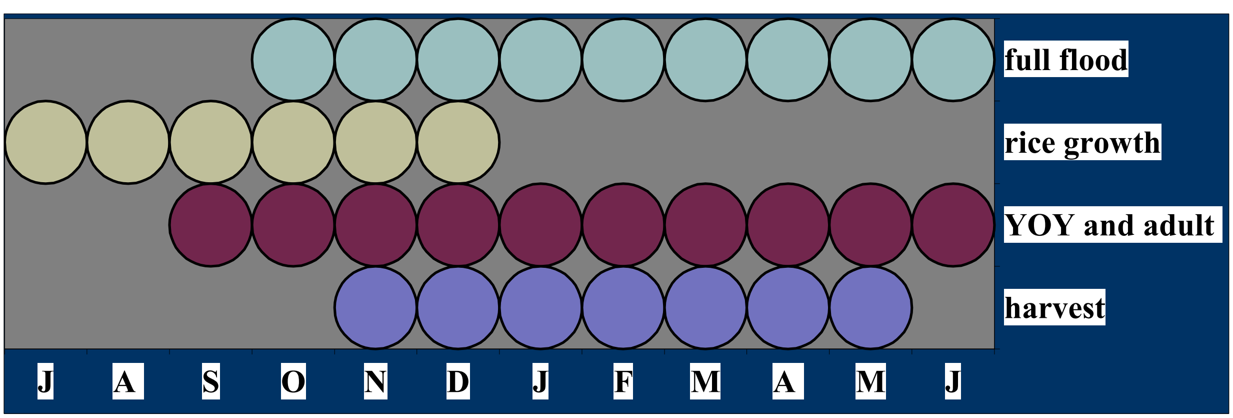

Figure 2.3. Single-crop crawfish system. The circles represent the typical months in which certain management practices or crawfish activities are occurring.

Double-Crop Rice/Crawfish System

Rice and crawfish are harvested from the double-crop rice/crawfish system (Fig. 2.4). In this system, production typically occurs in permanent ponds built for both rice and crawfish. Less than 20% of the crawfish farm area in southwest and south-central Louisiana uses this production system. Rice is planted in late spring (May/June) and the rice grain is harvested in late summer or early fall (August/September). Following rice harvest, a shallow flood is placed on the remaining rice stubble to enhance foliage production for crawfish forage. Crawfish are harvested in the fall, winter, and spring. This system is stocked once, and then relies on holdover or broodstock from the previous cycle to produce the next year's crop (Eversole and McClain 2000). Average depth during full flood is about 30 cm.

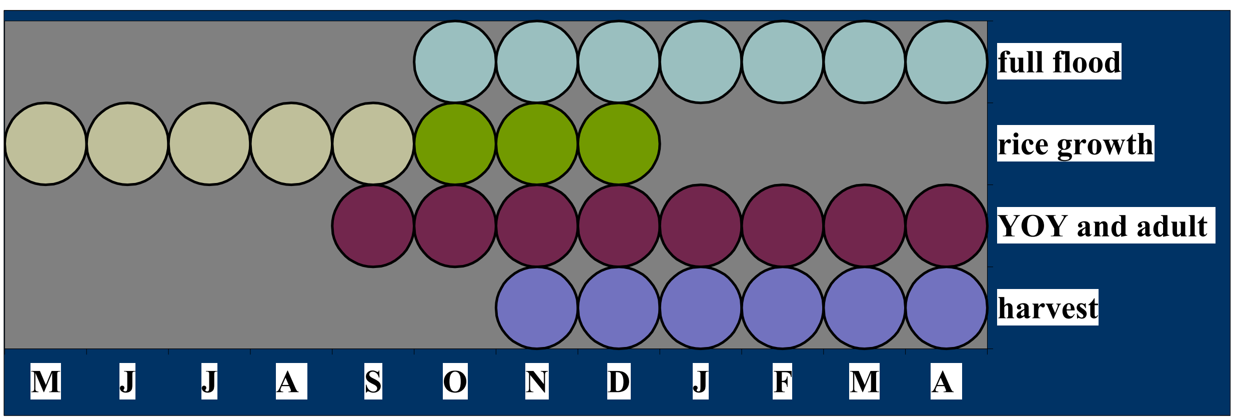

Figure 2.4. Double-crop rice/crawfish system. The circles represent the typical months in which certain management practices or crawfish activities are occurring.

Double-Crop Rice/Crawfish Rotational System

Rice and crawfish are harvested from the double-crop rice/crawfish rotational system (Fig. 2.5). In this system, crawfish are cultured in different locations each year to conform to typical field rotations of the rice crops to control weeds and plant diseases. It is estimated, that as much as 70% of the crawfish aquaculture area in southwest Louisiana uses this production system. Rice is planted in spring (March/April) and harvested in summer (July/August).

Following rice harvest, a shallow flood is placed on the remaining rice stubble to enhance foliage production for crawfish forage. Crawfish are harvested in winter and spring (Feb – May/June). This system is restocked with crawfish every year (Eversole and McClain 2000). Rice is the primary crop in this system and crawfish are secondary, thus the fields (ponds) are shallower because perimeter levees are not as high. Average depth during full flood is about 25 cm.

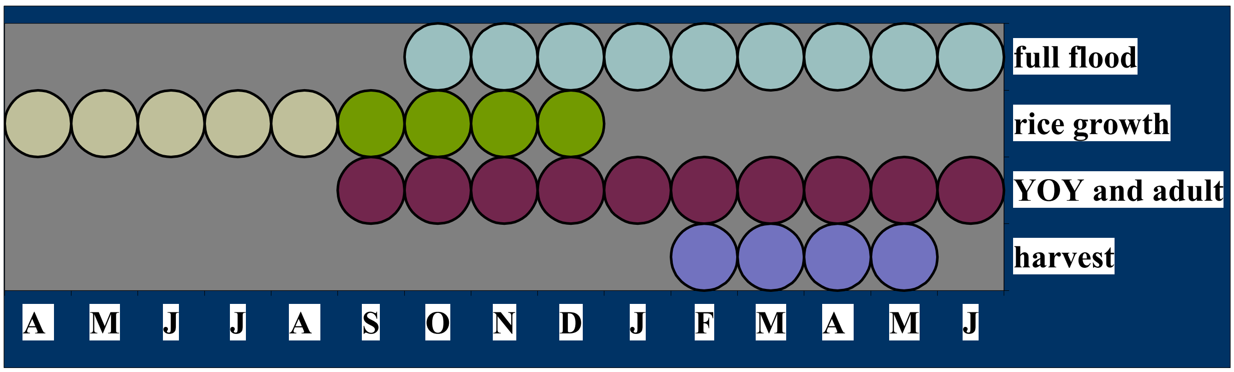

Figure 2.5. Double-crop rice/crawfish rotational system. The circles represent the typical months in which certain management practices or crawfish activities are occurring.

Rice Culture in Louisiana

Farmers have been growing rice in Louisiana since the early 1700s. Rice ($216 million) was second behind sugarcane ($620 million) in total value of terrestrial crops in 2001. Rice is a semi-aquatic plant and perfectly suited for Louisiana's climate (Fig. 2.6) (LCES 1999b). Rice is grown primarily in southwest, central, and northeast Louisiana (Fig. 2.7). Rice fields offer the most readily adaptable area for crawfish culture because (1) levees are present to impound water for the cultivation of rice and crawfish, (2) rice is cultivated in the spring and summer and crawfish are cultivated in the fall, winter, and spring, or until the next rice crop is planted, (3) rice stubble following rice grain harvest serves as a forage crop for crawfish, and (4) farm labor used in rice cultivation during the spring and summer can be used for harvesting crawfish in the fall, winter, and spring (personal communication, Dr. Robert P. Romaire, Professor, Louisiana

State University, 8 November 2002, Baton Rouge, Louisiana). For a detailed overview of rice production practices, refer to the Louisiana Rice Production Handbook (LCES 1999b).

Flooding rice soil allows for: elimination of moisture deficiency, increase in available nutrients, weed suppression, and provides for a more stable growing environment. Satisfactory rice plant survival occurs at average daily temperatures above 18.3° C (65° F), putting optimal first crop planting time for southwest Louisiana from March 20 – April 30 and for north Louisiana from April 10 – May 15 (LCES 1999b).

Louisiana's climate allows for the production of a second rice crop. It is recommended that the first crop be harvested by at least mid-August to allow time for a second crop to be produced. This second crop is sometimes referred to as a stubble or ratoon rice crop and it is produced from the regrowth on the stubble after the first crop has been harvested (LCES 1999b).

Figure 2.6. Dr. W. Ray McClain and Mr. Mark Shirley, Louisiana State University Agricultural Center inspecting a new variety of rice developed specifically as a crawfish forage.

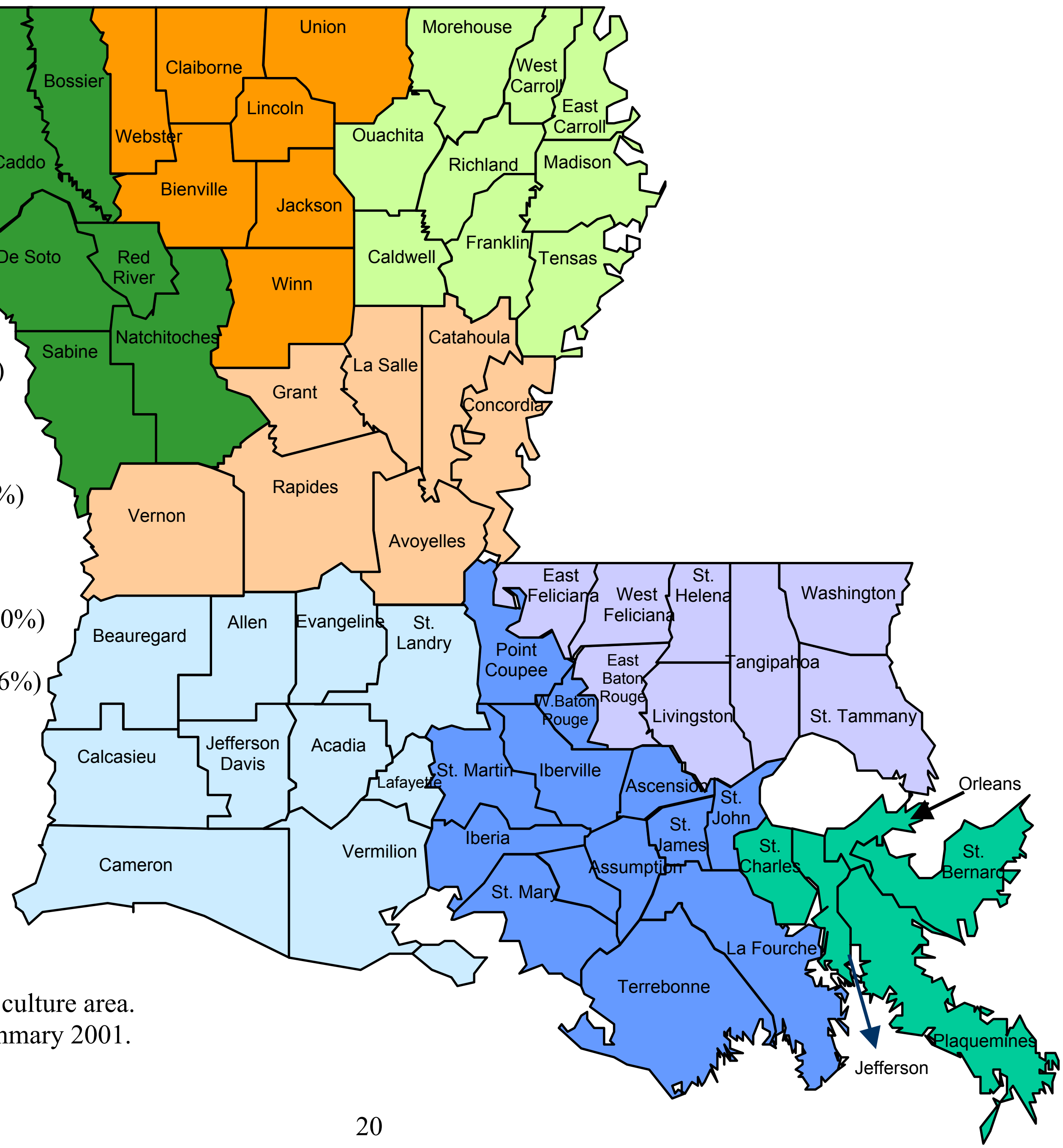

Figure 2.7. Louisiana rice culture area.
Source: Louisiana Ag Summary 2001.

Three basic methods are used to plant rice in Louisiana: water seeding (dry or presprouted seed broadcast onto a flooded field usually by aerial seeding), drill seeding (planting seed 18 cm to 25 cm apart with a drill) (Fig. 2.8), and dry seeding (dry seed applied to a drained or dry field by ground or aerial means). Dry seeding is the predominant method in north Louisiana and water seeding the predominant method in the south (LCES 1999b). Rice farmers who raise crawfish in rice fields, such as a double-crop rice/crawfish rotational system, typically use water seeding because this method fits best with the double cropping of rice and crawfish. When it is time to plant, the field is flooded, and tilled under flooded conditions, a cultural practice referred to as "mudding in" which suppresses red rice – a noxious rice biotype (Bollich and Feagley 1994). The field is then seeded with dry or pre-soaked rice seed.

Figure 2.8. Rice that has been drill seeded.

Next, are three management options: delayed flood, pinpoint flood, or continuous flood. A delayed flood system drains the field after water seeding for a period of 3 to 4 weeks before a permanent flood of 5 cm to 10 cm (2 in to 4 in). This method is preferable in areas where red rice is not a problem (LCES 1999b). A pinpoint flood system, the most common system used in south Louisiana, drains the field after water seeding long enough to allow the seed radicle to anchor into the soil, usually 3 to 5 days. The field is then permanently flooded and the rice plants emerge through the flood (LCES 1999b). A continuous flood system is used on a limited basis in

Louisiana. It does not drain the field after water seeding, and thus the rice plants emerge through the flood (LCES 1999b).

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Chapter 3

Water Discharge Models

Introduction

Management practices should favor the minimal use of water, even in the presence of plentiful, clean water. Conserving water in aquaculture systems frees water for other uses, reduces pumping costs, and reduces effluents.

Water budgets can be used to describe and identify the degree of inflows, storage, and outflows for aquaculture production systems, which has two significant implications: first, water must be used wisely to assure sustainable development of aquaculture; second, water budgets can be used to estimate effluent volume and develop options for managing discharged water (Hargreaves et al. 2002).

Water discharge models in this study were created to estimate the amount of intentional and unintentional monthly, seasonal, and annual water discharge for crawfish ponds representative of south-central Louisiana and southwestern Louisiana. This discharge data was multiplied by solid or nutrient concentrations from a previous study on crawfish effluents (Orellana 1992) to estimate mass loading (Chapter 4). Mass loading is the mass of a material being discharged, and it is useful in determining potential environmental impacts on receiving waterbodies (Tucker et al. 2002).

Water discharge models use data from evaporation pans (for estimating pond evaporation), lysimeters (for estimating infiltration), and complex formulas (for estimating evapotranspiration) to calculate water loss. Water budgets for land and water areas are more complex than budgets derived solely from evaporation pans and lysimeters. When modeling for a specific area, assumptions have to be made regarding the use of certain variables within the

model. Using accurate values will increase the probability of the water model's accuracy. When possible, use of data close to the site reduces the probability of large discrepancies between model output and actual data (Boyd and Yoo 1994). The following sections (precipitation, pond evaporation, evapotranspiration, infiltration, and pond water conservation) will describe each component used in this study's water discharge models.

Precipitation

Precipitation reduces the need for ground water use in aquaculture, and further reduction in ground water use can be accomplished by managing ponds to capture precipitation instead of letting it overflow. Managing crawfish ponds to capture precipitation reduces pond water discharge thereby reducing effluent (Tomasso 2002).

Precipitation data are normally collected daily and compiled into monthly and annual totals; these data are useful for planning and design purposes. Precipitation does not always follow a normal pattern; some years may be wetter or drier than normal (Boyd 1996). Daily precipitation is more variable than monthly or annual precipitation, and days with heavy precipitation can come at anytime. Furthermore, storms producing small amounts of precipitation are more common than those producing heavy amounts of precipitation (Boyd and Yoo 1994). Rarely does a year have normal precipitation, normal precipitation is an artificial statistic useful where the usual situation is of interest. Extreme values can occasionally be of more interest in planning and designing projects because water budgets should be based on the smallest or largest amount of precipitation expected (Boyd and Yoo 1994).

Pond Evaporation

Evaporation is important in aquaculture because it is a major loss of water from ponds (Fig. 3.1). Temperature and water availability are the most important factors affecting

evaporation rates followed by solar radiation, humidity, and wind velocity. Thus, there is considerable daily variation in evaporation rates.

However, monthly and annual pond evaporation totals are not as variable as daily evaporation totals. Temperature and solar radiation follow pan evaporation rates throughout the year (Boyd and Yoo 1994).

Figure 3.1. When no vegetation is in a pond, water loss is primarily lost through evaporation.

When no significant foliage is present in a crawfish pond, evaporation can be calculated by multiplying pan evaporation (a class A evaporation pan is 1.2 m wide and 25 cm deep) by a pan coefficient. Pan coefficients are developed by estimating evaporation from free water surfaces by mass transfer, energy budget, or water budget techniques and relating these values to pan evaporation; free water surface evaporation is divided by pan evaporation and the result is a pan coefficient (Boyd and Yoo 1994). For example, if using a pan coefficient of 0.80, you would have 2.0 cm (0.80 in) of pond evaporation for every 2.5 cm (1.0 in) of pan evaporation.

Pan evaporation coefficients range from 0.60 to 0.81. Pan coefficients calculated at Auburn, Alabama, averaged 0.81 for a year, and it was determined that it is best to make monthly estimates of pond evaporation from pan evaporation data. A strong positive relationship

(r^2=0.995) between monthly values for pan and pond evaporation was determined in Auburn, Alabama, over a year in one pond lined to prevent infiltration and fitted with a Class A evaporation pan (Boyd and Yoo 1994). Nationwide records of pan evaporation are published by the National Climatic Data Center, Asheville, North Carolina.

Evapotranspiration

Plant or crop evapotranspiration (ET_c) is a combination of evaporation and transpiration that occur simultaneously. Therefore, ET_c is total water loss by evaporation from vegetation, soil, and free water surfaces at a particular place (Boyd and Yoo 1994). Transpiration is the vaporization of liquid water contained in plant tissues and its removal to the atmosphere. Nearly all water taken up by plants is lost by transpiration and only a small fraction is used within the plant (FAO 1998) (Fig. 3.2).

Figure 3.2. When vegetation is in a pond, water loss is primarily through evapotranspiration.

The three main factors that influence ET_c are: all factors influencing evaporation from a free water surface, leaf characteristics (such as the leaf area index, the area of the leaf relative to the area of land or water over which the leaves stand), and soil moisture supply (Boyd and Yoo 1994). The Food and Agricultural Organization (FAO) Penman-Monteith equation is an accurate and simple representation of the physical and physiological factors driving the evapotranspiration process.

By using the FAO Penman-Monteith definition for reference crop evapotranspiration (ET_o), crop coefficients may be calculated at research sites by relating the measured ET_c with the calculated ET_o (i.e., $K_c = ET_c/Et_o$). With the crop coefficient approach, differences in the crop canopy and aerodynamic resistance relative to the hypothetical reference crop are represented within the crop coefficient. The K_c factor serves as a collection of the physical and physiological differences between crops and the reference definition (FAO 1998).

When a rice crop is in the early phases of growth, water is mostly lost through water surface evaporation. Once the crop is well developed and the leaves or canopy completely cover the water surface, transpiration becomes the main process of water loss. The partitioning of ET_c into evaporation and transpiration is calculated proportionally to leaf area per unit surface of water below it. At planting nearly 100% of ET_c comes from evaporation, while at full crop cover more than 90% of ET_c comes from transpiration (FAO 1998; personal communication with primary author Dr. Richard Allen, professor of water resources engineering, University of Idaho Research and Extension Center, Kimberly, Idaho, 7 August 2002).

The FAO Penman-Monteith method for calculating ET_o expresses the evaporating power of the atmosphere at a specific location and time and does not consider crop characteristics or soil characteristics. To alleviate the need to define specific evaporation parameters for each crop and stage of growth, the concept of a reference surface was introduced. Grass and alfalfa are well-studied crops regarding their aerodynamic and surface characteristics and are accepted worldwide as a reference surface (FAO 1998).

Plant or crop evapotranspiration (Et_c) rates of various crops (e.g. rice) are related to the ET_o rates from a reference surface (grass or alfalfa) by way of crop coefficients (K_c). The FAO Penman-Monteith ET_o method is selected as the method by which the evapotranspiration of this

reference surface (rice or alfalfa) can be unambiguously determined, and as the method that provides consistent ET_o values in all regions and climates (FAO 1998).

The K_c is calculated by dividing ET_c by ET_o. For example, if rice ET_c is 1.1 for the first stage of growth and the ET_o is 1, the K_c for rice during its first stage of growth is 1.1 (note: crop coefficients are dimensionless).

Reference crop evapotranspiration (Et_o) is multiplied by K_c and then multiplied by the number of days within a particular month to yield monthly rice crop Et_c (Table 3.4). The FAO recommends using the Penman-Monteith method as a new standard for the direct calculation of any ET_c (e.g. rice); therefore the FAO Penman-Monteith ET_o equation was used in this study.

Infiltration

Infiltration is the vertical permeation of water through soil layers. The term infiltration is used more in agriculture than in pond aquaculture. Seepage is a term commonly associated with pond aquaculture, seepage encompasses water loss through earth-filled dams, beneath the dams, along drain structures as well as infiltration through the pond bottom. Seepage can be a major loss of water from ponds, it is difficult to measure, and can vary greatly among ponds – some ponds lose a great deal of water through seepage.

Properly constructed ponds have infiltration rates less than 0.25 cm/d, and few have rates more than 0.64 cm/d. Generally, ponds with the greatest infiltration rates are always located well upslope on watersheds or they have a sand or gravel like bottom. Fine textured soils with a high clay content or soils with a mixture of silt and clay resist infiltration and make for watertight pond bottoms. Infiltration rates are also greater in the warm months versus the cool months because water viscosity decreases with increasing temperature, therefore infiltration is favored by low viscosity (Boyd and Yoo 1994).

Pond Water Conservation

When trying to conserve water, one technique used to maintain pond storage capacity is the capturing of precipitation or runoff, rather than allowing it to overflow through a discharge structure. Maintaining a water storage capacity of 20 cm to 30 cm (8 in to 12 in) can reduce the need for groundwater and effluent discharge by 40% to 60% compared to ponds maintained without water storage capacity (Hargreaves et al. 2002).

Crawfish ponds are usually filled once per year (in September – October) and drained in April – June. Water levels are maintained by pumping water from surface or subsurface sources and from precipitation. Water losses are from intentional management (intentional draining or intentional water exchanges), unintentional overflow (precipitation events), infiltration, evaporation, and evapotranspiration.

Recirculating with mechanical aerators or exchanging water in crawfish ponds introduces fresh oxygenated water, this helps maintain suitable water quality for optimal crawfish production (LCES 1999). A pond with dense vegetation may need seven to nine water exchanges (flushes) per season to maintain levels of dissolved oxygen (DO) in a suitable range for optimal crawfish production (LCES 1999). The practice of exchanging water to improve water quality is energy intensive compared to mechanical aeration. However, most commercial crawfish ponds in Louisiana are not set up for mechanical aeration, they instead use water exchanges (flushing) to improve water quality simply because mechanical aeration is not a feasible option for the location.

Total water usage for a season in a commercial crawfish pond can be as much as 3.05 to 4.88 ha – m / surface ha per season (LCES 1999). Although in reality few producers utilize this amount of water because of the high cost of pumping or limitation in pumping capacity relative

to the size of the ponds (Lovelace 1994; personal communication, Dr. Robert P. Romaire, Professor, Louisiana State University, 17 October 2002, Baton Rouge, Louisiana). Annual water requirement ranges for crawfish farms in south-central Louisiana were: 0.17 to 0.36 ha – m / surface ha per season for farmers using ground water only, 0.94 to 7.93 ha – m / surface ha per season for farmers using surface water only, and 0.39 to 0.79 ha – m / surface ha per season for farmers using a combination of ground and surface water (Lovelace 1994). The use of recirculation systems (mechanical aerators) can reportedly reduce water usage to 0.91 ha – m / surface ha (LCES 1999).

Methods

Water discharge models were created for each of Louisiana's three main crawfish production systems – single-crop crawfish, double-crop rice/crawfish, and double-crop rice/crawfish rotational – to predict annual discharge. The models account for water discharge from the time the rice would be planted until the time the ponds would typically be drained following the end of the crawfish harvest season. The models accounted for intentional and unintentional overflow and summer drawdown; water discharge for the entire crawfish production cycle was accounted for. The water discharge models were applied to six ponds (totaling 10.8 ha) at the Aquaculture Research Station (ARS), and to one pond (4.9 ha) at the Rice Research Station (RRS) consisting of 11 small ponds on each side of a lateral water supply; because all the ponds were connected by a common water supply and all the ponds drained through a single discharge structure it was treated as one pond. Locations for both sites are: ARS, LSU Agricultural Experiment Station, East Baton Rouge Parish, latitude 30.37°, longitude 91.17°; and RRS, LSU Agricultural Experiment Station, Acadiana Parish, latitude 30.25°, longitude 92.37°. The ARS represents areas producing crawfish in south-central Louisiana, and

the RRS represents areas producing crawfish in southwest Louisiana. Precipitation, evaporation, evapotranspiration, and infiltration were all available for the ARS and the RRS locations. Only the single-crop crawfish model was used for the ARS area because this is the common production system used in south-central Louisiana. All three model systems – single-crop crawfish, double-crop rice/crawfish, and double-crop rice/crawfish rotational – were used for the RRS because all of these systems can be found in southwest Louisiana.

Precipitation, pan evaporation, evapotranspiration, and infiltration were used to create water discharge models for south-central and southwest Louisiana. Water discharge was calculated by using the following equation: $O = P - (E + I)$. Where O = overflow, P = precipitation, I = infiltration, and E = evaporation or evapotranspiration (Boyd and Yoo 1994). Water discharge was calculated in two ways. The first model (Table 3.1) assumed the water level was maintained at the top of the drainage structure (0 cm storage capacity) by adding water in when evaporative and infiltration losses exceeded precipitation. Effluent discharged under this system would be from high precipitation events (unintentional discharge), water exchanges (intentional discharge), and final draining (intentional discharge). The second model (Table 3.2) assumed the water level would not be maintained at the top of the drainage structure after the initial flood in October; from October on only precipitation regulated the pond level. Effluent discharged under this system was from high precipitation events (unintentional discharge), exchanges (intentional discharge), and final drawdown. All models predicted monthly and annual discharge from the time the rice was planted – as either a crawfish forage or a grain crop – until the ponds were drained. All models were used to calculate discharge volume under several different systems, including: 0 cm, 5.1 cm, 10.2 cm, and 15.2 cm storage capacity and for one, three, seven, and nine water exchanges for water quality management using only 0 cm

storage capacity. All models were set up in Microsoft Excel 2000. The following sections (precipitation, pond evaporation, evapotranspiration, infiltration, and model validation) will describe each component used in the development of this study's water discharge models.

Table 3.1. A model example of a south-central single-crop crawfish system under an average precipitation year (30 year precipitation normals). Water was maintained at 10 cm for the July, August, and September rice growth period; and 36 cm for the full flood stage from October until June. The pond was 10.76 ha with an average depth of 35.6 cm. The pond volume was 3.83 ha – m.

				SCO[3] [cm]			
Month	P [cm]	ET_c[1] or E[2] [cm]	I [cm]	0	5.1	10.2	15.2
J	13.72	14.66[1]	1.18	-2.12	-7.20	-12.28	-17.36
A	14.53	16.40[1]	1.18	-3.05	-8.13	-13.21	-18.29
S	11.53	16.20[1]	1.14	-5.81	-10.89	-15.97	-21.05
O	9.17	13.02[1]	1.18	-5.03	0.00	0.00	0.00
N	12.22	8.10[1]	1.14	2.98	0.00	0.00	0.00
D	13.13	3.49[1]	1.18	8.46	6.36	1.28	0.00
J	15.09	5.08[2]	1.18	8.83	8.83	8.83	5.03
F	12.67	6.56[2]	1.07	5.04	5.04	5.04	5.04
M	12.65	9.57[2]	1.18	1.90	1.90	1.90	1.90
A	13.36	12.54[2]	1.14	-0.32	0.00	0.00	0.00
M	13.31	14.75[2]	1.18	-2.62	0.00	0.00	0.00
J	14.76	15.20[2]	1.14	-1.58	0.00	0.00	0.00
∑=	156.14	∑= 135.57	∑= 13.89				
Precipitation Overflow [cm] ∑ =				27.21	22.13	17.05	11.97
Final Drain [cm] ∑ =				35.56	36.13	41.21	46.29
Total Water Discharge [cm] ∑ =				62.77	58.26	58.26	58.26
Ha – m O/yr ∑ =				6.76	6.28	6.28	6.28
Ha – m O/surface ha – yr ∑ =				**0.63**	**0.58**	**0.58**	**0.58**

1 = evapotranspiration
2 = pond evaporation
3 = storage capacity overflow

P = precipitation
ET_c = crop evapotranspiration
E = pond evapotranspiration
I = infiltration
SCO = storage capacity overflow (note that negative values in columns represent water deficits and no water discharged)

Table 3.2. A model example of a south-central single-crop crawfish system under an average precipitation year (30 year precipitation normals). Water was maintained at 10 cm for the July, August, and September rice growth period; and filled to a depth of 35.6 cm at initial flood in October and at no time after was water pumped in. The pond was 10.76 ha with an average depth of 35.6 cm. The pond volume was 3.83 ha – m.

Month	P [cm]	ET_c[1] or E[2] [cm]	I [in]	Water + or - [cm]	Pond Level [cm]	SCO[3] [cm] 0	5.08	10.16	15.24
J	13.72	14.66[1]	1.18	-2.12	10.16	0.00	-5.08	-10.16	-15.24
A	14.53	16.40[1]	1.18	-3.05	10.16	0.00	-5.08	-10.16	-15.24
S	11.53	16.20[1]	1.14	-5.81	10.16	0.00	-5.08	-10.16	-15.24
O	9.17	13.02[1]	1.18	-5.03	30.53	0.00	-5.08	-10.16	-15.24
N	12.22	8.10[1]	1.14	2.98	33.51	0.00	-5.08	-10.16	-15.24
D	13.13	3.49[1]	1.18	8.46	35.56	6.41	1.33	-3.75	-8.83
J	15.09	5.08[2]	1.18	8.83	35.56	8.83	3.75	-1.33	-6.41
F	12.67	6.56[2]	1.07	5.04	35.56	5.04	-0.04	-5.12	-10.20
M	12.65	9.57[2]	1.18	1.90	35.56	1.90	-3.18	-8.26	-13.34
A	13.36	12.54[2]	1.14	-0.32	35.24	0.00	-5.08	-10.16	-15.24
M	13.31	14.75[2]	1.18	-2.62	32.62	0.00	-5.08	-10.16	-15.24
J	14.76	15.20[2]	1.14	-1.58	31.05	0.00	-5.08	-10.16	-15.24
	∑= 156.14	∑= 135.57	∑= 13.89						
		Precipitation Overflow [cm] ∑ =				22.18	5.16	0.00	0.00
		Final Drain [cm] ∑ =			31.05				
		Total Overflow [cm] ∑ =				53.23	53.23	53.23	53.23
		ha - m O / yr ∑ =				5.73	5.73	5.73	5.73
		ha - m O / surface ha – yr ∑ =				**0.53**	**0.53**	**0.53**	**0.53**

1 = evapotranspiration
2 = pond evaporation
3 = storage capacity overflow

P = precipitation
ET_c = crop evapotranspiration
E = pond evapotranspiration
I = infiltration
SCO = storage capacity overflow (note that negative values in columns represent water deficits and no water discharged)

Precipitation

The National Climatic Data Center (NCDC) publishes the latest 30 y precipitation normals (1971-2000) that were used as inputs for this study's water discharge models. Normal precipitation data from 1971-2000 NCDC was used for the ARS, and normal precipitation data (30 y average) from 1971-2000 NCDC was used for the RRS (Fig. 3.3-3.6). Because a crawfish production season overlaps two calendar years (starting in the beginning to middle of one year and finishing in the beginning to middle of the next), two high precipitation years and two low precipitation years were selected from the 1971-2000 precipitation normals for the ARS and the RRS. Monthly precipitation was matched to the corresponding month within each of the three crawfish production system models.

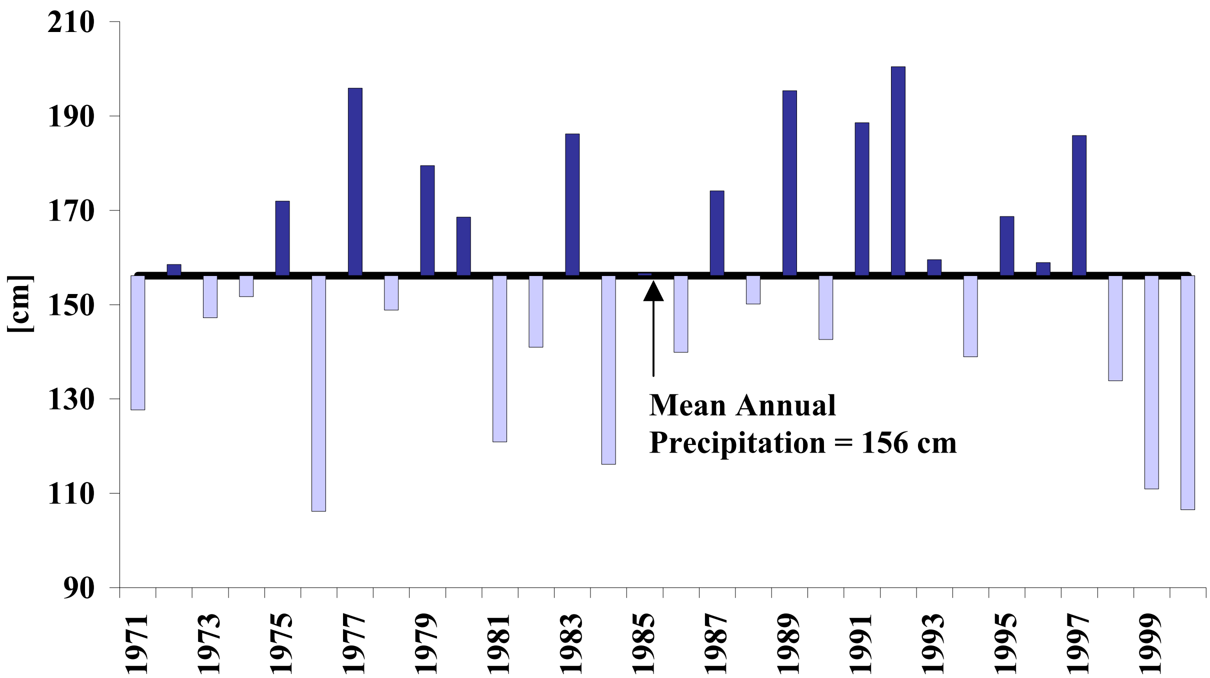


Figure 3.3. Mean annual precipitation for the Aquaculture Research Station from 1971-2000 taken from the LSU Ben Hur farm station (source: National Climatic Data Center).

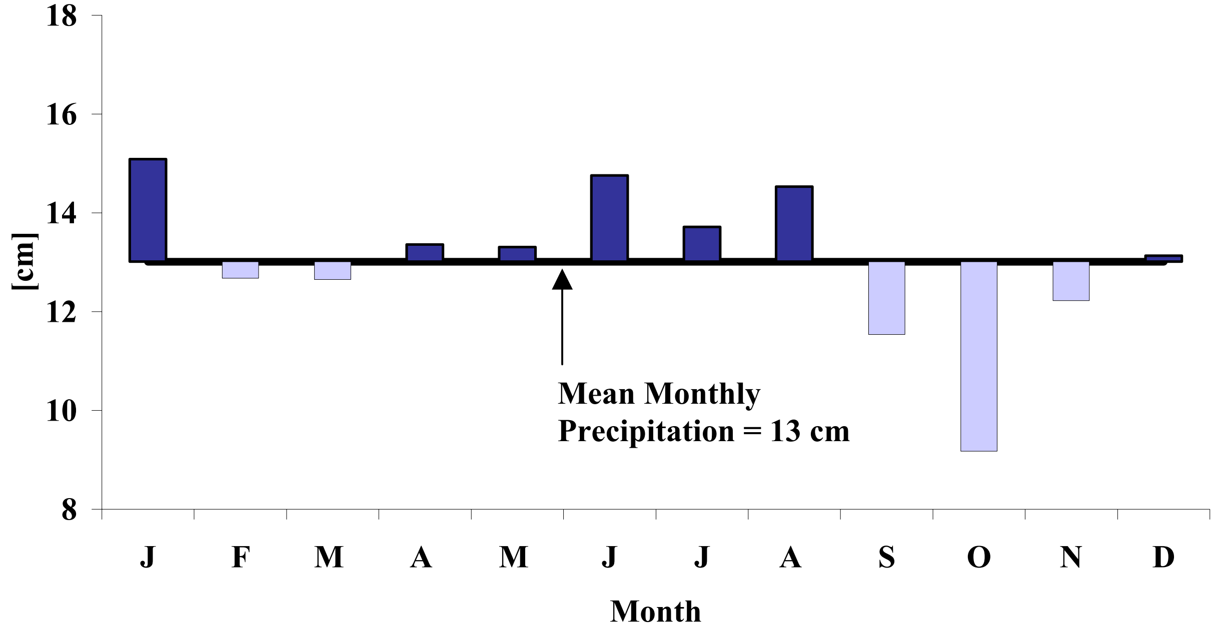


Figure 3.4. Aquaculture Research Station monthly precipitation patterns from 1971-2000 taken from the LSU Ben Hur farm station (source: National Climatic Data Center).

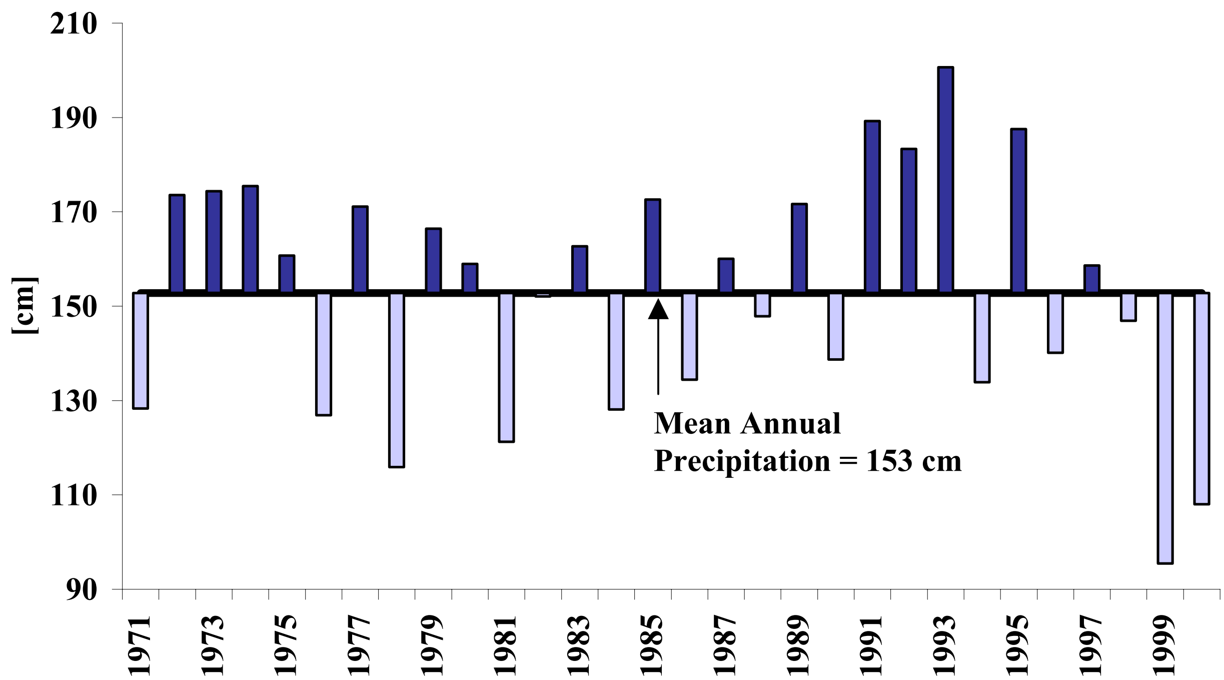


Figure 3.5. Mean annual precipitation for the Rice Research Station from 1971-2000 taken from the Crowley main station (source: National Climatic Data Center).

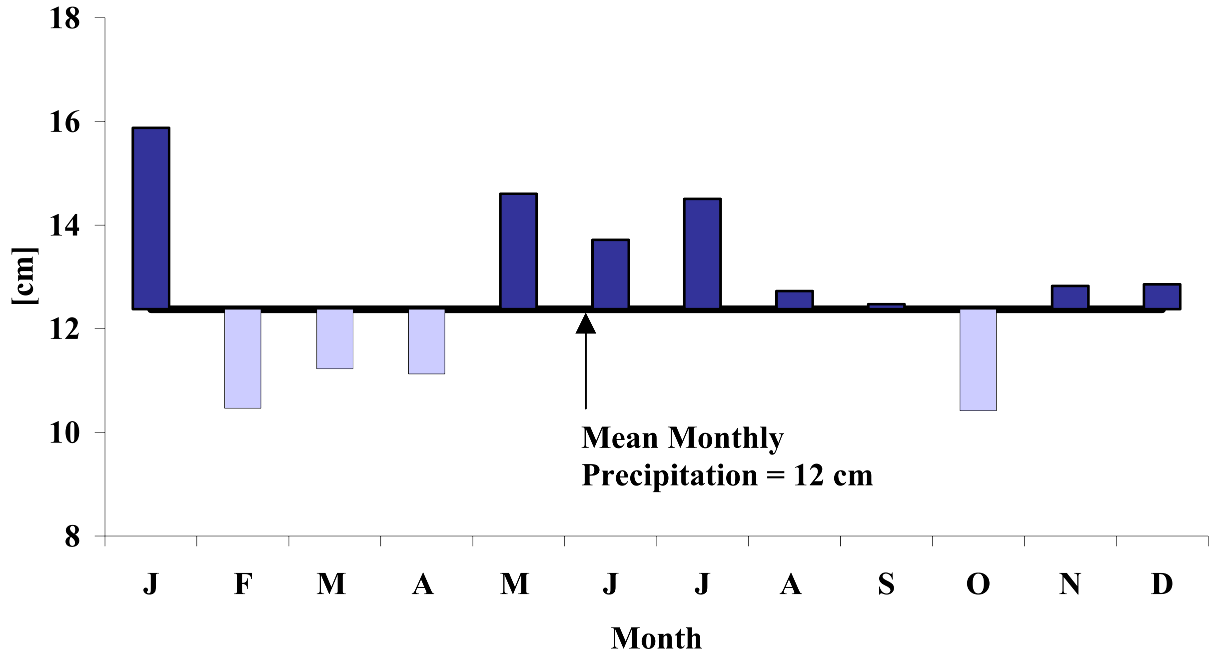


Figure 3.6. Rice Research Station monthly precipitation patterns from 1971-2000 taken from the Crowley main station (source: National Climatic Data Center).

Pond Evaporation

The NCDC also publishes the pan evaporation data that were used in developing this study's water discharge models. Pan evaporation data from 1963-2000 NCDC was used for the ARS and 1990-2000 NCDC pan evaporation data was used for the RRS from the Jennings station, Jefferson Davis Parish, latitude 30.20^{o}, longitude 92.67^{o} (there was no pan evaporation data for the RRS location so Jennings was used). The Joint Subcommittee on Aquaculture Catfish Production in Ponds Technical Subgroup did an effluent study on channel catfish ponds, where pan evaporation was multiplied by a pan evaporation coefficient of 0.8 to estimate pond evaporation (Tucker et al. 2000). As illustrated in Fig. 3.8-3.11 pond evaporation is used during the portion of the crawfish production cycle where rice is not being grown. Boyd and Yoo (1994) calculated for Auburn, Alabama, an average pan coefficient of 0.81 from a Class A pan over a year. This study used a pan evaporation coefficient of 0.80 (Table 3.3).

Table 3.3. An example of how pond evaporation was calculated for the Aquaculture Research Station, LSU Agricultural Center, Baton Rouge, Louisiana.

Month	Number of Years Available from 1963-2000	1963-2000 Monthly Mean for Pan Evaporation cm	Pan Evaporation Coefficient (0.8)	1963-2000 Monthly Mean for Pond Evaporation [cm]
January	21	6.35	0.8	5.08
February	34	8.20	0.8	6.56
March	34	11.96	0.8	9.57
April	32	15.67	0.8	12.54
May	33	18.44	0.8	14.75
June	35	19.00	0.8	15.20
July	37	17.81	0.8	14.25
August	32	16.46	0.8	13.17
September	37	14.63	0.8	11.70
October	37	12.93	0.8	10.34
November	35	8.53	0.8	6.82
December	31	6.73	0.8	5.38

Evapotranspiration

Reference crop evapotranspiration (Et_o) was multiplied by a rice crop coefficient (Fig. 3.8) and then multiplied by the number of days within a particular month to yield monthly rice crop evapotranspiration (Et_c) (Table 3.4).

Table 3.4. Table illustrating how Et_c was calculated for a single-crop crawfish system at the Aquaculture Research Station LSU Agricultural Center, Baton Rouge, Louisiana using the FAO Penman-Monteith method.

Month	Years of Data	FAO Penman-Monteith Method ET_o	Rice Coefficient (K_c)	Days per Month	Et_c Averages per Month [cm]
January	16	0.15	1.10	31	5.12
February	16	0.20	1.10	28	6.16
March	15	0.25	1.10	31	8.56
April	16	0.33	1.10	30	10.89
May	16	0.43	1.10	31	14.66
June	15	0.46	1.10	30	15.18
July	14	0.43	1.10	31	14.66
August	16	0.43	1.23	31	16.40
September	15	0.36	1.50	30	16.20
October	15	0.28	1.50	31	13.02
November	15	0.18	1.50	30	8.10
December	16	0.15	0.75	31	3.49

Rice evapotranspiration values for the ARS and the RRS were calculated by using the FAO Penman-Monteith ET_o method. The ET_o values were derived by Dr. Edling (personal communication with Dr. Robert Edling, Associate Professor, Department of Biological and Agricultural Engineering, Louisiana State University, 2002) for each of the LSU AgCenter's field research stations. As illustrated in Fig. 3.8-3.11, pond evapotranspiration is used during the portion of the crawfish production cycle where rice is being grown.

These coefficients are established for a 6-month rice production period and fit with a single-crop crawfish system (Fig. 3.7). However, the coefficients had to be averaged between months in order to fit into a double-crop rice/crawfish or a double-crop rice/crawfish rotational system (recommended by Dr. Edling).

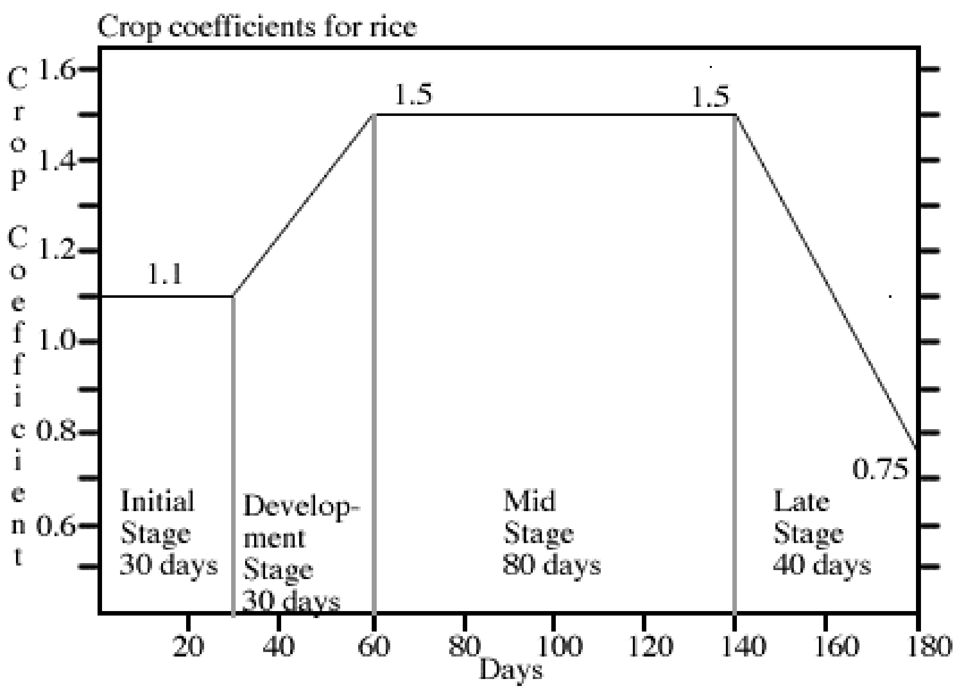


Figure 3.7. Vegetative phases of rice growth along with the corresponding rice crop coefficients (Edling 2002). The figure illustrates the different vegetative phases of rice growth along with the corresponding rice crop coefficients – as determined by the Food and Agricultural Organization – that were used in determining Et_c for each of the crawfish production systems in Louisiana.

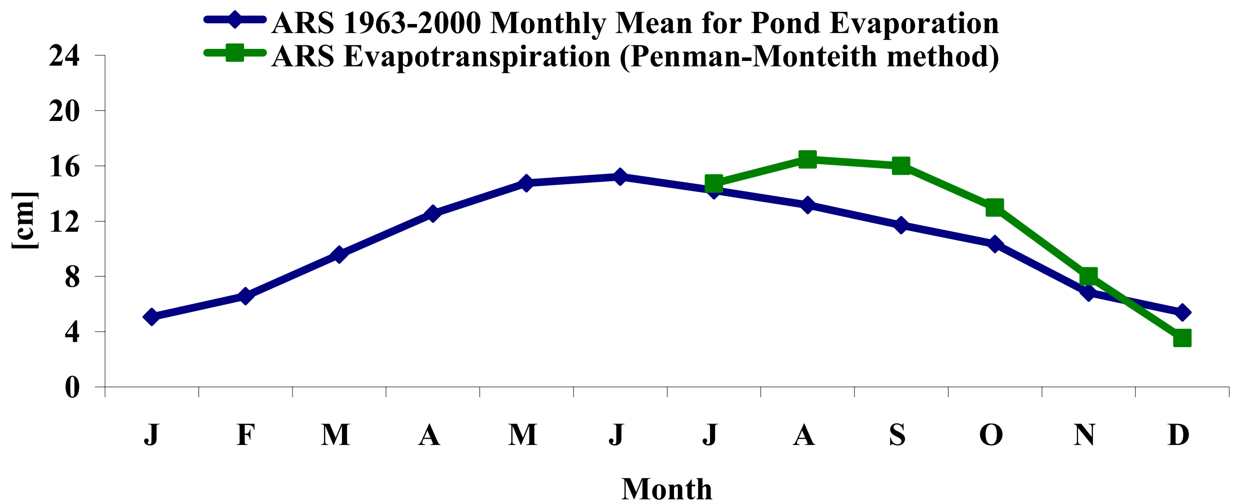


Figure 3.8. Aquaculture Research Station pond evaporation and evapotranspiration for a single-crop crawfish system. Pond evaporation (blue diamonds) occurs until July when rice is planted and evapotranspiration begins (green squares) and continues, usually, through December.

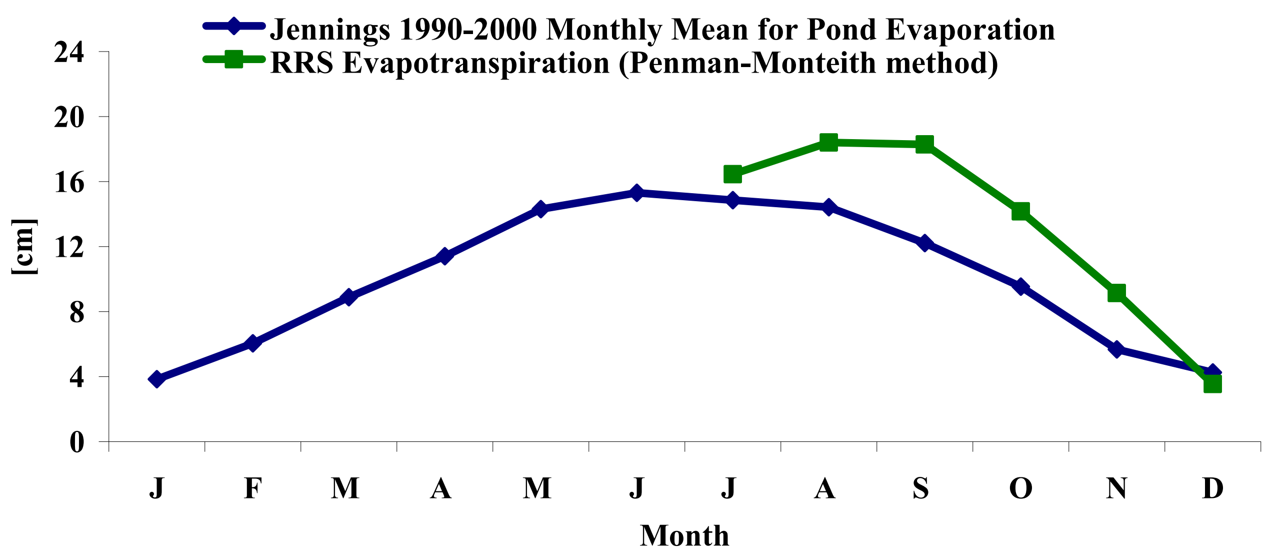


Figure 3.9. Rice Research Station pond evaporation and evapotranspiration for a single-crop crawfish system. Pond evaporation (blue diamonds) occurs until July when rice is planted and evapotranspiration begins (green squares) and continues, usually, through December.

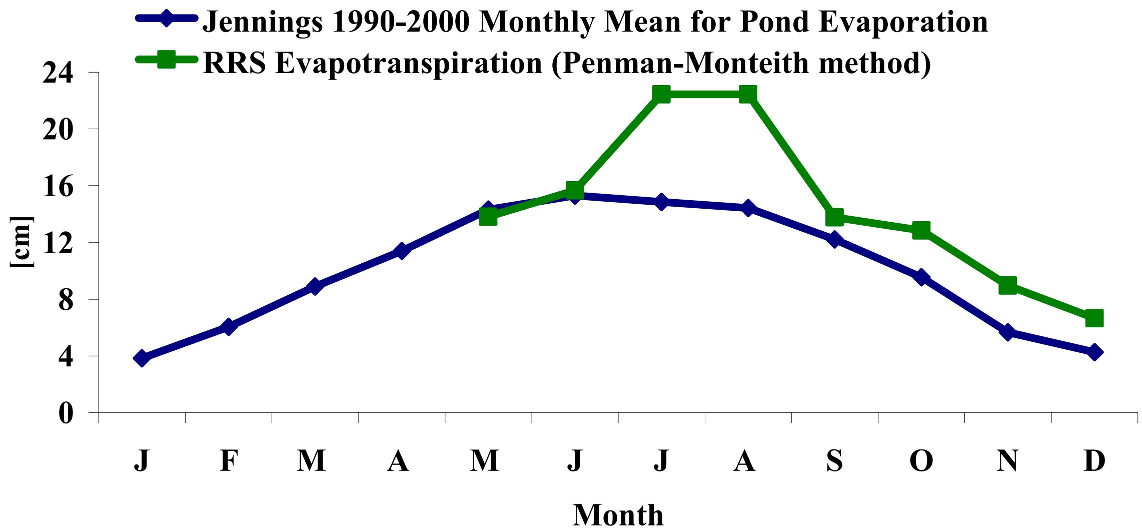


Figure 3.10. Rice Research Station pond evaporation and evapotranspiration for a double-crop rice/crawfish system. Pond evaporation (blue diamonds) occurs until May when rice is planted and evapotranspiration (green squares) begins and continues through September when rice is harvested. Ratoon is fertilized after harvest and evapotranspiration continues through December.

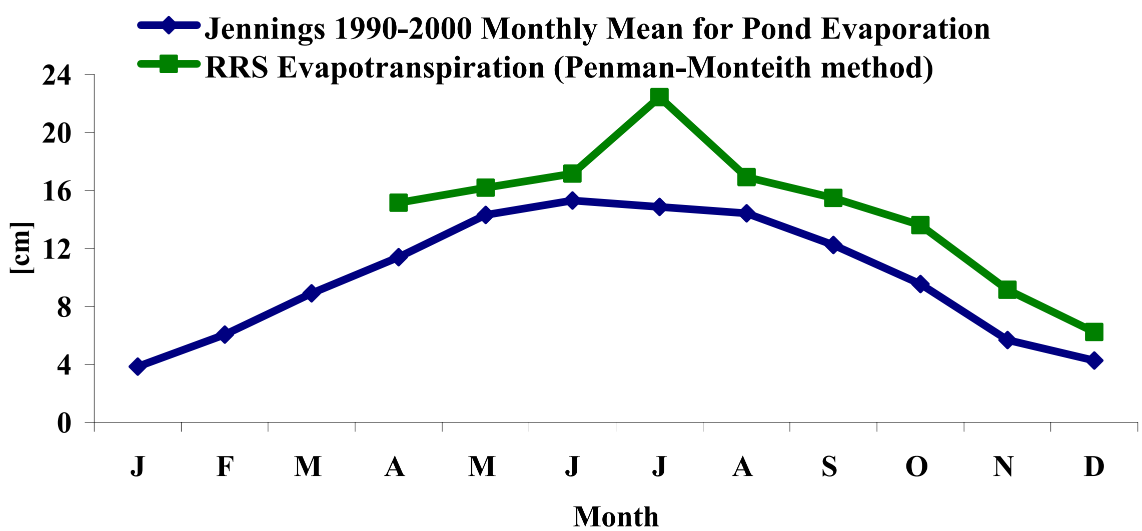


Figure 3.11. Rice Research Station pond evaporation and evapotranspiration for a double-crop rice/crawfish rotational system. Pond evaporation (blue diamonds) occurs until April when rice is planted and evapotranspiration (green squares) begins and continues through August when rice is harvested. Ratoon is fertilized after harvest and evapotranspiration continues through December.

Infiltration

Soil at the Aquaculture Research Station is similar to that of rice fields in northwest Mississippi, which are classified as Alligator and Sharkey series soil. An infiltration rate of 0.04 cm/d was reported for northwest Mississippi rice fields and was used for single-crop crawfish ponds representing south-central Louisiana (Tucker et al. 2000). A similar type study on catfish ponds with the same soil type as the ARS used 0.04 cm/d (SRAC 1998). An infiltration rate of 0.04 cm/d was used for double-crop rice/crawfish and double-crop rice/crawfish rotational ponds in southwest Louisiana using data collected from soils at the RRS (Shah 1995). Rice Research Station soil is defined as Crowley (fine, montmorillonitic, thermic Aeric Ochraqualf).

Model Validation

The water discharge produced by the models was validated with field data for water budgets during the crawfish production cycle at the RRS. The study occured from fall 1999 through spring 2002 and encompassed three crawfish production cycles. Water monitoring equipment was established on a 4.9 ha water surface area, which was the experimental crawfish pond at the RRS as was previously described. Data was collected from pond flooding to final drawdown during the crawfish production phase (Oct through May) for each three crawfish production seasons. Water leaving the pond, whether intentional or unintentional, was accounted for. Precipitation was recorded at the study site. Discharge consisted of: intentional exchanges for water quality management (low DO), unintentional overflow from excess precipitation or levee breakage, and final drawdown. By inserting the precipitation data collected at the RRS into the rotational pond model, the accuracy of the model's cumulative evaporation, evapotranspiration, and infiltration values could be validated with the field data. Any difference in actual discharge from the experimental pond and estimated discharge from the model would

indicate the magnitude of combined error in the evaporation, evapotranspiration, and infiltration values. The difference between real and calculated discharge includes errors for one or any combination of the three variables (evaporation, evapotranspiration, and infiltration).

Results

The difference between real overflow and empirically determined overflow at the RRS was 9.0 cm for 1999-2000, 9.0 cm for 2000-2001, and 2.0 cm for 2001-2002 (Table 3.5). The results of the eight-month comparisons were very close. If an imaginary basin – with the same dimensions as the actual pond – were put beneath the drain pipe of the actual pond and the hypothetical pond represented by the model to hold all the water discharged from the actual pond and the model the greatest difference in depth would be 9 cm and the least difference in depth 2 cm for 8 months.

Table 3.5. Rice Research Station discharge and model discharge comparison for three 8-month periods.

	8 Month Precipitation at RRS Pond Site (cm)	Actual Measured Discharge ha-m	Simulated Discharge Using Model ha-m	% Difference
1999-2000	40.0	0.36	0.27	25%
2000-2001	107.8	0.71	0.80	13%
2001-2002	65.2	0.53	0.55	4%

Water discharge (ha-m water discharge / surface ha – production system) was predicted for south-central and southwest Louisiana (Table 3.6). Models for south-central and southwest Louisiana with a 15 cm storage capacity showed that excess precipitation overflow (final drawdown not included) can be decreased by 28% for a high precipitation year, 61% for an average precipitation year, and 100% for a low precipitation year. Pond evaporation and evapotranspiration are the greatest sources of water loss during a crawfish production cycle (Figures 3.12 – 3.17). The major sources of effluent from crawfish ponds were (1) overflow

during winter – when precipitation exceeds evaporation, evapotranspiration, and infiltration (Fig. 3.18 – 3.23) and (2) discharge during the summer drawdown period (Tables 3.6 and 3.7).

Table 3.6. Predicted water discharge for a single-crop crawfish system for the south-central and southwest regions. Precipitation overflow and final drawdown discharge are for an entire production season. Water exchanges are one, three, seven, or nine, pond volume exchanges added to the total discharge of 0 SCO [cm]. Total discharge values are in ha-m / surface ha – production season.

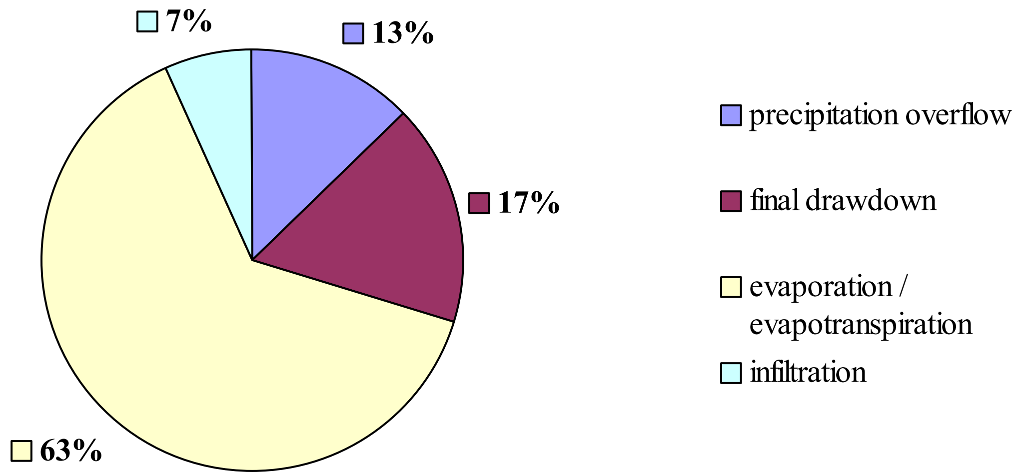
	SCO [cm][1]				Water Exchanges (0 cm SCO)			
Single-crop crawfish	0	5	10	15	1	3	7	9
	SC[2] Average Precipitation Year							
Precipitation overflow	0.27	0.22	0.17	0.12				
Final drawdown discharge	0.36	0.36	0.41	0.46				
Total discharge	0.63	0.58	0.58	0.58	0.98	1.69	3.12	3.83
	SC High Precipitation Years 1991-1992							
Precipitation overflow	0.49	0.41	0.36	0.31				
Final drawdown discharge	0.35	0.38	0.38	0.40				
Total discharge	0.84	0.79	0.74	0.71	1.20	1.91	3.33	4.04
	SC Low Precipitation Years 1999-2000							
Precipitation overflow	0.09	0.03	0	0				
Final drawdown discharge	0.36	0.36	0.36	0.36				
Total discharge	0.45	0.39	0.36	0.36	0.81	1.52	2.94	3.65
	SW[3] Average Precipitation Year							
Precipitation overflow	0.27	0.21	0.16	0.11				
Final drawdown discharge	0.25	0.26	0.31	0.36				
Total discharge	0.52	0.47	0.47	0.47	0.77	1.28	2.30	2.80
	SW High Precipitation Years 1992-1993							
Precipitation overflow	0.87	0.75	0.70	0.65				
Final drawdown discharge	0.25	0.31	0.36	0.41				
Total discharge	1.12	1.06	1.06	1.06	1.37	1.88	2.90	3.41
	SW Low Precipitation Years 1999-2000							
Precipitation overflow	0.06	0	0	0				
Final drawdown discharge	0.25	0.25	0.25	0.25				
Total discharge	0.31	0.25	0.25	0.25	0.56	1.07	2.09	2.60

(1) Storage Capacity Overflow = SCO
(2) Aquaculture Research Station models = south-central = SC
(3) Rice Research Station models = southwest = SW

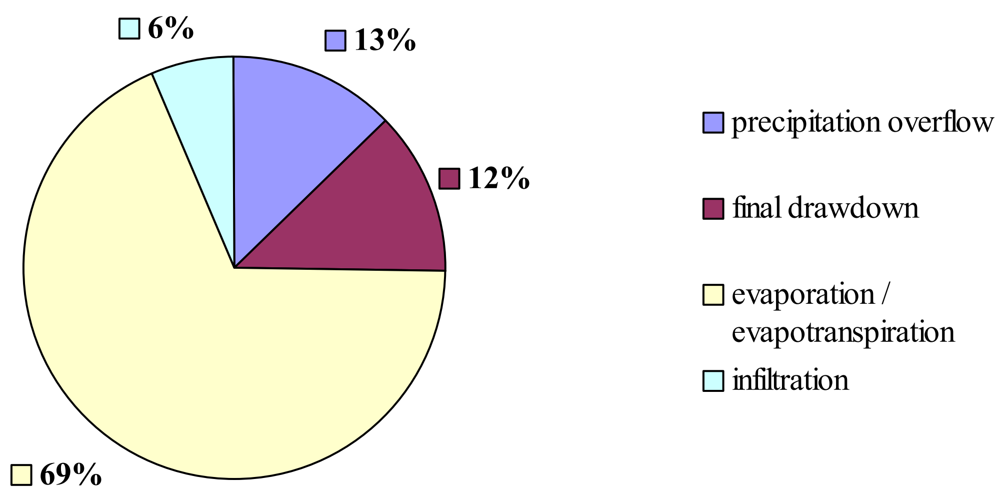
Table 3.7. Predicted water discharge for a double-crop rice/crawfish system and a double-crop rice/crawfish rotational system for the southwest region. Precipitation overflow and final drawdown discharge are for an entire production season. Water exchanges are one, three, seven, or nine, pond volume exchanges added to the total discharge of 0 SCO [cm]. Total discharge values are in ha-m / surface ha – production season.

	SCO [cm][1]				Water Exchanges (0 cm SCO)			
	0	5	10	15	1	3	7	9
Double-crop rice/crawfish	SW[2] Average Precipitation Year							
Precipitation overflow	0.24	0.19	0.13	0.08				
Final drawdown discharge	0.25	0.29	0.35	0.40				
Total discharge	0.49	0.48	0.48	0.48	0.74	1.25	2.27	2.77
	SW High Precipitation Years 1992-1993							
Precipitation overflow	0.61	0.56	0.51	0.45				
Final drawdown discharge	0.25	0.30	0.35	0.41				
Total discharge	0.86	0.86	0.86	0.86	1.12	1.62	2.64	3.15
	SW Low Precipitation Years 1999-2000							
Precipitation overflow	0.04	0	0	0				
Final drawdown discharge	0.22	0.25	0.25	0.25				
Total discharge	0.26	0.25	0.25	0.25	0.51	1.02	2.04	2.54
Double-crop rice/crawfish rotational	SW Average Precipitation Year							
Precipitation overflow	0.24	0.19	0.13	0.08				
Final drawdown discharge	0.25	0.25	0.31	0.36				
Total discharge	0.49	0.44	0.44	0.44	0.74	1.25	2.27	2.78
	SW High Precipitation Years 1992-1993							
Precipitation overflow	0.84	0.73	0.67	0.62				
Final drawdown discharge	0.25	0.30	0.36	0.41				
Total discharge	1.09	1.03	1.03	1.03	1.34	1.85	2.87	3.37
	SW Low Precipitation Years 1999-2000							
Precipitation overflow	0.03	0	0	0				
Final drawdown discharge	0.25	0.25	0.25	0.25				
Total discharge	0.28	0.25	0.25	0.25	0.54	1.04	2.06	2.57

(1) Storage Capacity Overflow = SCO
(2) Rice Research Station = southwest = SW

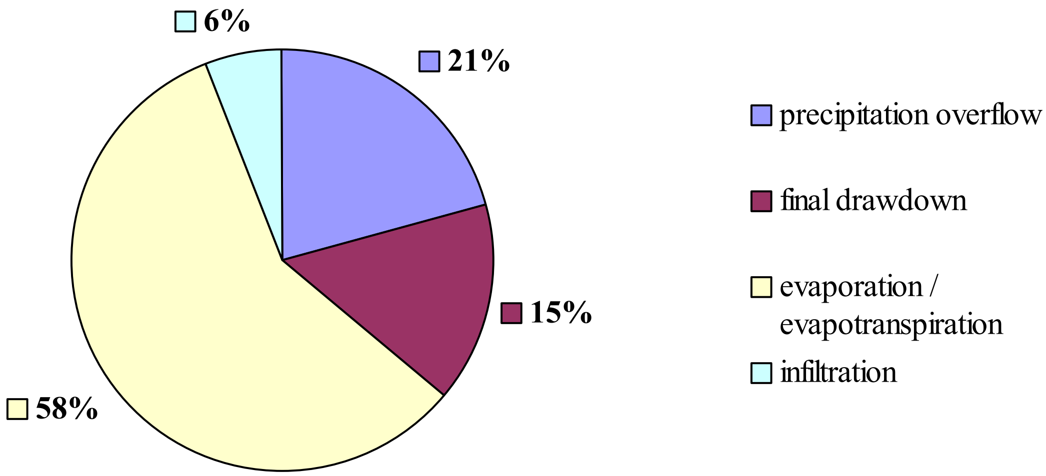


A. Production Cycle Water Loss 211 cm

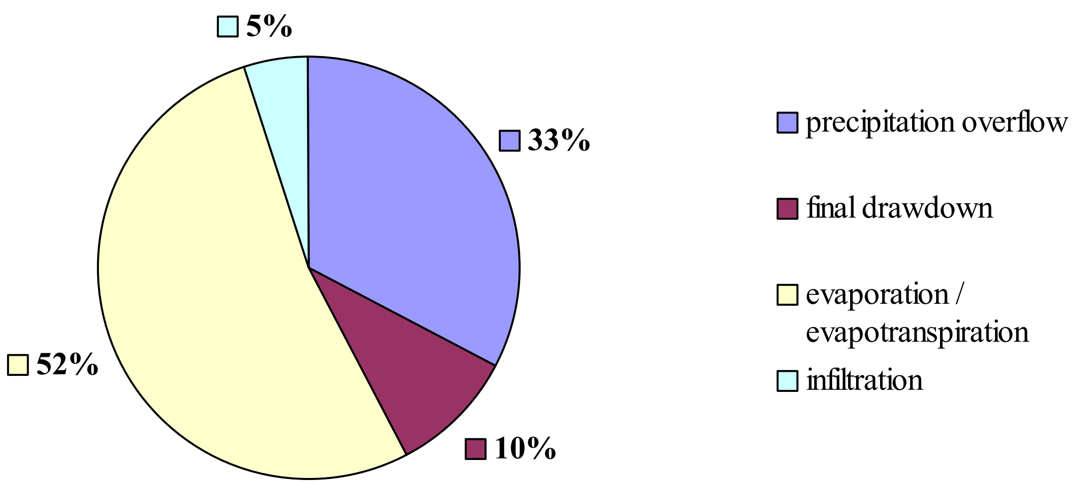


B. Production Cycle Water Loss 203 cm

Figure 3.12. Single-crop crawfish production cycle water loss estimates based on model results for the south-central region (A) and the southwest region (B). Precipitation used in both models was based on 1971-2000 precipitation normals.

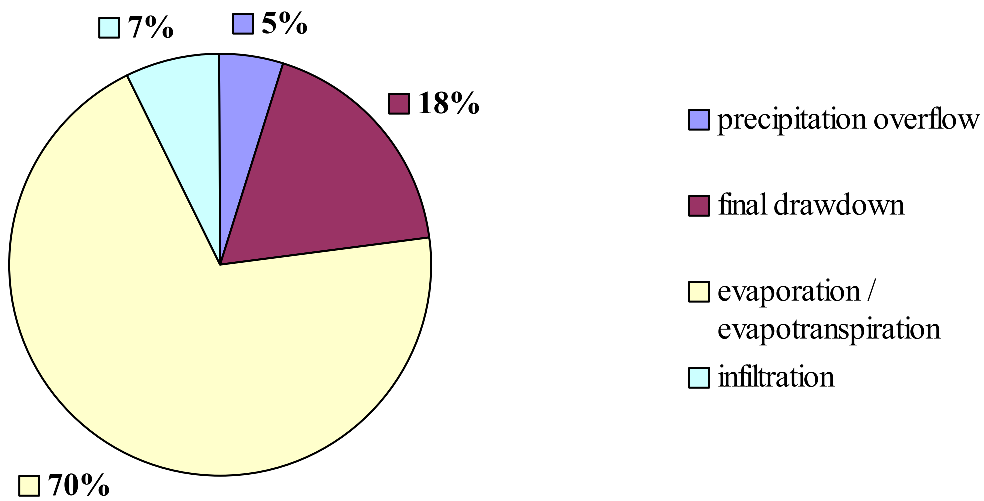


A. Production Cycle Water Loss 231 cm

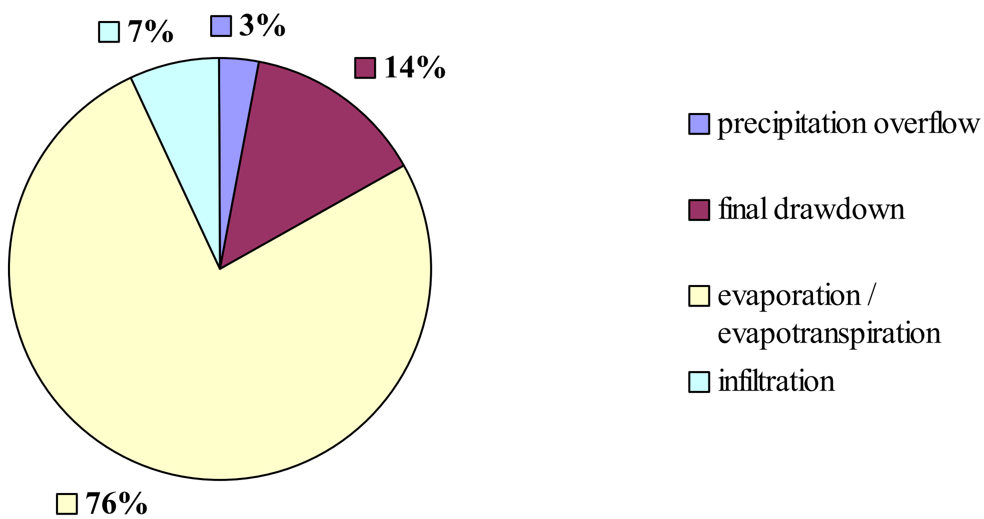


B. Production Cycle Water Loss 264 cm

Figure 3.13. Single-crop crawfish production cycle water loss estimates based on model results for the south-central region (A) and the southwest region (B). Precipitation used for the south-central region was based on 1991-1992 high precipitation years. Precipitation used for the southwest region was based on 1992-1993 high precipitation years.

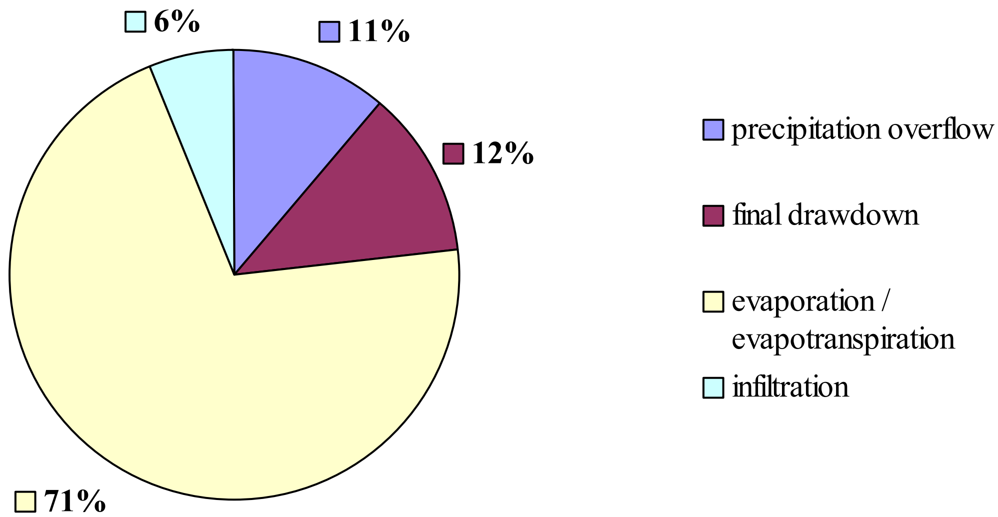


A. Production Cycle Water Loss 193 cm

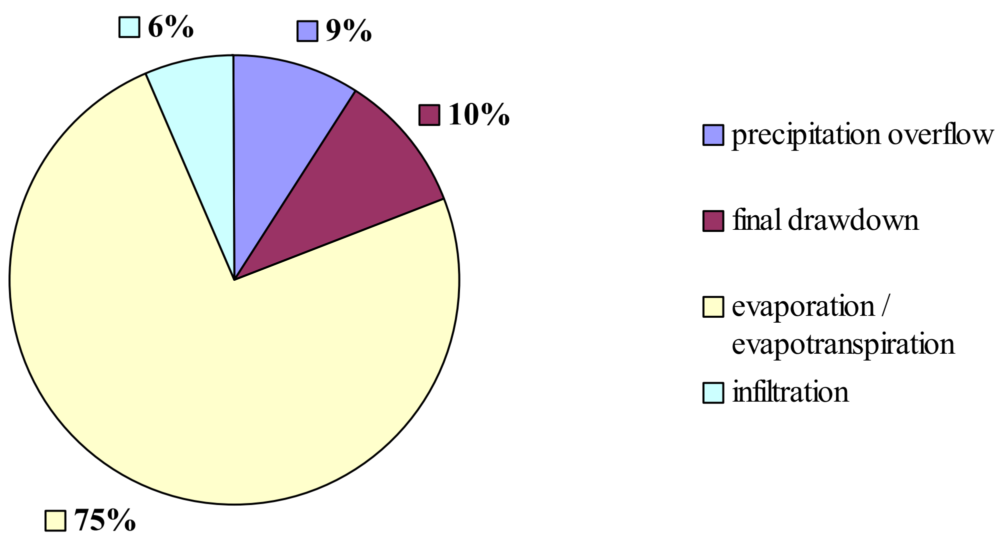


B. Production Cycle Water Loss 183 cm

Figure 3.14. Single-crop crawfish production cycle water loss estimates based on model results for the south-central region (A) and the southwest region (B). Precipitation used for the south-central region was based on 1999-2000 low precipitation years. Precipitation used for the southwest region was based on 1999-2000 low precipitation years.

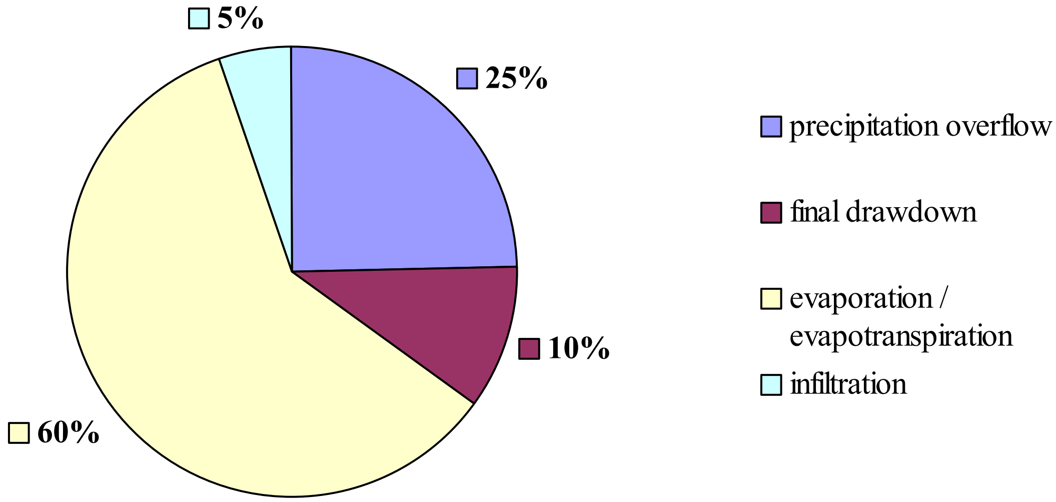


A. Production Cycle
Water Loss 208 cm

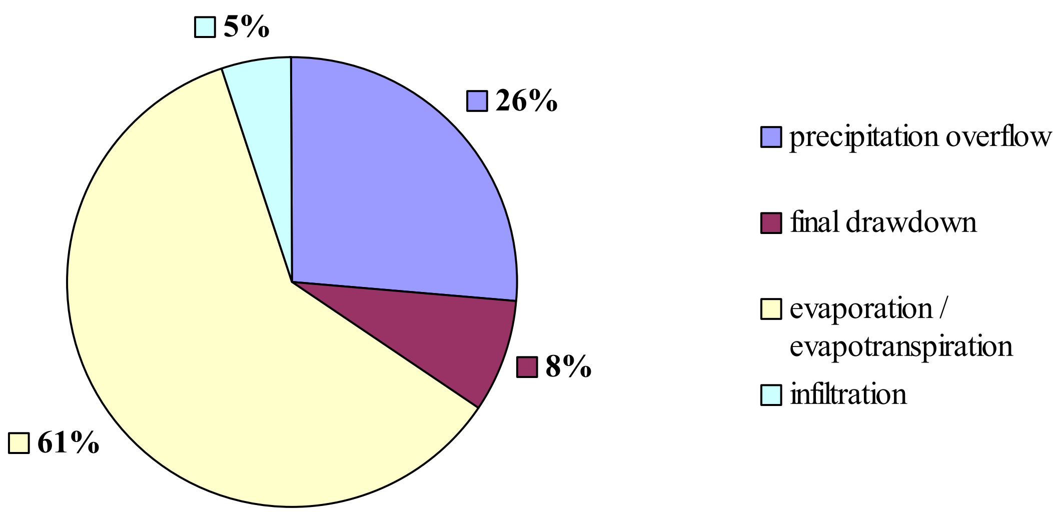


B. Production Cycle
Water Loss 257 cm

Figure 3.15. Double-crop rice/crawfish production cycle water loss estimates based on model results for the southwest region (A). Double-crop rice/crawfish rotational water loss estimates based on model results for the southwest region (B). Precipitation used in both models was based on 1971-2000 precipitation normals.

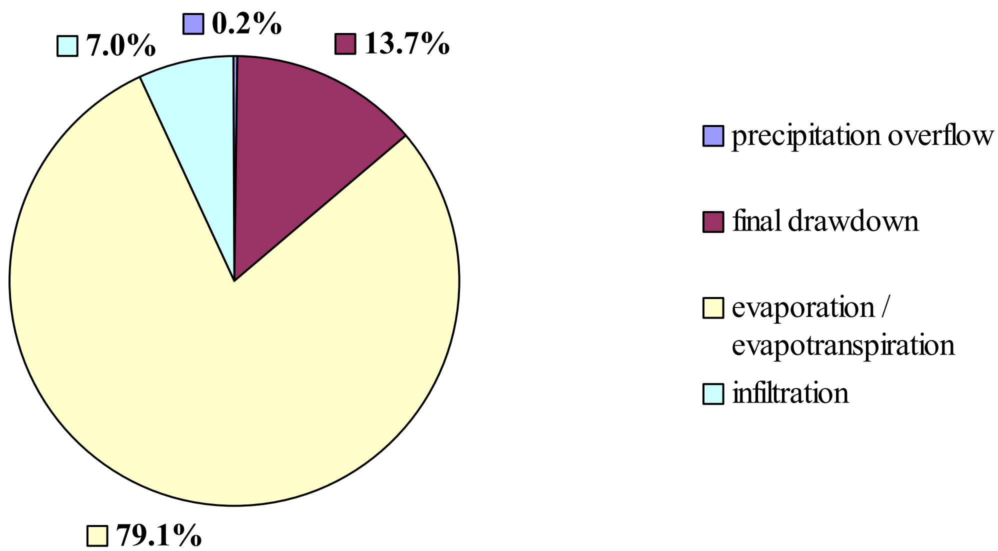


A. Production Cycle Water Loss 246 cm

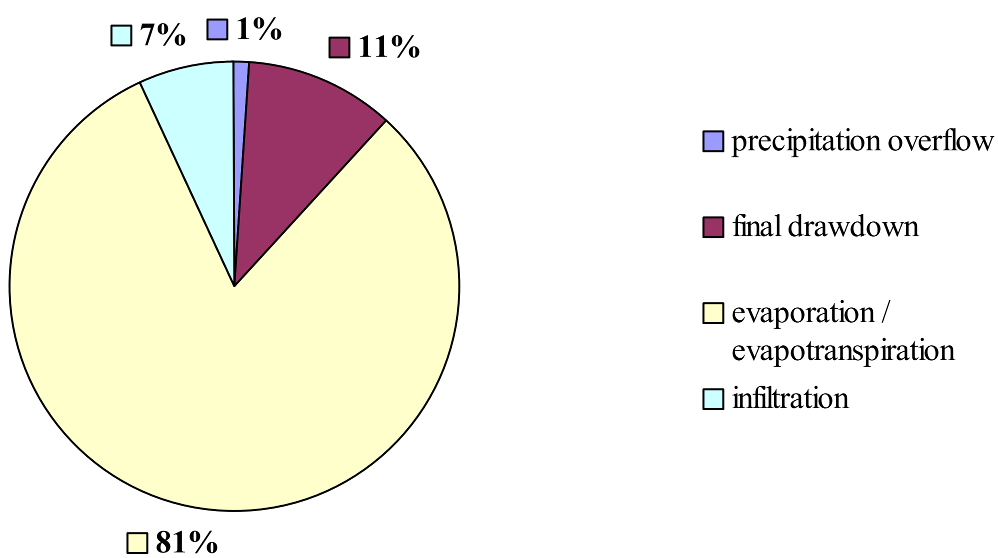


B. Production Cycle Water Loss 317 cm

Figure 3.16. Double-crop rice/crawfish production cycle water loss estimates based on model results for the southwest region (A). Double-crop rice/crawfish rotational water loss estimates based on model results for the southwest region (B). Precipitation used for the southwest region was based on 1992-1993 high precipitation years.



A. Production Cycle Water Loss 185 cm



B. Production Cycle Water Loss 236 cm

Figure 3.17. Double-crop rice/crawfish production cycle water loss estimates based on model results for the southwest region (A). Double-crop rice/crawfish rotational water loss estimates based on model results for the southwest region (B). Precipitation used for the southwest region was based on 1999-2000 low precipitation years.

The major sources of effluent from crawfish ponds were during winter and during the summer drawdown period. Predicted deficits and overflow for all three crawfish production systems for high, average, and low precipitation years are presented in Figures 3.18 – 3.23. Predicted overflow for extreme high and low precipitation years are presented in Figures 3.22 – 3.23. Light colored bars represent shallow flood for rice. Dark colored bars represent full flood for crawfish production. The top of the standpipe is represented by the 0 cm axis. All light and dark bars below the 0 cm axis represent a deficit (water level at or below top of drain pipe), all light and dark bars above 0 cm axis represent precipitation overflow.

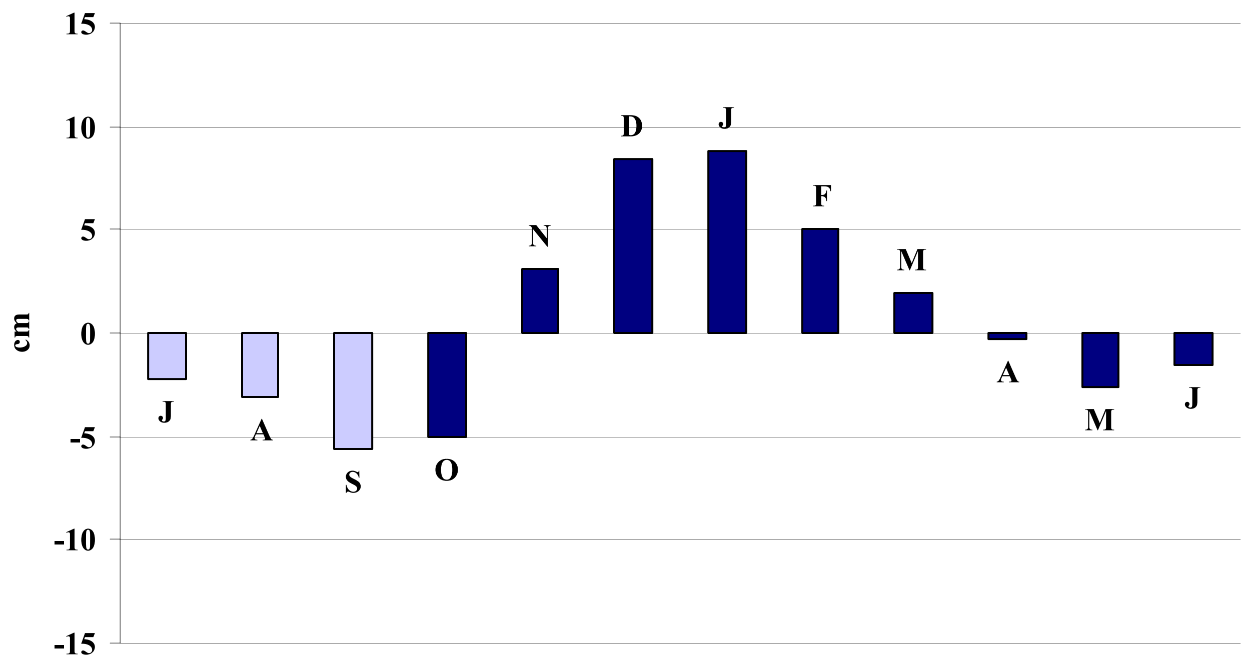


Figure 3.18. Aquaculture Research Station average precipitation year (based on 1971-2000 precipitation normals). Pond overflow for a single-crop crawfish system.

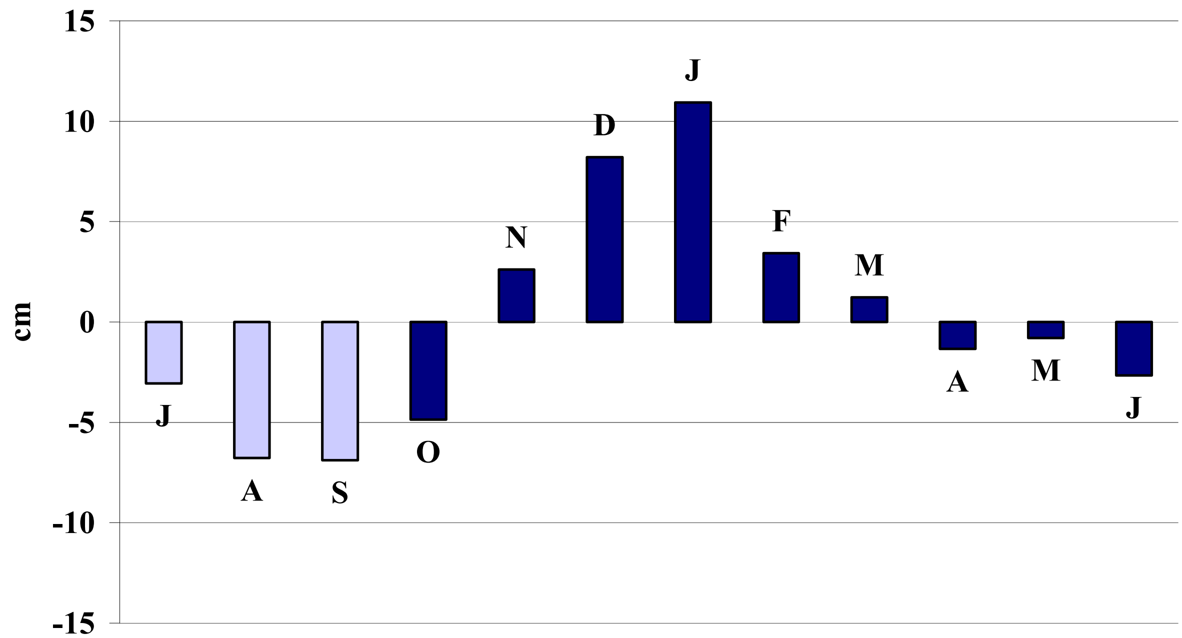


Figure 3.19. Rice Research Station average precipitation year (based on 1971-2000 precipitation normals). Pond overflow for a single-crop crawfish system.

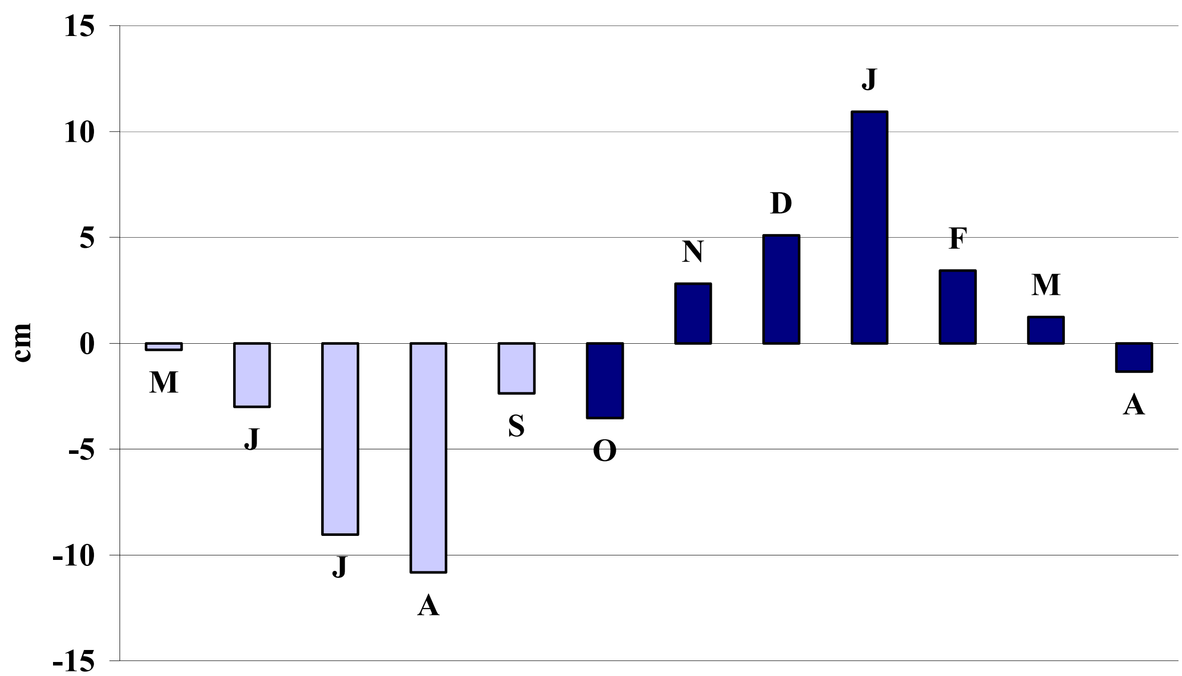


Figure 3.20. Rice Research Station average precipitation year (based on 1971-2000 precipitation normals). Pond overflow for a double-crop rice/crawfish system.

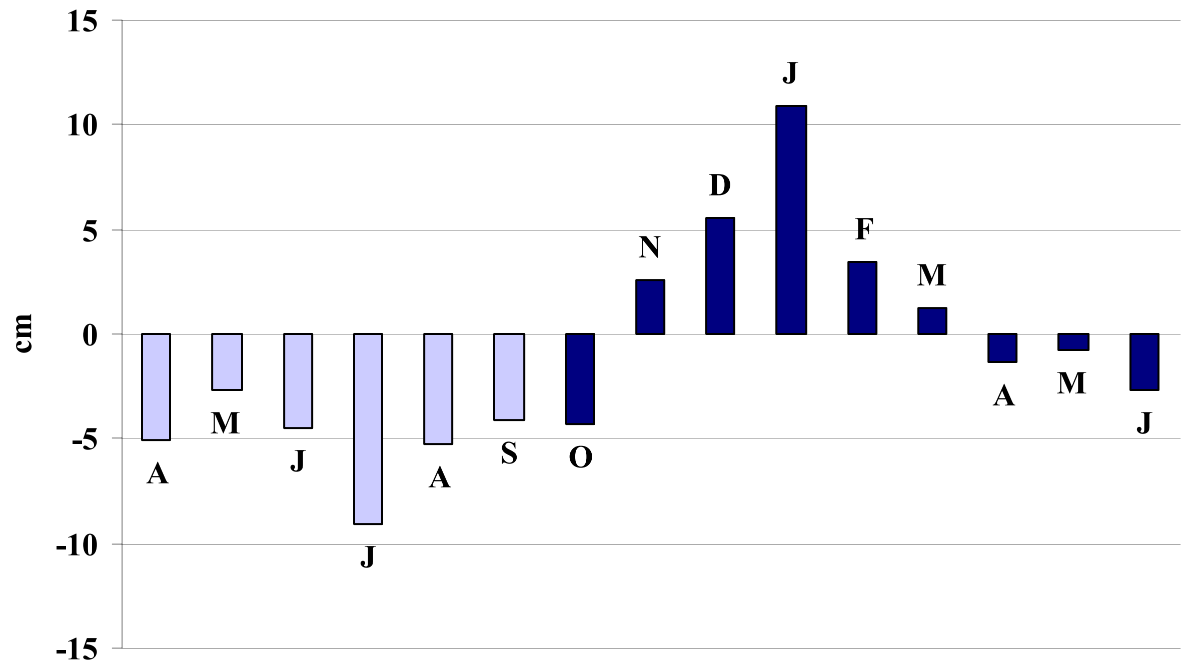


Figure 3.21. Rice Research Station average precipitation year (based on 1971-2000 precipitation normals). Pond overflow for a double-crop rice/crawfish rotational system.

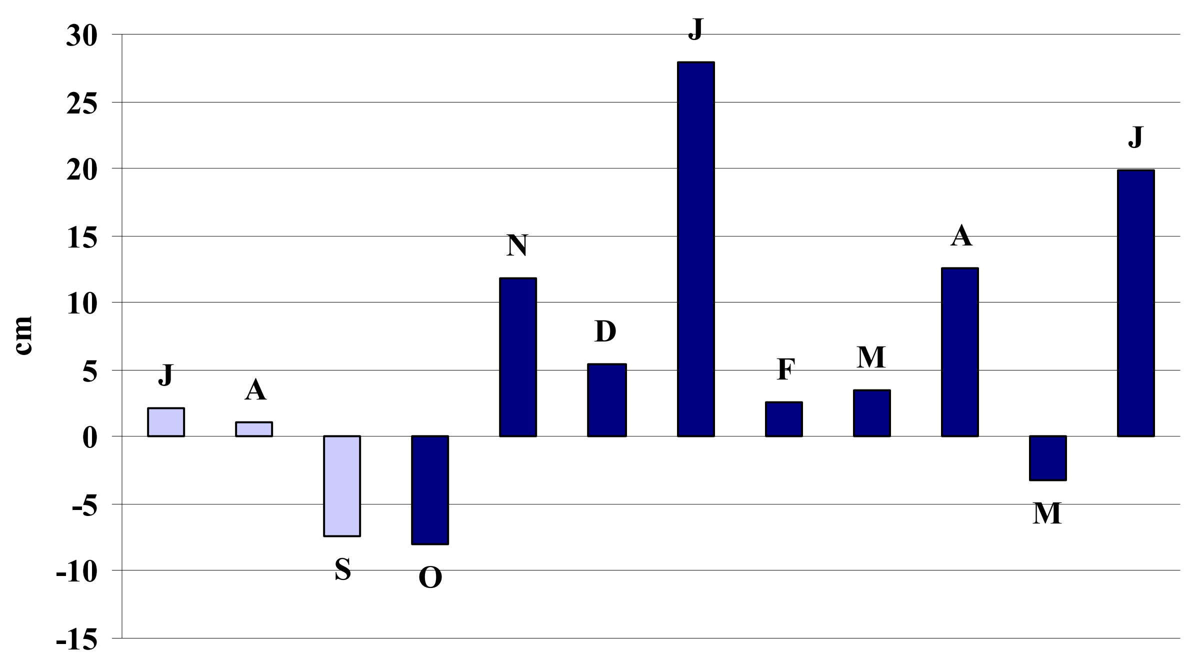


Figure 3.22. Rice Research Station high precipitation during production season (1992-1993). Pond overflow for a single-crop crawfish system.

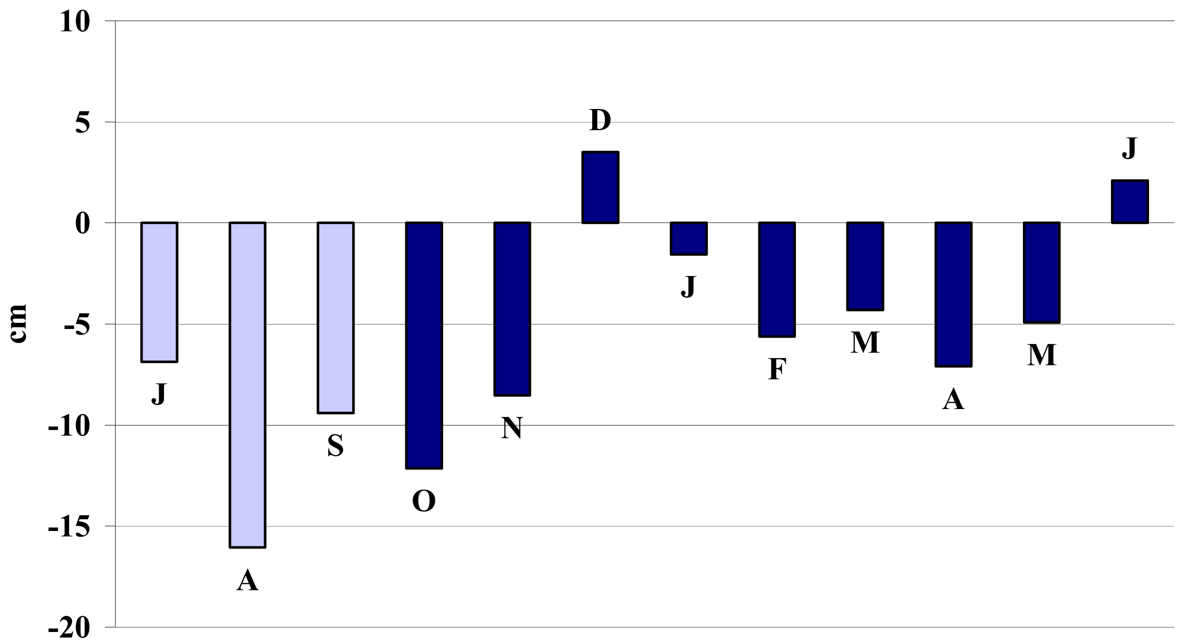


Figure 3.23. Rice Research Station low precipitation during production season (1999-2000). Pond overflow for a single-crop crawfish system.

Discussion

Modeling uses variables to make past, current, or future predictions (e.g. water overflow in an average precipitation year for a single-crop crawfish system). This study developed three models that represented the three typical crawfish production systems in Louisiana. When comparing model generated discharge and actual discharge over 8 months, the greatest difference occurred within a low precipitation year with a difference of 9 cm (25%). In an average precipitation year, the model generated discharge and actual discharge had a difference of 9 cm as well, but because more water was being compared in the average precipitation year the difference in terms of percent was less (13%).

When accurate precipitation data are not available for the area of interest, the difference may be greater between the model generated discharge and actual discharge. When modeling, it

is important to use reliable data. As the distance increases between the site where precipitation is recorded and the area of interest, more error will likely occur because there are very few places where precipitation is distributed evenly spatially and temporally throughout the year. Furthermore, when moving from annual to monthly to daily precipitation variability increases in similar order (Boyd and Yoo 1994).

For a single-crop crawfish system (time of rice planting until drainage) precipitation exceeded evaporation, evapotranspiration, and infiltration for average and high precipitation years. For a double-crop rice/crawfish and a double-crop rice/crawfish rotational system (time of rice planting until drainage) evaporation, evapotranspiration, and infiltration combined exceeded precipitation for average and low precipitation years. Evaporation and evapotranspiration combined accounted for the highest water loss within all three production systems (average of 68%), ranging from half to three quarters of total water loss. Typically, November through March is when most overflow occurred because precipitation exceeded evaporation, evapotranspiration, and infiltration during these months for all three production systems. After initial October flooding, the majority of pond volume was typically maintained by precipitation during average and high precipitation years under a 0 cm storage capacity. Furthermore, pumping costs and effluents could be reduced even more by creating a storage capacity of 5 cm to 15 cm.

According to the water discharge models, the amount of precipitation received during a crawfish production season makes a substantial difference in where most of the water loss takes place: during the production cycle or during final drawdown. For both locations (southwest and south-central) modeled under a 0 cm storage capacity, the amount of annual precipitation determined whether or not more water was lost from precipitation overflow (unintentional) or

from final drawdown (intentional). An average 48% of all water discharged in an average precipitation year was unintentional; an average 71% of all water discharged in a high precipitation year was unintentional; and an average 12% of all water discharged in a low precipitation year was unintentional.

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Chapter 4

Effluent Discharge

Introduction

Louisiana's Water Quality Inventory Reports indicate that there are still pollution problems that exist in many of the state's rivers, lakes, and estuaries. Louisiana Department of Environmental Quality (LDEQ) and the United States Environmental Protection Agency (USEPA) Region 6 in Dallas are working together to develop Total Maximum Daily Loads (TMDLs) for those water bodies that are impaired because of pollution. The ultimate goal of the LDEQ and USEPA is to manage and control pollution to put Louisiana's waters back to their designated uses by the year 2015, but acknowledges that to do so it will need "the cooperation of all of the people that live within the watershed or have management responsibilities for the lands and the water bodies that comprise it (LDEQ 2000)." This environmental concern is the primary reason behind the second objective of this thesis: final drawdown effluent quality and seasonal mass loading of solids and nutrients.

Water quality from 17 commercial crawfish ponds in southern Louisiana were characterized in 1991-1992 (Orellana 1992), and the samples were taken seasonally (fall, winter, spring, summer) and represented discharge only during "non-precipitation" events. This study set out to develop a complete picture of crawfish pond effluents by (1) developing water discharge models, (2) characterizing final drawdown effluent quality and seasonal mass loading of solids and nutrients based on Orellana's data and this study's modeled water discharge, and (3) identifying Best Management Practices (BMPs) that could reduce effluent discharge and improve effluent quality. Also, crawfish pond solid concentrations during the summer drawdown period were investigated for the first time in this study. Previous data in combination with the

results of this study's objectives would assist in characterizing mass loading potential of solids and nutrients released from Louisiana crawfish ponds. This data is important to LDEQ to ascertain the contribution of crawfish aquaculture to Total Maximum Daily Loads (TMDLs) for Louisiana. All land use categories within the state (e.g. agriculture or industry) discharge a certain amount of pollutants.

In the 1987 amendment of the Clean Water Act (CWA), section 319 mandated that states address issues related to nonpoint sources of pollution. Section 319 also requires states to identify the land-use categories that are the sources of non-point pollution that contribute to these water quality impairments. Eight categories were created: agriculture, forestry, urban, construction, home sewerage systems, hydromodification, resource extraction, and saltwater intrusion, which collectively contribute sediments, nutrients, bacteria, carbon, and other oxygen demanding substances impairing water bodies across the state (LDEQ 2000).

Nutrients, solids, and organic matter in crawfish pond effluents have the potential to negatively influence the environment if they are discharged at a rate that surpasses the capacity of the receiving waters to assimilate or treat the discharged matter. From the evaluated water bodies in the nation, approximately 40% of impairment in rivers, 51% in lakes, and 57% in estuaries are due to nutrient enrichment from TN and TP (Kubasek and Silverman 2002). However, pond waters discharged at a time of low flow in receiving streams may not necessarily result in a negative ecological impact (Tucker et al. 2002).

Although crawfish farming is an important agricultural industry in Louisiana, it accounts for a small portion, 0.3%, of Louisiana's total land area. In 2001, there were approximately 34,251 ha of crawfish ponds in the state of Louisiana, and the 1997 National Resource Inventory for Louisiana (most recent report for total land use in state) puts Louisiana's total surface area at

12,697,791 ha (LCES 2002; NRCS 2000) (Fig. 4.1). Nearly 90% of the crawfish aquaculture area is located in two impaired water basins – Mermentau and Vermilion-Teche river basins – both located in southwest and south-central Louisiana.

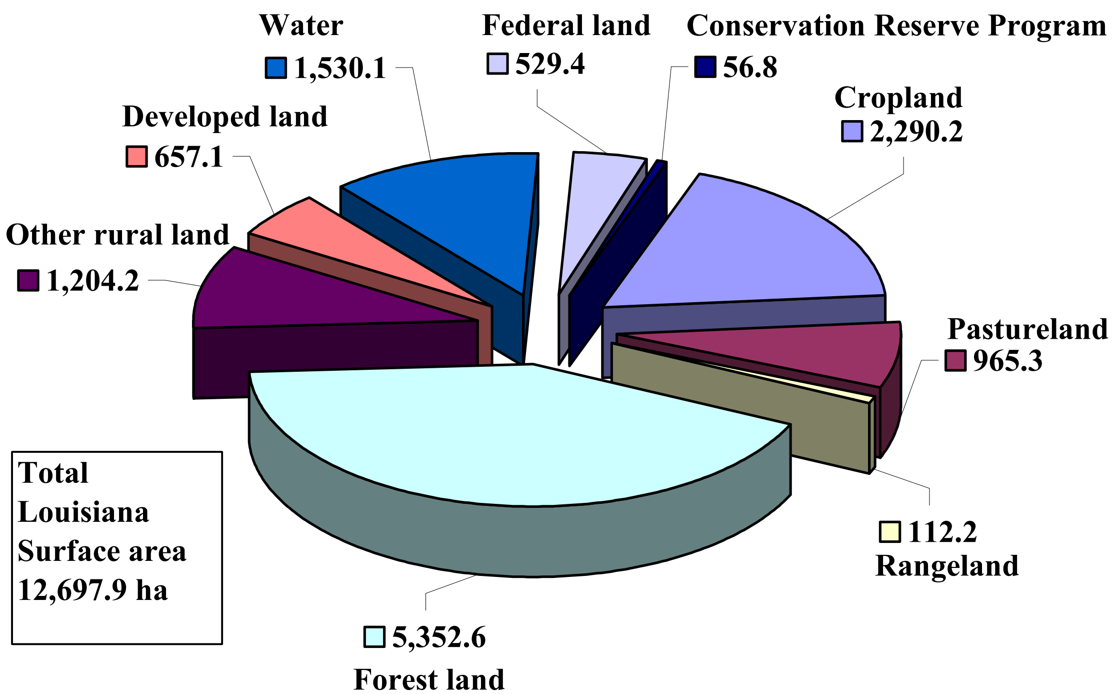

Figure 4.1. Natural Resource Inventory for Louisiana (1997) in thousands of hectares. Crawfish pond surface area represents 1.5% of cropland area.

Total suspended solids (TSS), total phosphorus (TP), and ammonia constitute the highest concentrations of channel catfish pond effluents relative to water quality criteria in NPDES permits (Schwartz and Boyd 1994). Nutrients that are released in the discharge of pond waters, while dilute and at lower levels than municipal treatment plant discharges, contribute to overall nutrient loading (Engle and Valderrama 2002). This contribution to overall receiving stream nutrient loading is important, especially in relation to Total Maximum Daily Loads (TMDLs). A result of organic nutrient loading is an increased oxygen demand in waters downstream from the effluent pipe, solids may settle out downstream of the effluent pipe, and nitrogen and phosphorus

may stimulate algal blooms in the waters downstream from the discharge point (SRAC 1998). Over 2 years, samples were taken from 25 commercial catfish ponds in Alabama and 75% of the samples exceeded the TSS limit, 80% exceeded the TP limit, 25% exceeded the ammonia limit, and 2% exceeded the carbonaceous biochemical oxygen demand (CBOD) limit (Schwartz and Boyd 1994). Catfish ponds contain high amounts of solids due to seining and fish activity in the last 10% to 20% of the effluent discharge (SRAC 1998). Furthermore, the USEPA found concentrations of solids, nutrients, and organic matter in pond effluents during final drawdown can be relatively high during the initial 5% of the draining period and the last 20% of the draining period (USEPA 2002).

Water quality from 17 commercial crawfish ponds in southern Louisiana were characterized in 1991-1992 (Orellana 1992). The ponds generally met the National Pollutant Discharge Elimination System (NPDES) discharge limits for pH and settable solids, and most often exceeded minimal dissolved oxygen (DO), turbidity, and TSS effluent discharge limits (Orellana 1992). The concentrations of effluents were higher in the spring and summer than the fall and winter, and the summer drainage period exhibited poorest effluent quality; furthermore the type and quantity of vegetative foliage established in the pond had a significant influence on the quality of the water discharged from the crawfish ponds (e.g. pond with volunteer vegetation had lower concentrations of nutrients and solids than ponds with rice or sorghum-sudan grass). The discharge samples in Orellana's study were taken seasonally (fall, winter, spring, summer) and represented discharge only during "non-precipitation" events (Orellana 1992). Effluents have also been evaluated from several different types of ponds in Florida including: catfish, tilapia, alligator, and crawfish (Cichra and Shireman 1990). Carbonaceous biochemical oxygen demand (CBOD), chlorophyll a, TSS, fecal coliform (FC), total kjeldahl nitrogen (TKN), total

ammonia nitrogen (TAN), nitrite-nitrogen, nitrate-nitrogen, TP, pH, temperature, and DO were measured (Cichra and Shireman 1990). The study concluded that solids and nutrients and oxygen demand were sufficiently low, having no deleterious impact on Florida's receiving waters.

Total Maximum Daily Loads

A TMDL is a pollution budget for a given waterbody. A TMDL estimates the sum of allowable point pollution (e.g. sewage treatment plants, industrial sites, and aquaculture ponds) and nonpoint pollution (e.g. agricultural runoff) that can be released into a waterbody without causing the waterbody to become impaired or violate water quality standards (Borel 2001).

Total Maximum Daily Loads were created under the Federal Water Pollution Control Act (FWPCA) of 1972 and focused mainly on point sources of pollution; it should be noted that prior to TMDLs there were other established technologies and controls in place for handling point source pollution. As a result, point sources of pollution have been controlled to such a degree that the remaining pollution comes largely from nonpoint sources (Kubasek and Silverman 2002). In addition, LDEQ also reports that point source pollution in Louisiana has been greatly reduced through the NPDES (LDEQ 2000).

Non-governmental organizations have initiated legal actions against the USEPA seeking a listing of impaired water bodies as well as the development of TMDLs as required in the FWPCA of 1972. The USEPA Region 6 is required by court order to establish 1,711 TMDLs for 349 water bodies in Louisiana over 7 years (1999-2007), and LDEQ has, through an agreement with the USEPA, received primary responsibility for the development of those TMDLs by 31 December 2007 (Borel 2001). Nonpoint pollution originates from a variety of sources, which in combination can result in significant pollution. The USEPA estimates between 50% and 70% of

impaired or threatened surface waters are influenced by nonpoint agricultural runoff with urban runoff adding another 5% to 10% (Kubasek and Silverman 2002).

Solid and Nutrient Dynamics in Pond Aquaculture and the Environment

A multi-year study of pond effluent from channel catfish, crawfish, and hybrid striped bass ponds in the southeast found that TSS, TP, and possibly TN have the greatest potential negative impact to the environment (SRAC 1998).

The major concern with solids that are discharged from aquaculture ponds is on the oxygen demand associated with the decomposition of the organic solid fraction. Concentrations of TSS of an algal origin in fish ponds are highest during the summer and fall, but this is when discharge is usually low due to low precipitation. During the winter and spring, streams in the southeastern US have high concentrations of inorganic suspended solids derived from topsoil erosion from fallow fields and other areas (Tucker et al. 2002). Total nitrogen and TP in catfish pond effluent are contained in dissolved organic matter or particulate matter because there is little ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen relative to total Kjeldahl-nitrogen (organic nitrogen) (Tucker et al. 2002). Concentrations of inorganic nitrogen can vary greatly in natural waters and are seldom high in unpolluted waters. Organic nitrogen is present in the form of living and dead particulate organic matter, and concentrations of organic nitrogen are usually below 1 mg/L in unpolluted natural waters. In some fish ponds, plankton blooms are heavy, and can have concentrations of organic nitrogen as high as 2 mg/L or 3 mg/L. Nitrogen is assimilated by plants or deposited into pond muds as a component of organic matter (Boyd 1996).

Phosphorus is an important metabolic nutrient and the supply of this nutrient often dictates the productivity of natural waters. In fact, most natural waters increase plant production after the addition of phosphorus. Concentrations of phosphorus in waters are usually low, the

concentration of TP seldom exceeds 1 mg/L in natural waters. In fertilized fish ponds in Alabama, TP averaged 0.17 mg/L. Phosphorus is a minor constituent in water, but its biological importance is great and often it is considered the element that most frequently limits productivity in aquatic ecosystems (Boyd 1996).

Mass Loading

Generic effluent management practices can be applied for aquaculture effluents regardless of the species being produced to reduce overall mass loading. In a report published by the Southern Regional Aquaculture Center, the following generic effluent management practices were recommended to reduce mass loading for aquaculture ponds: "use high quality feeds and efficient feeding practices; provide adequate aeration and circulation of pond water; minimize water exchange; if water must be exchanged in ponds, consider reusing the effluent for some other purpose, such as irrigating terrestrial crops; reuse water that is drained from ponds whenever possible; maintain some storage volume in ponds to capture precipitation and reduce overflow; optimize watershed areas to reduce excessive discharge; and consider treating effluents by using constructed wetlands (SRAC 1998)."

The USEPA (2002), concluded that aquaculture ponds typically do not have continuous discharge, discharging only during storm events or at final drawdown. Furthermore, most aquatic animal producers minimize water use because water is a valuable asset. Most importantly, the USEPA found that earthen ponds have the ability to, when operated within the limits of their carrying capacity, remove over 90% of solids, phosphorus, and BOD, and over 70% nitrogen. Mechanical aeration aids the natural assimilative processes within ponds by raising oxygen levels and mixing the water. When the ponds are drained, the pollutant loads are "likely to have been significantly reduced or contained within the sediment at the bottom of the pond."

Therefore, during final drawdown, it is important to minimize disturbance of the sediments at the bottom of the pond because that will ensure that the water discharged is of high quality (USEPA 2002). All of the above mentioned, assist in reducing mass loading.

Methods

Eight experimental crawfish ponds were sampled from 18 June 2002 through 30 July 2002 during the final drawdown phase in summer. At the Rice Research Station (RRS), 4.9 ha consisting of 11 small ponds on each side of a lateral water supply were sampled; since all the ponds were connected by a common water supply and had two central drainage structures from which the samples were taken and then averaged it was treated as one pond. Six ponds totaling 10.8 ha at the Aquaculture Research Station (ARS), and one 1.9 ha pond at the University of Louisiana at Lafayette (ULL). Locations for sites are: ARS, LSU Agricultural Experiment Station, East Baton Rouge Parish, latitude 30.37^o, longitude 91.17^o; RRS, LSU Agricultural Experiment Station, Acadiana Parish, latitude 30.25^o, longitude 92.37^o; and ULL, The University of Louisiana at Lafayette Model Sustainable Agricultural Complex, St. Martin Parish, latitude 30.05^o, longitude 91.52^o. These locations were sampled to characterize summer drawdown solids. In all eight ponds, a minimum of nine depth measurements were taken (three depth measurements uniformly spaced over one transect; three transects per pond) to estimate water volume within each pond 24 hours prior to the beginning of the end-of-season drawdown. Pond volume was determined by multiplying average depth by pond area.

The pond at the RRS (4.9 ha) was drained over 3 d (18 June 2002 – 20 June 2002) for a total drain time of 54.5 h. Two 20.3 cm diameter corrugated pipes, maintaining water level on opposite sides of the pond, were lowered to drain the pond. Each drain pipe represented a sampling location. Discharge during the initial stage of pond draining (approximately 45 sec

after the drain pipe was lowered) and at 50%, 20%, 10%, and 5% of remaining pond volume was collected. Collections were taken at the opening of the discharge pipe on the discharge side of the levee. At the 50% pond volume, a sample was taken at the discharge pipe, 268 m, 536 m, and 805 m from the drain pipe to measure solid concentrations in a non-vegetated receiving ditch.

Six ponds from the ARS (1.42 ha, 1.89 ha, 1.42 ha, 1.99 ha, 2.19 ha, and 1.86 ha) were each drained in approximately 40 h. The first 50% of each pond volume was removed on 9 July 2002 – 10 July 2002 by lowering the PVC drain pipe (90^{o} swivel elbow) into the pond until the bottom edge of the drain pipe was 20.3 cm below the water surface. The remaining 50% was removed on 21 July 2002 by lowering the drain pipe to the pond bottom. Each pond had one 25.4 cm diameter drain pipe, which represented a sampling location. Discharge during the initial stage of pond draining (approximately 45 sec after the drain pipe was lowered) and at 50%, 20%, 10%, and 5% of remaining pond volume was collected. Samples were taken at the opening of the discharge pipe on the discharge side of the levee. At the 0% and 50% drawdown stages, samples were taken from the discharge pipe, upstream from discharge (control), then downstream where effluent from the five ponds converged; and then 268 m, 536 m, and 805 m from the confluence point down a semi-vegetated ditch.

The pond at ULL (1.9 ha) was drained on 30 July 2002 over approximately 7 h. The pond had one 45.7 cm diameter drop pipe that connected into a 38.1 cm diameter drain pipe with a 90^{o} bend that discharged into a receiving stream. Discharge during the initial stage of pond draining (approximately 45 sec after the drain pipe was lowered) and every 15 min after the initial sample (96%, 93%, 90%, and 86% pond volume) was measured. Discharge was also collected during 80%, 50%, 20%, 10%, and 5% of remaining pond volume at the opening of the discharge pipe

on the receiving ditch side of the levee. At the 0%, 50%, and 20% pond volume, a sample was taken from the receiving steam at 268 m, 536 m, and 805 m from the drain pipe to measure the effects a vegetated ditch has on solid concentrations.

Each water sample obtained was analyzed for the following parameters from Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA 1998): total solids, total volatile solids, total dissolved solids, total suspended solids, and particulate organic matter. Monthly water discharge from the modeling portion of this study (Chapter 3) was combined with Orellana's seasonal water quality data for fall, winter, spring, and summer for TN, TP, and BOD_5 to predict seasonal mass loading. In addition, Orellana's data for TSS from fall, winter, and spring was combined with this study's summer TSS measurements, averaged from the ponds at the three study sites, to estimate mass loading of this parameter. Mass loading of TN, TP, BOD_5, and TSS, was calculated by multiplying predicted seasonal water discharge by the analytical concentration of the defined parameter (mass loading = volume x concentration). Orellana derived his seasonal analytical concentrations for TN, TP, TSS, and BOD_5 by averaging samples taken from crawfish ponds with rice, sorghum-sudan grass, and native vegetation.

Results

Final Drawdown

Summer had the highest levels of solids due primarily to the complete draining of the ponds. A process that scours the pond bottom of sediments and nutrients (Fig. 4.2-4.9). The average TSS concentration in effluent for summer drawdown for all ponds sampled in this study was 332 mg/L; Orellana (1992) reported an average TSS concentration of 377 mg/L for the summer season for all ponds sampled.

ARS Pond D-1 Solids Over Time at Drain Pipe

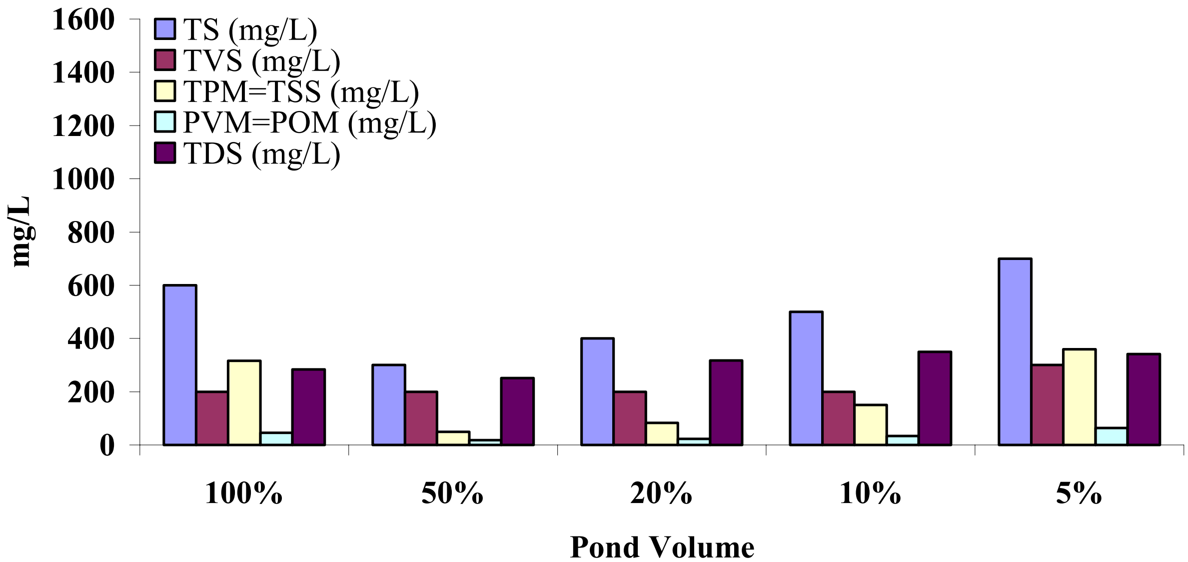

Figure 4.2. Aquaculture Research Station pond D-1 samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

ARS Pond D-2 Solids Over Time at Drain Pipe

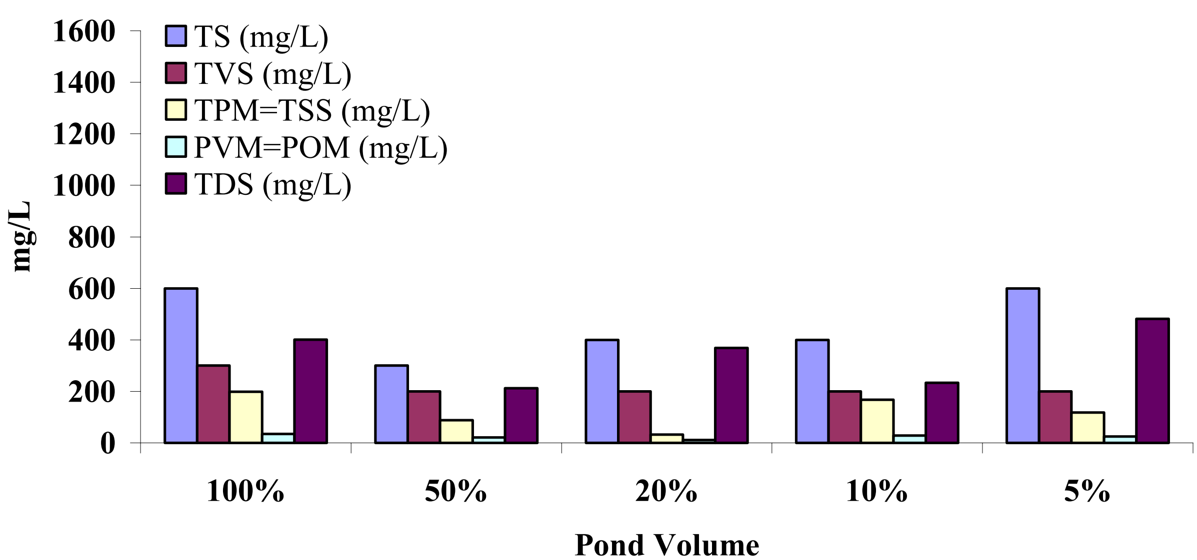

Figure 4.3. Aquaculture Research Station pond D-2 samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

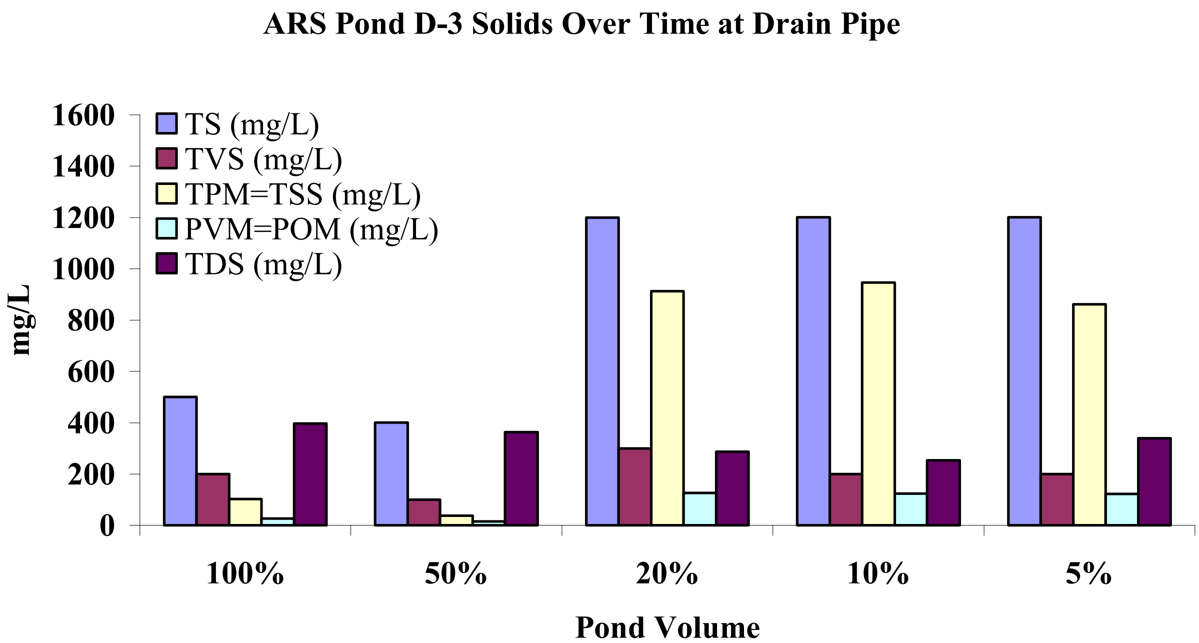

Figure 4.4. Aquaculture Research Station pond D-3 samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

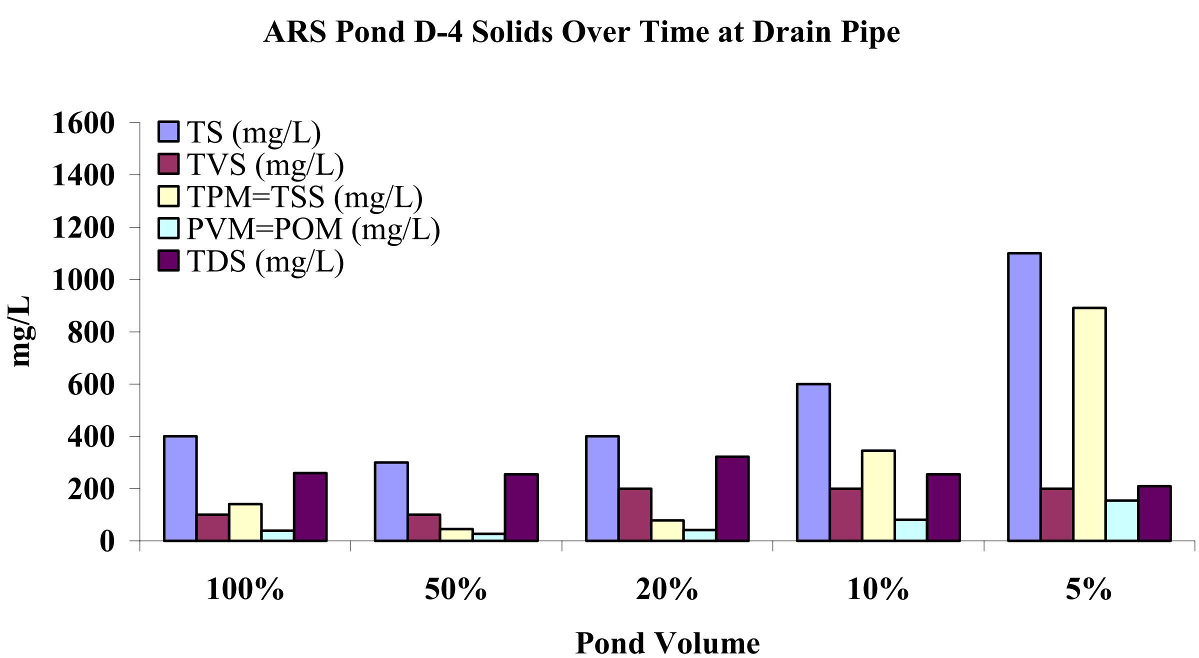

Figure 4.5. Aquaculture Research Station pond D-4 samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

ARS Pond D-5 Solids Over Time at Drain Pipe

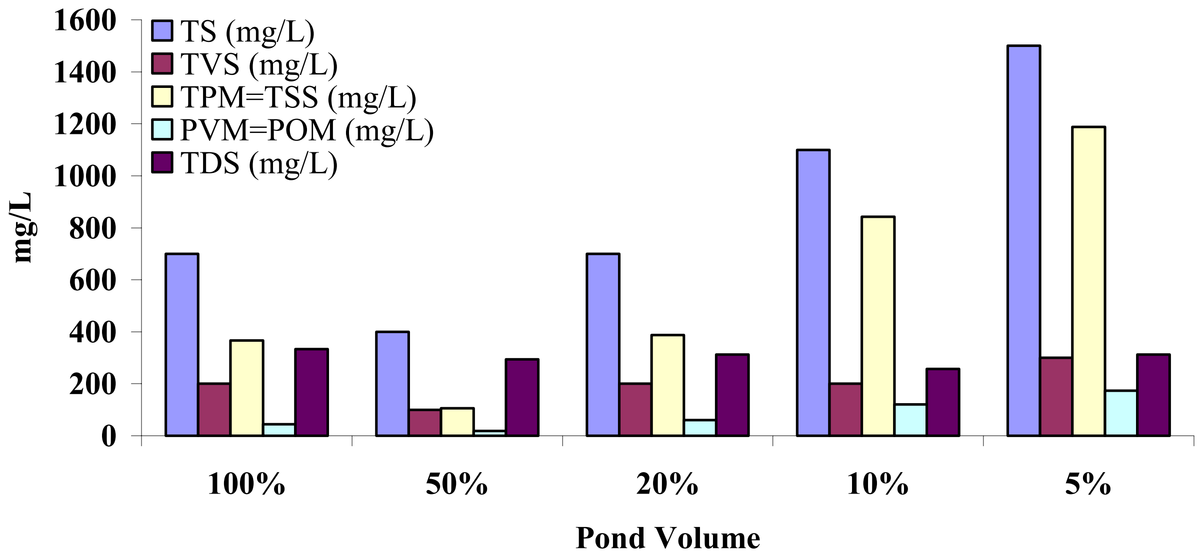

Figure 4.6. Aquaculture Research Station pond D-5 samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

ARS Pond D-6 Solids Over Time at Drain Pipe

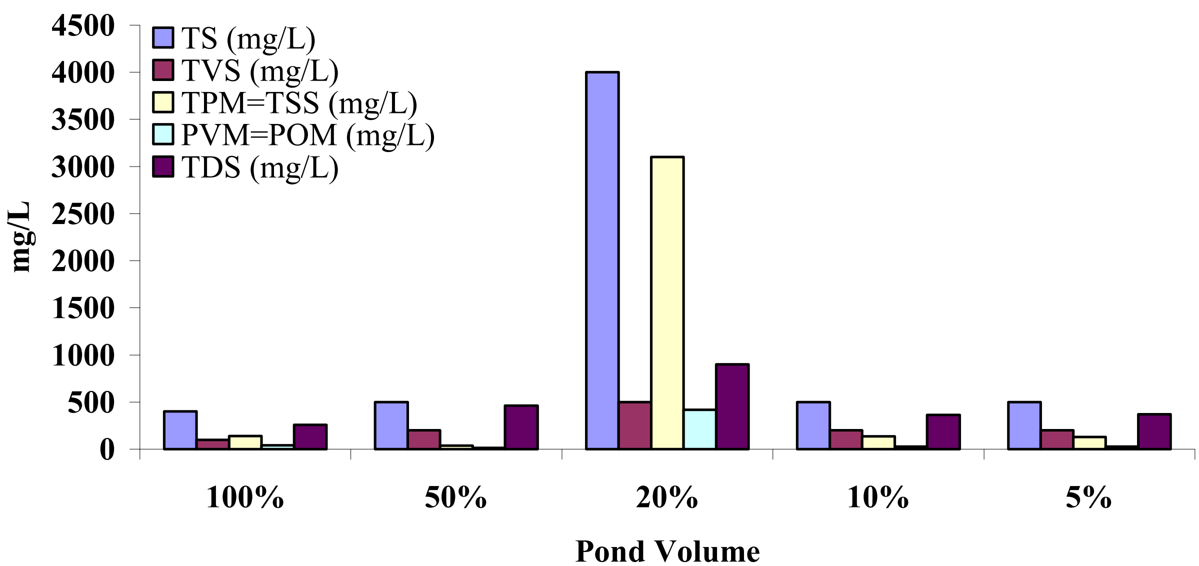

Figure 4.7. Aquaculture Research Station pond D-6 samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

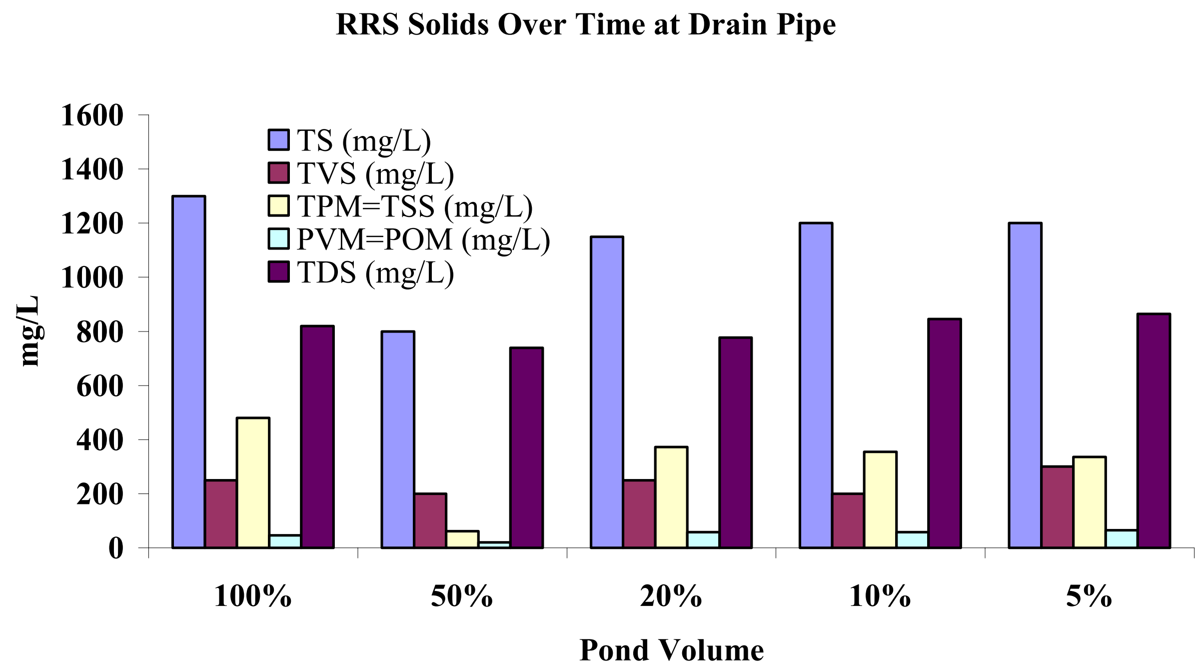

Figure 4.8. Rice Research Station samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

ULL Solids Over Time At Drain Pipe

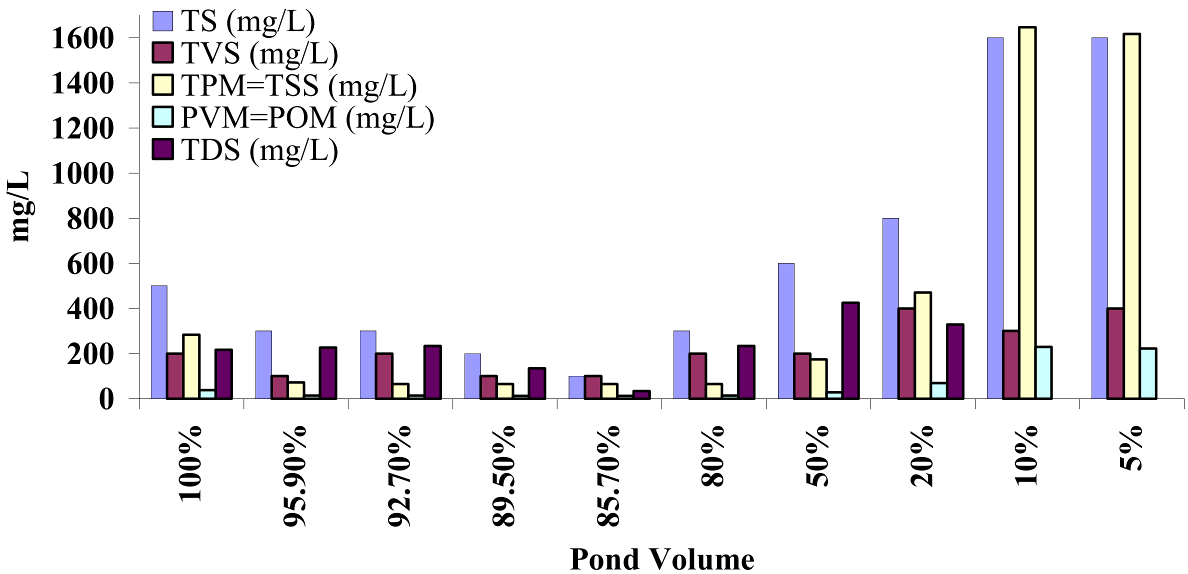

Figure 4.9. University of Lafayette in Louisiana samples taken over time according to pond volume. Total solids (TS), total volatile solids (TVS), total suspended solids (TSS), particulate organic matter (POM), total dissolved solids (TDS), and dissolved organic matter (DOM).

Figure 4.10. Picture on the left shows the first few seconds of draining at the University of Lafayette in Louisiana. The picture on the right shows water quality after 7% of the pond volume was discharged.

During the summer drawdown phase, TSS most often exceeded LDEQ's municipal effluent limits for receiving streams. In every pond sampled, the greatest proportion of the TSS consisted of inorganic material (Fig. 4.2-4.9). The first few seconds (or first few percent of pond volume) have the highest levels of solids during final drawdown (Fig 4.10). In the above illustrated ULL case even more so, a backhoe tractor was needed to remove built up sediment from around the drop pipe in order to remove the drop pipe rings. Regardless, discharge cleared within a matter of minutes, and then represented bulk pond water until the last 20% of the pond volume was reached. The diameter of the ULL drain pipe was 38.1 cm. The drain pipe's wide diameter and its opening at the bottom of the pond created a great deal of head pressure which pulled sediment far from across the pond.

<u>Seasonal Effluent</u>

Winter and summer had the greatest predicted mass loading for all three crawfish production system's found in Louisiana. This was expected as the winter overflow is driven by

the high amounts of precipitation usually occurring during this season in Louisiana (Tables 4.1-4.8), and mass loading was high during summer because of the summer drawdown phase.

Table 4.1. Predicted seasonal mass loading of total nitrogen, total phosphorus, and total suspended solids (kg/ha-production cycle of pond surface area) for all six Aquaculture Research Station single-crop crawfish ponds (26.6 ha). No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Total Nitrogen (as N)						
Fall	0.94	0.1	0.15	0	0.73	0
Winter	3.12	2.71	7.52	5.99	0.47	0
Spring	0.22	0.22	1.14	0.45	0	0
Summer	10.89	10.89	10.89	10.89	10.89	10.89
Total	15.17	13.92	19.70	17.33	12.09	10.89
Total Phosphorus (as P)						
Fall	0.12	0.01	0.02	0	0.1	0
Winter	0.56	0.49	1.35	1.08	0.08	0
Spring	0.02	0.02	0.12	0.05	0	0
Summer	2.18	2.18	2.18	2.18	2.18	2.18
Total	2.88	2.70	3.67	3.31	2.36	2.18
Total Suspended Solids (TSS)						
Fall	33	3	5	0	26	0
Winter	223	194	538	429	34	0
Spring	17	17	90	36	0	0
Summer	1091	1091	1091	1091	1091	1091
Total	1364	1306	1725	1556	1151	1091

Table 4.2. Predicted seasonal mass loading of total nitrogen, total phosphorus, and total suspended solids (kg/ha-production cycle of pond surface area) for a Rice Research Station 12.2 ha single-crop crawfish pond. No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Total Nitrogen (as N)						
Fall	0.88	0.05	1.67	0.57	0.25	0
Winter	3.11	2.68	6.00	6.00	0.20	0
Spring	0.14	0.14	9.31	8.15	0.52	0
Summer	7.78	7.78	7.78	7.78	7.78	7.78
Total	11.91	10.65	24.76	22.50	8.75	7.78
Total Phosphorus (as P)						
Fall	0.11	0.01	0.22	0.07	0.03	0
Winter	0.56	0.48	1.08	1.08	0.04	0
Spring	0.01	0.01	0.96	0.87	0.05	0
Summer	1.56	1.56	1.56	1.56	1.56	1.56
Total	2.24	2.06	3.82	3.58	1.68	1.56
Total Suspended Solids (TSS)						
Fall	31	2	59	20	9	0
Winter	223	192	430	430	14	0
Spring	11	11	738	675	41	0
Summer	688	688	688	688	688	688
Total	953	894	1915	1813	753	688

Table 4.3. Predicted seasonal mass loading of total nitrogen, total phosphorus, and total suspended solids (kg/ha-production cycle of pond surface area) for a Rice Research Station 12.2 ha double-crop rice/crawfish pond. No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Total Nitrogen (as N)						
Fall	0.67	0	1.46	0.37	0.03	0
Winter	2.94	2.25	5.82	5.82	0.02	0
Spring	0.14	0.14	4.36	4.36	0	0
Summer	7.78	7.78	7.78	7.78	7.78	7.78
Total	11.53	10.17	19.42	18.33	7.83	7.78
Total Phosphorus (as P)						
Fall	0.09	0	0.19	0.05	0	0
Winter	0.53	0.40	1.05	1.05	0	0
Spring	0.01	0.01	0.45	0.45	0	0
Summer	1.56	1.56	1.56	1.56	1.56	1.56
Total	2.19	1.97	3.25	3.11	1.56	1.56
Total Suspended Solids						
Fall	24	0	52	13	1	0
Winter	210	161	417	417	2	0
Spring	11	11	346	346	0	0
Summer	688	688	688	688	688	688
Total	933	861	1502	1464	691	688

Table 4.4. Predicted seasonal mass loading of total nitrogen, total phosphorus, and total suspended solids (kg/ha-production cycle of pond surface area) for a Rice Research Station 12.2 ha double-crop rice/crawfish rotational pond. No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Total Nitrogen (as N)						
Fall	0.68	0	1.47	0.38	0.06	0
Winter	2.96	2.29	5.84	5.84	0.05	0
Spring	0.14	0.14	9.31	8.31	0.52	0
Summer	7.78	7.78	7.78	7.78	7.78	7.78
Total	11.56	10.21	24.4	22.31	8.41	7.78
Total Phosphorus (as P)						
Fall	0.09	0	0.19	0.05	0.01	0
Winter	0.53	0.41	1.05	1.05	0.01	0
Spring	0.01	0.01	0.96	0.87	0.05	0
Summer	1.56	1.56	1.56	1.56	1.56	1.56
Total	2.19	1.98	3.76	3.53	1.63	1.56
Total Suspended Solids						
Fall	24	0	52	13	2	0
Winter	212	164	419	419	3	0
Spring	11	11	738	675	41	0
Summer	688	688	688	688	688	688
Total	936	864	1897	1795	735	688

Table 4.5. Predicted seasonal mass loading of 5-day biological oxygen demand (kg/ha-production cycle of pond surface area) for all six Aquaculture Research Station single-crop crawfish ponds (26.6 ha). No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Biological Oxygen Demand						
Fall	2.4	0.2	0.4	0	1.8	0
Winter	6.4	5.6	15.5	12.4	1.0	0
Spring	0.4	0.4	1.8	0.7	0	0
Summer	11.6	11.6	11.6	11.6	11.6	11.6
Total	20.8	17.8	29.3	24.7	14.4	11.6

Table 4.6. Predicted seasonal mass loading of 5-day biological oxygen demand (kg/ha-production cycle of pond surface area) for a Rice Research Station 12.2 ha single-crop crawfish pond. No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Biological Oxygen Demand						
Fall	2.2	0.1	4.2	1.4	0.6	0
Winter	6.4	5.5	12.4	12.4	0.4	0
Spring	0.2	0.2	15.1	13.8	0.8	0
Summer	11.6	11.6	11.6	11.6	11.6	11.6
Total	20.4	17.4	43.3	39.2	13.4	11.6

Table 4.7. Predicted seasonal mass loading of 5-day biological oxygen demand (kg/ha-production cycle of pond surface area) for a Rice Research Station 12.2 ha double-crop rice/crawfish pond. No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Biological Oxygen Demand						
Fall	1.7	0	3.7	0.9	0.1	0
Winter	6.1	4.6	12.0	12.0	0.1	0
Spring	0.2	0.2	7.1	7.1	0	0
Summer	11.6	11.6	11.6	11.6	11.6	11.6
Total	19.6	16.4	34.4	31.6	11.8	11.6

Table 4.8. Predicted seasonal mass loading of 5-day biological oxygen demand (kg/ha-production cycle of pond surface area) for a Rice Research Station 12.2 ha double-crop rice/crawfish rotational pond. No S = pond water level managed with no water storage capacity, S = pond water level managed with storage capacity of 10.2 cm.

	Average yr	Average yr	Wet yr	Wet yr	Dry yr	Dry yr
	No S	S	No S	S	No S	S
Biological Oxygen Demand						
Fall	1.7	0	3.7	0.9	0.2	0
Winter	6.1	4.7	12.1	12.1	0.1	0
Spring	0.2	0.2	15.1	13.8	0.8	0
Summer	11.6	11.6	11.6	11.6	11.6	11.6
Total	19.6	16.5	42.5	38.4	12.7	11.6

By adding 10.2 cm of storage capacity to the model pond, minor reductions could be made in solid and nutrient discharge from capturing precipitation rather than letting it overflow (Table 4.9).

Table 4.9. Percent solids and nutrients could be reduced in ponds sampled if a storage capacity of 10.2 cm (4 in) were added to the pond to reduce unintentional discharge from precipitation. Percentages do not include final drawdown.

	TN	TP	TSS	BOD
Average Precipitation Production Season (30 year normals)	12%	9%	7%	15%
High Precipitation Production Season	10%	7%	6%	11%
Low Precipitation Production Season	8%	5%	6%	11%

Solid and Nutrient Effect on Receiving Streams

The ARS and the ULL both had receiving streams that were vegetated with aquatic and semi-aquatic plants (e.g. cut grass), and the RRS had a dry unvegetated drainage ditch (Fig. 4.11-4.13). At the ARS, the TSS concentration was 22% greater in the receiving stream after the ponds had released 50% of their volume into the stream. At the ULL, TSS concentration was 3% less in the receiving stream after the pond had released 50% of its volume into the stream. Total suspended solids were reduced over a distance of 268 m by 28% at the ARS (wide, shallow, non-vegetated ditch) (Fig. 4.14). Total suspended solids increased over a distance of 268 m by 15% at the RRS (narrow, non-vegetated ditch) (Fig. 4.15). Total suspended solids (TSS) were reduced over a distance of 268 m by 80% at ULL (deep vegetated ditch) (Fig. 4.16).

Figure 4.11. University of Lafayette in Louisiana deep vegetated ditch.

Figure 4.12. Aquaculture Research Station wide, shallow, non-vegetated ditch.

Figure 4.13. Rice Research Station narrow, non-vegetated ditch.

The greatest fraction of solids in the all the ditches sampled after 50% of the pond volume had been discharged was inorganic. The same result was found in the samples taken at the drain pipe. The heaviest of the TS settled out between the drain pipe and the first 268 m of the ditch, and very little increase or decrease in TS took place between the 268 m sample location and the 805 m sample location on the receiving ditch (Fig. 4.11 – 4.13).

The mean annual TSS, TN, and TP concentrations from crawfish ponds in Louisiana (Orellana 1992; this study) are presented in Table 4.10. For comparison purposes, six impaired stream segments – not meeting their designated uses – were averaged monthly from LDEQ's Ambient Water Quality Data Website on 16 September 2002. The Vermilion Teche River Basin segments (Vermilion River North of Intracoastal City, Intracoastal Waterway at mile 170, Vermilion River Cutoff southwest Abbeville) and the Mermentau River Basin segments (Bayou Des Cannes northeast of Jennings, Bayou Plaquemine Brule near Estherwood, Bayou Queue de Tortue north of Gueydan) were used to calculate the averages found in Table 4.10. Much of Louisiana's crawfish aquaculture takes place in these two basins. Although TP levels between crawfish ponds and impaired streams were comparable, TSS and TN were much higher in the crawfish ponds.

Table 4.10. Average concentration (mg/L) of total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) for commercial crawfish ponds and impaired streams in southwest Louisiana.

	TSS	TN	TP
Commercial Crawfish Ponds (mg/L)	186.3	2.26	0.35
Impaired Streams (mg/L)	67.2	1.71	0.30

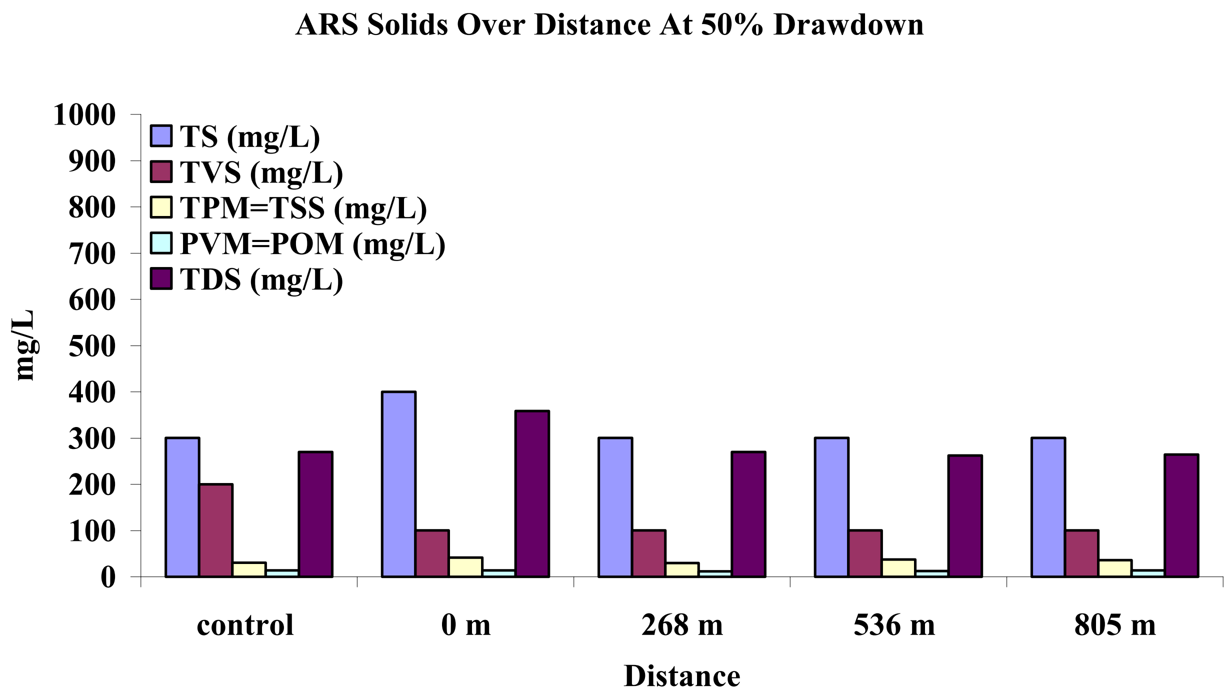

Figure 4.14. Aquaculture Research Station receiving stream solids concentration over distance.

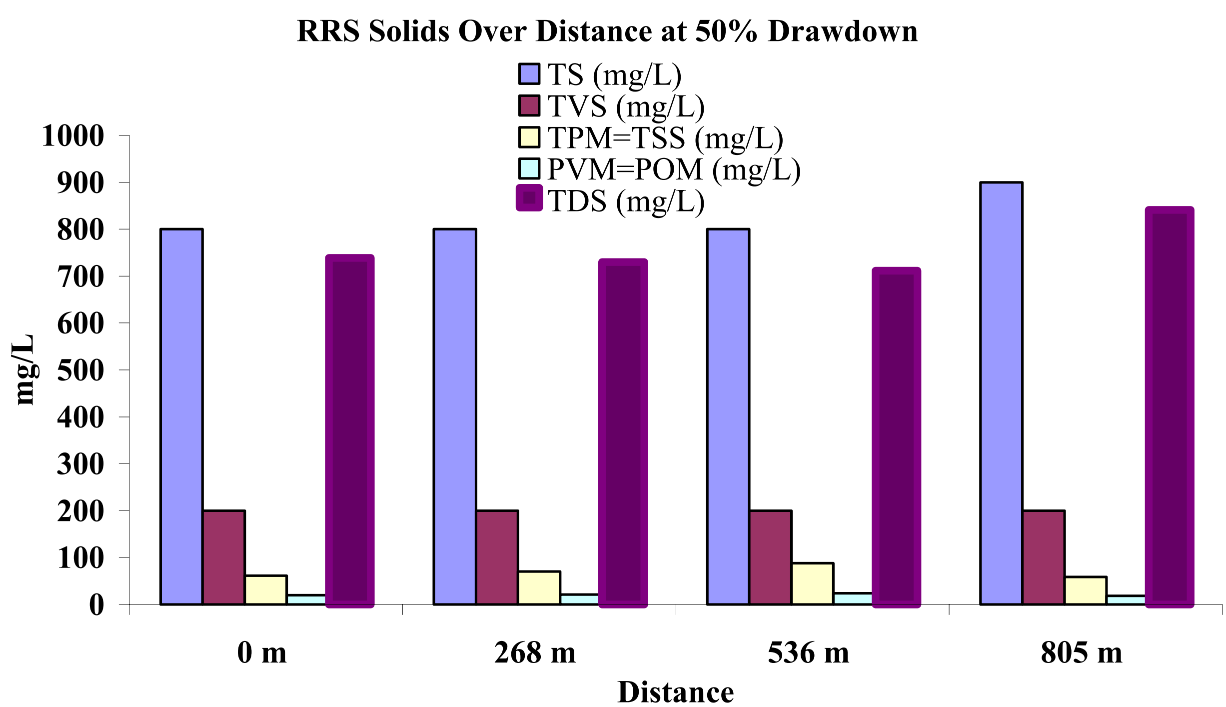

Figure 4.15. Rice Research Station receiving stream solids concentration over distance.

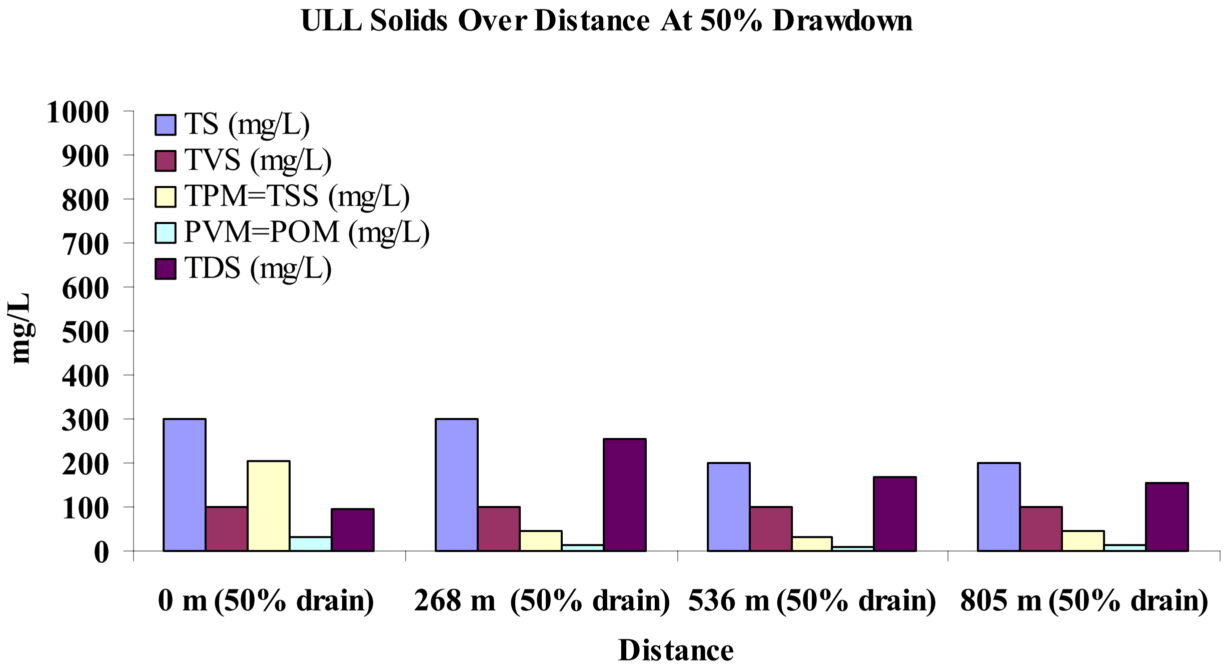

Figure 4.16. University of Lafayette in Louisiana receiving stream solids concentration over distance.

Discussion

Seasonal and Final Drawdown Effluents

Crawfish ponds have similarities with other aquaculture ponds in terms of seasonal precipitation overflow and final drawdown trends. For example, in catfish ponds the quality of potential effluents from season to season and from pond to pond varied considerably with the exception of summer. Generally, solids, organic matter, TP, and TN were the poorest in the summer because of summer's optimal conditions for phytoplankton production; phytoplankton constitutes most of the particulate material in catfish ponds (Tucker et al. 2002). This study found the same pattern to be true for crawfish ponds in southern Louisiana. The two main sources of effluent from catfish ponds are overflow when precipitation exceeds pond storage capacity and discharge during final drawdown (Tucker et al. 2002). The same pattern is apparent in crawfish ponds, and it should be noted that an average year, high precipitation year, or low precipitation year will make a difference in where the majority of water discharge falls during the production season (i.e. during high precipitation events or during final drawdown).

The design of channel catfish levee ponds is similar to that of crawfish ponds. Both are generally constructed with fixed drains extending from the deepest part of the pond, through the levee, and then into a drainage ditch. When draining channel catfish levee ponds, effluent clears in 5 min to 30 min, and after this, effluent quality is identical to the bulk pond water until the last 20% of the pond volume (Tucker et al. 2002). Furthermore catfish pond research reported that nutrient and organic matter concentrations in overflow will never approach levels calculated from the quantities of waste produced by fish because natural processes remove much of the waste from the water before it is discharged (Tucker et al. 2002).

Crawfish pond TSS mass loading is much less than catfish pond TSS mass loading primarily because catfish ponds receive solid input in the form of feed and crawfish ponds receive no feed. Row crop farming lacks the containment and settling characteristics of pond systems and therefore has the highest mass loading values (Table 4.11).

Table 4.11. Crawfish pond total suspended solids (TSS) averaged from predicted mass loading values (Tables 4.1 – 4.4). Catfish pond and row crop mass loading taken from Lutz (2001).

	Crawfish Ponds	Catfish Ponds	Row Crop Farming	
TSS	1,047	3,044	6,738	Kg/ha-yr

For crawfish ponds, effluent quality was found to have the highest concentrations of solids and nutrients during the summer drainage period (Orellana 1992). This was likely a result of phytoplankton and zooplankton production that was favored by warmer temperatures and a longer photoperiod, decomposition of macrophytes, crawfish foraging activities, and crawfish harvesting activates (SRAC 1998). The drainage trend (i.e. pulses of solids relative to pond volume) for crawfish ponds depends on how the ponds are drained and the production system used. Some farmers, e.g. single-crop crawfish farmers, will usually drain their ponds slowly over a few weeks by setting the drain pipe down a few centimeters below the surface. This is usually done for two reasons. First, to allow sufficient time for the crawfish that have not burrowed to begin to do so for reproductive purposes. Second, draining the pond down to a level that just covers the bottom portion of the pond with water allows rice to be flown onto the field (i.e. water seeding method); this marks the beginning of the next production cycle. The rice then soaks for a few days, and then the farmer quickly removes the water from the rice by putting the drain pipes all the way to the bottom, or if drop pipes are used, pushing them down all the way to the bottom (in some cases the drop pipes are pulled out completely).

Draining from the surface reduces the amount of solids exiting the pond because water is being pulled from the surface rather than the solid and nutrient rich bottom. By setting the drain pipes to the bottom of the pond during final drawdown, there is an initial spike of solids when draining begins and an increase in solids in the last 20% of the pond volume. This pattern was established in all eight experimental ponds at all three locations.

The RRS double-crop rice/crawfish rotational system and the ULL single-crop crawfish system were both drained by dropping the corrugated pipe (which drains from the bottom) or by pulling out the drop pipe rings. In these two situations, there was an initial spike in solid concentration due to the water's high flow scouring effect on the loosely consolidated sediment directly surrounding the drain pipe within the pond, within the drain pipe itself, and at the mouth of the drain pipe on the receiving stream side. After a short period, the loose sediment is carried away and mainly bulk pond water with a lower sediment load is drained until the remaining 20% of the pond volume is reached. This last 20% of water is agitated by birds and crawfish remaining in the pond; also, pockets and layers of sediment once at the bottom of the water column (therefore kept from the majority of flow) in the early phases of draining are carried away in the remaining few centimeters of water toward the pipe.

Unintentional effluent releases (i.e. solids and nutrients) can be reduced by adding storage capacity to ponds. Storage capacity can also reduce precipitation overflow and reduce pumping costs. Using mechanical aeration instead of pumping surface or ground water into the pond for water quality management (DO) can also reduce effluents. Mechanical aerators are energy efficient and lessen water use, and thus effluents. During final drawdown, draining from the top of the water column down over several weeks by dropping the drain pipe a few centimeters every few days reduces mass loading. Whenever possible, the draining of the last

20% of the pond volume should be avoided; for example, this could be done for a double-crop rice/crawfish rotational system as it will typically be out of use for the next season. The greater the height of water in the pond, the greater the head pressure, thus the greater the amount of flow across the pond toward the drain carrying with it valuable solids and nutrients necessary for rice and crawfish production. More research needs to be done to find an optimal depth for the production of crawfish; and of course a reasonable depth must be maintained to permit easy harvesting by boat.

<u>Receiving Streams During Final Drawdown</u>

After the first 268 m, distance and vegetation density did little in reducing solids for the ARS and ULL locations. Heavier solids settled in the first 268 m, and lighter solids remained suspended after 268 due to the discharge flow rate.

Figure 4.17. The Aquaculture Research Station receiving stream shortly after drain pipes were put down. An initial spike of solids was caused by loose sediment around the drain pipe and in the ditch. Picture on right shows receiving stream shortly before the ponds have drained 50% of their water.

Total suspended solids were reduced over a distance 268 m by 80% at ULL (deep vegetated ditch), and concentrations changed little after that because the larger solids settled out

in the first 268 m and the smaller solids remained suspended due to the flow rate. The flow rate in the ULL ditch was relatively slow because of the dense vegetation and deepness of the ditch when compared to the other ditches sampled. Total suspended solids were reduced over a distance of 268 m by 28% at the ARS (wide, shallow, non-vegetated ditch) because the larger solids settled out in the first 268 m and the smaller solids remained suspended due to the flow rate. The flow rate here was higher than the ULL ditch because there was less vegetation and the ditch was more shallow. Total suspended solids increased over a distance of 268 m by 15% at the RRS (narrow, non-vegetated ditch), because the narrow, shallow nature of the ditch gave it a much higher flow rate than the ARS or ULL ditches. The RRS had very little settling of solids in the first 268 m all the way out to 805 m.

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Chapter 5

Best Management Practices

Best Management Practices (BMPs) are environmentally oriented agricultural practices voluntarily implemented by producers to control the generation and delivery of pollutants from agriculture activities into water resources (Borel 2001).

As aquaculture has grown, so has interest from environmentally oriented individuals and non-governmental organizations (NGOs) concerning aquaculture's impact on the environment. This has led to legal action by NGOs against the United States Environmental Protection Agency (USEPA) that has brought about the development and implementation of BMPs for aquaculture (Romaire 1999). Best Management Practices must be economically feasible and ecologically justifiable. Essentially, the market demand for crawfish – total farm value in 2001 was $37 million – must be weighed against the potential negative environmental impact crawfish production might have on Louisiana's waters (Fig. 5.1). Crawfish farmers in Louisiana currently use only 0.3% of the state's total land area but much is located on impaired water bodies that receive non-point discharge from other agriculture operations such as rice, soybeans, etc. Nonetheless, BMPs for

Figure 5.1. Ted Noel runs traps on his crawfish farm. Crawfish are an important part of the Louisiana culture.

crawfish farms in Louisiana can reduce the contribution or ripple effect nutrients and solids have on Louisiana's water bodies (Fig. 5.2).

To reduce solids in aquaculture pond effluent, it was recommended to allow effluents to settle with the use of retention ponds (Cichra and Shireman 1990). A 4-day water residence time in constructed wetlands reduces solids and nutrients substantially relative to untreated waters from aquaculture ponds (SRAC 1998). In a study on shrimp farm effluents, reported containment of effluents in sedimentation ponds could reduce TSS by 60% with a residence time of 0.5 d to 1 d, and TN and TP could be reduced 20% to 35% in systems with a residence time of 2 d to 3 d (Jackson et al. 2001).

Figure 5.2. Solid and nutrient pollution ripples outward into ecosystems.

Given the large volume of research available on catfish ponds, it is feasible that certain catfish BMPs may be applicable to crawfish ponds in certain situations. For example, reducing effluent volume appears to be the best way to reduce nutrient and organic matter discharge from catfish ponds. Two ways of practically doing this are by reusing water and maintaining water storage capacity by capturing precipitation (Tucker et al. 2002). Modeling in this study shows there are similar results in crawfish ponds and catfish ponds in terms of reducing effluent by adding storage capacity to capture excess precipitation.

By deepening one catfish pond in the midst of others, that pond can receive overflow

from the others and thereby reduce effluents into the environment (Tucker et al. 2002). Natural water purification processes would improve the water's quality over time and even allow the water to be reused. This is essentially a settling basin, which is just as effective as wetlands in improving catfish pond effluents. Much of the solids, organic matter, and nutrients in pond effluents are associated with the last 20% of water discharged from the ponds; these settle quickly when effluent is held in settling basins. Or, the final volume may be held in the pond for 2-3 d to allow solids to settle before completely draining, or even more desirable, would be to discharge this last 20% into drainage ditches and hold it there, or to simply hold the last 20% within the pond (Tucker et al. 2002). Reducing effluent volume by manipulating water storage capacity and water during final drawdown can significantly reduce the amount of effluent discharged from ponds. Also, predicted mass discharge for catfish ponds was greatest in the winter when the overflow volume was at its maximum and not during the summer when concentrations of nutrients and organic matter in the pond were the highest. Furthermore, during periods of high precipitation, pond effluents will have little impact on receiving stream water quality because the stream flows are high, and this greatly reduces any material discharged in pond effluents, and stream water quality is already greatly impacted from the erosion of fallow row crop lands (Tucker et al. 2002). The final drawdown and receiving stream portion of this study found high solids associated with the last 20% of crawfish pond discharge as in catfish ponds. It is therefore feasible that many of the techniques used on catfish ponds to reduce solids in the final stages of draining would also be applicable to crawfish ponds.

No measurable production benefits from water exchanges have been shown in large commercial aquaculture ponds (i.e. catfish ponds). Furthermore, incoming water is greatly diluted when added to large ponds, and it is likely that water cannot be exchanged quickly

enough to have a beneficial effect during acute water quality crises. Mechanical aeration in catfish ponds is the most common procedure for improving water quality. Mechanical aeration provides the ponds with zones of elevated dissolved oxygen that maintain the cultured fish biomass, prevent thermal stratification, reduce anaerobic conditions in deeper water, increase nitrification rates of ammonia to nitrate (which is lost to denitrification), and increase rates of inorganic phosphorus removal (Tucker et al. 2002). The use of mechanical aeration in crawfish ponds is not always feasible because of the location of the ponds, limited electrical access, and the rotational nature under which some ponds are managed (i.e. double-crop rice/crawfish rotational). However, using mechanical aeration is still the optimal way to conserve energy, water, and reduce pumping costs (LCES 1999) and should be further investigated.

Generic effluent management practices for aquaculture effluents can be applied regardless of the species being produced. A Southern Regional Aquaculture Center (SRAC) report recommends the following generic effluent management practices: “use high quality feeds and efficient feeding practices; provide adequate mechanical aeration and circulation of pond water; minimize water exchange; if water must be exchanged in ponds, consider reusing the effluent for some other purpose, such as irrigating terrestrial crops; reuse water that is drained from ponds whenever possible; maintain some storage volume in ponds to capture precipitation and reduce overflow; optimize watershed areas to reduce excessive discharge; and consider treating effluents by using constructed wetlands (SRAC 1998).”

All of the above effluent management practices could be applicable to crawfish ponds with the exception of using high quality feeds and efficient feeding practices as crawfish are not fed formulated feeds on a regular basis as are food fish ponds (i.e. catfish).

During the rice production phase of the crawfish production cycle, significant amounts of

solids and nutrients are released from a practice called "mudding in". "Mudding in" is a process used generally in southwest Louisiana where rice fields are tilled under flooded conditions prior to the planting of rice; this process is effective in suppressing red rice – a noxious rice biotype. With this rice production practice, effluent problems are associated with the initial drain after the rice is planted. As with final drawdown at the end of the crawfish production cycle, it was found that TSS decreased over time after being allowed to settle, and TS were significantly reduced as well after being allowed to settle for two weeks (Bollich and Feagley 1994).

Current BMPs that have been suggested for crawfish ponds are: (1) avoid pumping and draining at the same time when exchanging water in the pond; (2) develop baffle levees with mechanical aeration, when possible, to increase circulation; and (3) minimize sediment loading when draining by postponing draining until most crawfish have burrowed in early summer and by suspending harvest activities for 1-2 weeks prior to draining (Lutz and Romaire 2002). Furthermore, crawfish ponds with native vegetation have lower concentrations of solids and nutrients than ponds with rice or sorghum-sudan grass (Orellana 1992).

Based on this study's results and the review of relative scientific literature on the subject of aquaculture effluents, I propose the following BMPs to reduce water discharge and therefore effluents within crawfish ponds.

First, conserve water through the addition of water storage capacity in combination with the previously mentioned crawfish pond BMPs as reported by Romaire and Lutz (2002). Based on modeling, this can be done by creating a 5 cm to 15 cm storage capacity above or below the top of the drain pipe after full flood to capture precipitation. Precipitation overflow usually occurs in late fall throughout winter in all three production systems based on model output. Most

precipitation can be utilized instead of being lost as discharge, and thus water pumping costs can be reduced.

Second, minimize or avoid water exchanges (pumping and flushing) whenever possible early in the season. Monitor dissolved oxygen and exchange water only when necessary in ponds that are not designed for mechanical aeration. Ideally, use energy efficient mechanical aeration whenever possible to circulate and aerate waters. Using aerators conserves energy and water, and is less expensive than pumping from wells (LCES 1999).

Third, the best way to reduce effluents during final drawdown, and save sediment and nutrients for use in crop production, is to always drain slowly from the top of the water column down. Whenever possible, avoid draining the last 20% of the pond volume as this has the highest amount of sediments and nutrients. If this is not possible, consider treating the last 20% of the pond volume by running it through deep vegetated ditches, settling basins, or constructed wetlands with a residence time of 4 d – 14 d. Given the high flow rate of discharged water during a rapid drain, very little settling and assimilation occur in receiving streams or ditches (with the exception of the settling of heavy solids in the first few hundred meters), unless a residence time is applied. The best possible solution for reducing crawfish pond effluents is to not drain the remaining 20% of the pond volume, but to let the water evaporate (i.e. double-crop rice/crawfish rotational). When this is not possible, then drain the first 80% of the pond volume by gradually setting the drain pipe lower so it is always pulling from the top of the water column, and allow the last 20% of the pond volume to evaporate. Another added benefit of draining slow from the top down is that this indicates to the crawfish that it is time to burrow because as the water level drops the water temperature rises, and the warming water temperatures indicate to the crawfish that it is time to burrow.

In summation, avoid or minimize water exchanges (Fig. 5.5); use mechanical aeration (Fig. 5.4) along with baffle levees (Fig. 5.7) when possible; postpone draining until early summer when most crawfish have burrowed and suspend harvest activities for 1-2 weeks prior to draining (Fig. 5.6) (Lutz and Romaire 2002), create a 5 cm to 15 cm water storage capacity (Fig. 5.3); whenever possible drain slowly from the top of the water column (Fig. 5.8) down to the last 20% of the pond volume and let evaporate; if this is not possible, drain the remaining 20% of the pond volume through deep vegetated ditches, settling basins, or constructed wetlands with a residence time of 4 d to 14 d (Fig. 5.10); removable drop pipes (Fig. 5.9) should be replaced by vertically adjustable drainage structures (Fig. 5.8) because water being discharged from the bottom of the pond has higher levels of solids and nutrients than water discharged from the surface; and finally, an average depth within the range of 25 cm to 46 cm should be maintained during full flood, the more water, the more effluent and higher pumping costs (Fig. 5.11). More research needs to be done to find an optimal depth for the production of crawfish that can meet the environmental needs of the crawfish, the logistical requirements of the harvesting equipment (boats), and yet allow for a reduction in volume of water discharged during summer drawdown.

<u>Crawfish Production Season BMPs</u>

Figure 5.3. A 5 cm to 15 cm storage capacity should be used to capture rainwater to reduce surface and subsurface water use, and reduce effluents.

Figure 5.4. Use mechanical aeration whenever possible as this conserves energy and water more effectively than exchanging water (pumping and flushing). Also, it eliminates effluent discharge.

Figure 5.5. When water exchanges are necessary, and mechanical aeration is not an option, avoid pumping and draining at the same time.

A B

C D

Figure 5.6. Minimize sediment loading when draining by postponing draining until most crawfish have burrowed (A side view of burrow; B top view of burrow) in early summer and by suspending harvest activities (C combine) for 1-2 weeks prior to draining because boat activity stirs up sediments (D propeller).

Figure 5.7. Develop baffle levees with paddle wheels (Fig. 5.4) to increase circulation.

Figure 5.8. Drain slowly from the top of the water column.

Figure 5.9. Removable drop pipes should be replaced by vertically adjustable drainage structures because water being discharged from the bottom of the pond has higher levels of dissolved nutrients and sediments than waters discharged from the surface. Bottom picture shows a greater flow because there is 1 m between the water's surface and the bottom drain.

A

B

Figure 5.10. When rapid drain is unavoidable, deep vegetated ditches (A), settling basins (B), or constructed wetlands should be used with a 4 d – 14 d residence time to assimilate nutrients and settle out solids.

Figure 5.11. Average depth of 25 cm to 46 cm should be maintained, as this will reduce final drawdown volume. More research needs to be done to find an optimal depth for the production of crawfish.

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Vita

Landon David Parr was born on 8 August 1973, in Williamsburg, Virginia. He attended Auburn University at Auburn, Alabama, where he received his Bachelor of Arts degree in journalism in 1996. While an undergraduate, Landon worked for the Auburn Plainsman and the Opelika-Auburn News. Also during the summer of 1995, Landon studied Spanish in Salamanca, Spain, at the Colegio do Espana. After graduation, Landon left Auburn and headed for California for no apparent reason. Landon made it as far as Baton Rouge, Louisiana, where his car broke down in January of 1997. From 1997 through 1998, Landon was employed by Medical Management Options, Inc., where he took part in the successful startup of a new business, Delta Transportation Service, Inc. Specifically, Landon was responsible for recruiting staff, setting up business office procedures, developing scheduling and communication capabilities, and staff supervision. From mid 1999 to December 2002, Landon attended Louisiana State University in pursuit of a Master of Science in fisheries, which will be awarded through the School of Renewable Natural Resources on December 20, 2002. “And what is the secret of life,” Landon asked as he stood in front of his crew on asteroid B-612. A moment later Levin Kahn stepped forward with his cosmopolitan smile and said in his confident, superior way, “The secret of life is realizing that every good and bad event or word chisels our souls ever closer to their original perfect form.”