Natural Resource Economics Meeting:
Aquaculture and Effluents
Proceedings of a Regional Workshop

*SERA-IEG-30 Workshop Proceedings*

*May 16 - 17, 2002*

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(SERA-IEG-30)
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and Farm Foundation
Theme: Aquaculture and Effluents

Mini Topic: TMDL's and A

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SERA-IEG 30 is the designation for the Southern Natural Resource Economics Workgroup that is committed to integrating research and extension in the natural resource economics area. The 2002 SERA-IEG 30 meeting had two themes for the 2002 meeting. The first concerned aquaculture-environmental interactions and the on-going EPA regulatory process to determine if and how various aquaculture industries' effluent should be regulated; and the second theme involved watershed analysis and TMDL limits for agriculture. The workshop was held May 16-17, 2002 at the Bost Extension Center, Mississippi State University, Starkville, MS.

The primary objective of this workshop was to exchange information on aquaculture water use issues, specifically pond effluents, and how EPA regulations could affect these growing industries and overall water quality. Aquaculture effluent regulation is complicated because of the complexity and diversity of the numerous aquacultured species, production systems, and farm scale. An underlying motivation for the workshop was to help equip land-grant university research and extension faculty and staff to facilitate aquaculture water use planning and management that supports efficient production and environmental standards. Aquaculture effluent regulations are a major issue affecting all areas of the United States. Effluent regulations will impact catfish pond culture in the southeast, salmon pen culture in the northeast and northwest, trout raceway culture throughout the U.S., ornamental pond/cage culture in Florida, and shrimp culture along eastern and Gulf of Mexico coasts. Aquaculture occurs in all 50 States and is conducted in fresh, brackish, and saltwater. Together these industries have total annual sales of over one billion dollars.

Hanson's presentation provides details on specific U.S. aquaculture practices setting the framework for the following presentations. Hargreaves presentation provides a history of the on-going USEPA aquaculture effluent regulatory effort and its rulemaking process. Potential problems with pond effluents involve nitrogen and phosphorus causing nuisance blooms of algae, organic matter loading, and sedimentation. He highlights the consequences of regulation on catfish farming in the U.S. Engle and Quagrainie look at current EPA aquaculture effluents and the potential regulatory costs involved in compliance using EPA's main criterion of best available technology that is economically achievable. Posadas presents research on constructed wetlands to remove pollutants from effluents and Cathcart presents deep pond methods to conserve and regulate aquaculture pollutants. Coble presented a new risk management project with potentially large consequences to the aquaculture world. The project is a feasibility study looking at the potential for risk reducing tools directed at four major aquaculture species. Insurance and non-insurance methods of risk reduction are being researched. Another risk to all aquaculture systems is the problem of bird predation and King's presentation discusses the USDA/APHIS/WS approaches to controlling this peril of concern to all fish and shellfish producers.

The second theme of this workshop involved watershed analysis and TMDL limits for agriculture. Popp assessed economic and environmental impacts of on-farm reservoirs using the Modified Arkansas Off-Stream Reservoir Analysis (or MARORA) model. Intarapapong presented research of conservation practices on water quality impacts under environmental constraints using the Mississippi delta agriculture as a case study. Paudel's research investigates
relationships between economic growth and environmental degradation, specifically for water pollution using watershed level information. Kari's research looks at the value of winter flooded rice fields as a surrogate wetland from market and non-market perspectives.

The editor of these proceedings would like to first thank all of the authors who contributed papers, and their time and effort, to these proceedings. I also gratefully acknowledge the financial support of the Farm Foundation, Southern Rural Development Center, Mississippi Agricultural and Forestry Experiment Station, Mississippi Extension Service. It is hoped that these proceedings will in a small way stimulate further cross disciplinary efforts to study and manage natural resources in ways that lead to healthy economies and ecosystems now and in the future.

Terrill R. Hanson
Mississippi State University
"An Empirical Test of Environmental Kuznets Curve for Water Pollution Using the Watershed Level Information"

Dr. Krishna Paudel and Dwi Susanto,
Louisiana State University, Dept. of Agricultural Economics and Ag Business
An Empirical Test of Environmental Kuznets Curve for Water Pollution Using the Watershed Level Information

Krishna P. Paudel
and
Dwi Susanto

Department of Agricultural Economics and Agribusiness

Louisiana State University
Baton Rouge, Louisiana

4/28/2009
Abstract

In economic setting, the extent of pollution has been frequently associated with income per capita, which lead to the so-called “Kuznets Curve”. This paper analyzed the relationship between water pollution and income per capita. Fixed and random effect models were applied to estimate the relationship. The overall results indicated the existence of an inverted U-curve between water pollution and income per capita. It was also found that coastal parishes were more polluted than the inland parishes.

KEY TERMS: Environmental Kuznets Curve; coastal area pollution; poverty; economics; water pollution
Introduction

The Environmental Kuznets Curve Hypothesis: there exists a quadratic relationship between economic growth and environmental degradation.

- Recent Literature
Provides information to assess and exercise water pollution related policies.

First study on the analysis of the water pollution-income relationship using parish (watershed) level data.
Model Specification

\[ y_{it} = \sum_{k=1}^{K} x_{itk} \beta_k + u_{it} \quad i = 1,2,\ldots, N; \quad t = 1,2,\ldots, T \]

\[ u_{it} = \nu_i + \epsilon_{it} \]

\[ u_{it} = \nu_i + e_t + \epsilon_{it} \]
The term $V_i$ captures the heterogeneity across parishes (64 parishes) and the term $e_t$ represents the heterogeneity over time.

$V_i$ and $e_t$ can either be random or nonrandom and is a classical $\varepsilon_{it}$ error term with zero mean and a homoscedastic covariance matrix.
\[ w_{it} = \alpha_i + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 PD_{it} + \beta_3 D_{it} + u_{it} \]

\(w\) is water pollutants, \(y\) is real per capita GDP income, \(PD\) is population density, \(D\) is a coastal dummy that takes a value of 1 if a parish is located in the coastal region and 0 otherwise, \(i\) and \(t\) are indices of parish and time, respectively.
Watersheds in Louisiana

Sixty Watersheds

- **08070202** Amite; state(s): LA, MS
- **08080101** Atchafalaya; state(s): LA
- **08040205** Bayou Bartholomew; state(s): AR, LA
- **08040306** Bayou Cocodrie; state(s): LA, MS
- **08040206** Bayou D’arbonne; state(s): AR, LA
- **08050002** Bayou Macon; state(s): AR, LA, MS
- **11140206** Bayou Pierre; state(s): LA, TX
- **08070201** Bayou Sara-Thompson; state(s): LA, MS
- **08080102** Bayou Teche; state(s): LA
- **08040305** Black; state(s): LA
- **11140209** Black Lake Bayou; state(s): LA
- **11140205** Bodcau Bayou; state(s): AR, LA
- **08050001** Boeuf; state(s): AR, LA
- **03180005** Bogue Chitto; state(s): LA, MS
- **08080201** Mermentau Headwaters; state(s): LA
- **11140202** Middle Red-Coushatta; state(s): LA
- **12010002** Middle Sabine; state(s): LA, TX
- **03170009** Mississippi Coastal; state(s): AL, LA, MS
- **11140204** Red Chute; state(s): LA
- **12040201** Sabine Lake; state(s): LA, TX
- **11140208** Saline Bayou; state(s): LA
- **08080103** Vermilion; state(s): LA
- **08090302** West Central Louisiana Coastal; state(s): LA
- **08080205** West Fork Calcasieu; state(s): LA
- **08080204** Whisky Chitto; state(s): LA

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<table>
<thead>
<tr>
<th>Location Code</th>
<th>Description</th>
<th>State(s)</th>
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<tr>
<td>11140306</td>
<td>Caddo Lake; (state(s): LA, TX)</td>
<td></td>
</tr>
<tr>
<td>08040302</td>
<td>Castor; (state(s): LA)</td>
<td></td>
</tr>
<tr>
<td>08060204</td>
<td>Coles Creek; (state(s): LA, MS)</td>
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<tr>
<td>11140304</td>
<td>Cross Bayou; (state(s): AR, LA, TX)</td>
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<tr>
<td>08030209</td>
<td>Deer-Steele; (state(s): AR, LA, MS)</td>
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<tr>
<td>08040303</td>
<td>Dugdemona; (state(s): LA)</td>
<td></td>
</tr>
<tr>
<td>08090301</td>
<td>East Central Louisiana Coastal; (state(s): LA)</td>
<td></td>
</tr>
<tr>
<td>08090203</td>
<td>Eastern Louisiana Coastal; (state(s): LA)</td>
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<td>08060205</td>
<td>Homochitto; (state(s): LA, MS)</td>
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<td>08070204</td>
<td>Lake Maurepas; (state(s): LA)</td>
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<td>08090202</td>
<td>Lake Pontchartrain; (state(s): LA)</td>
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<td>Little; (state(s): LA)</td>
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<td>Loggy Bayou; (state(s): AR, LA)</td>
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<td>Lower Calcasieu; (state(s): LA)</td>
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<td>Tangipahoa; (state(s): LA, MS)</td>
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<td>Upper Calcasieu; (state(s): LA)</td>
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<td>08070100</td>
<td>Lower Mississippi-Baton Rouge; (state(s): LA)</td>
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<td>08030100</td>
<td>Lower Mississippi-Greenville; (state(s): AR, LA, MS)</td>
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<td>Lower Mississippi-Natchez; (state(s): LA, MS)</td>
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<td>Lower Mississippi-New Orleans; (state(s): LA)</td>
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<td>Lower Red-Lake Iatt; (state(s): LA)</td>
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<td>Mckinney-Posten Bayous; (state(s): AR, LA, TX)</td>
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</tr>
<tr>
<td>08080202</td>
<td>Mermentau; (state(s): LA)</td>
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Figure 1. Plots of complete data set
Figure 2. Plots of complete data set
Table 1: Characteristics of Sample Data

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<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
<th>Number of Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (mg/l)</td>
<td>0.306</td>
<td>0.319</td>
<td>0.029</td>
<td>2.95</td>
<td>742</td>
</tr>
<tr>
<td>Phosphorus (mg/l)</td>
<td>0.198</td>
<td>0.125</td>
<td>0.032</td>
<td>1.071</td>
<td>742</td>
</tr>
<tr>
<td>Income per capita ('000 US Dollars)</td>
<td>10.353</td>
<td>1.946</td>
<td>6.013</td>
<td>16.269</td>
<td>742</td>
</tr>
<tr>
<td>Population Density (persons/squares miles)</td>
<td>161</td>
<td>375</td>
<td>5</td>
<td>2572</td>
<td>742</td>
</tr>
</tbody>
</table>
## Table 2. Estimation Results for Nitrogen Water Pollutant

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed Effect Model</th>
<th>Random Effect Model</th>
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<tbody>
<tr>
<td></td>
<td>One-way</td>
<td>Two-way</td>
</tr>
<tr>
<td>Intercept$^1$</td>
<td>-0.9637</td>
<td>-0.7553</td>
</tr>
<tr>
<td>Income</td>
<td>0.2051***</td>
<td>0.1911***</td>
</tr>
<tr>
<td></td>
<td>(3.77)</td>
<td>(3.14)</td>
</tr>
<tr>
<td>Income Squares</td>
<td>-0.0079***</td>
<td>-0.0084***</td>
</tr>
<tr>
<td></td>
<td>(-3.12)</td>
<td>(-3.20)</td>
</tr>
<tr>
<td>Population Density</td>
<td>-0.0006</td>
<td>-0.0007</td>
</tr>
<tr>
<td></td>
<td>(-1.31)</td>
<td>(-1.49)</td>
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<tr>
<td>Dummy Variable</td>
<td>0.1145</td>
<td>0.1145</td>
</tr>
<tr>
<td></td>
<td>(1.53)</td>
<td>(1.55)</td>
</tr>
<tr>
<td>R2</td>
<td>0.5138</td>
<td>0.5226</td>
</tr>
<tr>
<td>Hausman Test</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>F Test for No Fixed Effect</td>
<td>13.59</td>
<td>11.06</td>
</tr>
<tr>
<td>Turning point ($)</td>
<td>12,981</td>
<td>11,375</td>
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</table>

$^1$ Standard errors in parentheses
## Estimation results for Phosphorus water Pollutant

<table>
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<th>Variable</th>
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</thead>
<tbody>
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<td>One-way</td>
<td>Two-way</td>
<td>One-way</td>
<td>Two-way</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.0782</td>
<td>-0.1492</td>
<td>0.1545</td>
<td>0.1139</td>
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<tr>
<td>Income</td>
<td>0.0206</td>
<td>0.0458***</td>
<td>0.0149</td>
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<tr>
<td></td>
<td>(1.13)</td>
<td>(2.27)</td>
<td>(0.83)</td>
<td>(1.11)</td>
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<tr>
<td>Income Squares</td>
<td>-0.0014</td>
<td>-0.0016**</td>
<td>-0.0011</td>
<td>-0.0012</td>
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<tr>
<td></td>
<td>(-1.61)</td>
<td>(-1.90)</td>
<td>(-1.32)</td>
<td>(-1.45)</td>
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<tr>
<td>Population Density</td>
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<td>-0.0003</td>
<td>0.00003</td>
<td>-0.00004</td>
</tr>
<tr>
<td></td>
<td>(-1.32)</td>
<td>(-1.55)</td>
<td>(-0.90)</td>
<td>(-1.10)</td>
</tr>
<tr>
<td>Dummy Variable</td>
<td>-</td>
<td>-</td>
<td>0.0664**</td>
<td>0.0639*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2.05)</td>
<td>(1.95)</td>
</tr>
<tr>
<td>R2</td>
<td>0.6427</td>
<td>0.6584</td>
<td>0.0187</td>
<td>0.0114</td>
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<tr>
<td>Hausman Test</td>
<td>-</td>
<td>-</td>
<td>2.10</td>
<td>8.89</td>
</tr>
<tr>
<td>F Test for No Fixed Effect</td>
<td>23.14</td>
<td>19.48</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Turning point ($)</td>
<td>7,357</td>
<td>14,312</td>
<td>6,773</td>
<td>8,417</td>
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</tbody>
</table>

4/28/2009
Figure 4: Phosphorus Pollutant, Inland and Coastal Regions
Figure 3: Nitrogen Water Pollutant, Inland and Coastal regions
Conclusions

- The estimated parameters have the expected signs.

- The relationship between income and water pollutant under study follow the standard EKC.

- The turning points:
  - Nitrogen: $11,375 to $12,981
  - Phosphorus: $6,773 to $14,312.
Densely populated rich counties are relatively more sensitive to water pollution.

Although consistent with theory, the results are not reliable to make future predictions with regard to income and water quality indicators.
Need to consider policy variables such as the impact of Clean Water Act 1987 on watershed pollution level.
An Empirical Test of the Environmental Kuznets Curve for Water Pollution

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1 We would like to thank Richard F. Kazmierczack, Jr. and John Westra for their helpful comments to improve this paper. We benefited from the comments of the meeting participants at the SERA-IEG 30 workshop at Mississippi State University and at the AWRA meeting in New Orleans.
An Empirical Test of the Environmental Kuznets Curve for Water Pollution

Abstracts: The Environmental Kuznets Curve (EKC) on water pollution was investigated using parish level data in the State of Louisiana. Both fixed effects and random effects models and one-way and two-way specifications within these two models were employed. We found that the one-way random effect model was the most preferred model among all the specifications considered. Results indicated the existence of the EKC in water pollution with turning points ranging from $6,636 to $12,993.

Key words: Kuznets Curve, fixed effects, random effects, water pollution, turning points.
An Empirical Test of Environmental Kuznets Curve for Water Pollution in Louisiana

1. Introduction

There have been numerous theoretical and empirical studies with respect to an income-pollution relationship, which is usually referred to as the “environmental Kuznets curve (EKC)” (Grossman and Krueger, 1995; Moomaw and Unruh, 1997; Vincent, 1997; Hilton and Levinson, 1998; Hettige, Mani, and Wheeler, 2000; Stern and Common, 2001, Harbaugh, Levinson, and Wilson, 2002). The hypothesis underlying the Kuznets curve is that there exists a relationship between economic growth and environmental degradation. Captured in the Kuznets curve is the hypothesis that the level of environmental degradation will increase as per capita income increases up to a threshold. Beyond this income threshold, or the turning point, further growth in income is hypothesized to be beneficial for the environment. Hence, the EKS curve takes an inverted U-shape (Kuznets, 1955).

Previous theoretical studies have focused on deriving the transition paths for pollution, abatement effort, and development under alternative assumptions about social welfare functions, pollution damage, the cost of abatement, and the productivity of capital (Dasgupta et al., 2002). More specifically, theoretical work is concerned with whether an inverted U-shape pollution-income path can be consistent with the Pareto optimality principle (Harbaugh et al, 2002). Theoretical models, however, cannot predict well on how environmental quality will evolve with changes in per capita income (Shafik, 1994). Empirical studies have tended to analyze cross-
sectional data for a sample of developing and developed countries by regressing measures of ambient air and water quality on different specification of income per capita. Most data used in these analyses are from the Global Environmental Monitoring System (GEMS). The results of these empirical studies have shown a mixed relationship between income and pollution measures, with several studies demonstrating concave functions. Several other studies, however, have found convex, downward sloping, and flat functions (Grossman and Krueger, 1995; Hettige et al., 2000).

The mixed empirical results of past studies have motivated researchers to further investigate the underlying hypothesis by applying various functional forms, different data sets, and different estimation procedures. In a recent study, Harbaugh et al. (2002) replicated and modified Grossman and Krueger’s model to study the relationships between air pollution and income in major cities of the world. They demonstrated that altering previous specifications in modest ways resulted in less robust coefficient estimates than had been claimed.

Aside from criticism of past studies, further investigation into pollution-income relationships is worth undertaking because it can provide information to assess and implement environmental policies locally, nationally, and internationally. In this paper, we reexamined the empirical evidence for an inverted U-curve hypothesis on water pollution. In doing so, we use watershed level data for Louisiana—a stark contrast to aggregate cross-country level data used in other studies. Because aggregation problem remains the Achilles’ heel in any econometric estimation.
procedure, the disaggregated data used in this study should provide more reliable results for policy formulation.

2. Empirical Model and Estimation Procedures

Data that have both time series and cross sections, usually referred to as panel data, are common in economics. Many recent studies of the Kuznets curve have used panel data because it provides a rich source of information about the economy and allows researchers great flexibility in modeling differences in behavior across individuals. In our study, we used panel data covering three different water pollutants in 53 Louisiana parishes over a 14-year period (Figure 1).

Kuznets curve models have been estimated either in quadratic or in cubic specifications between pollutant concentration and per capita income. We adopt both of these specifications in our analysis. The general form of the panel data model used to describe the relationship between pollution and income in this study is given in equations (1) and (2).

\[
\begin{align*}
    w_{it} &= \alpha_i + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 D_{it} + \beta_4 PD_{it} + u_{it} \\
    w_{it} &= \alpha_i + \beta_1 y_{it} + \beta_2 y_{it}^2 + \beta_3 y_{it}^3 + \beta_4 D_{it} + \beta_5 PD_{it} + u_{it}
\end{align*}
\]

Here, \( w \) is a water pollutant, \( y \) is per capita income, \( i \) and \( t \) represent indices of parish and time, respectively. \( PD \) is population density (persons per square mile) and \( D \) represents a dummy variable for coastal regions. We hypothesize a positive relationship because coastal parishes receive many of the spill-over effects of pollutants in other parishes. \( D \) takes the value of 1 if a parish is located in the coastal
region and 0 otherwise. Population density is used in the model as a proxy for human behavior on water pollution. The hypothesis underlying this variable is that the more populated parishes are likely to be more concerned about reducing water pollution. Hence, population density is expected to have a negative sign\(^2\).

The error components, \( u_t \), can take different structures. The specification of error components can depend solely on the cross section to which the observation belongs or both on the cross section and time series. If the specification depends on cross section, then we have \( u_t = v_t + \epsilon_t \); and if the specification is assumed to be dependent on both cross section and time series, then the error components follow \( u_t = v_t + e_t + \epsilon_t \). The term \( v_t \) is intended to capture the heterogeneity across individuals and the term \( e_t \) is to represent the heterogeneity over time. Furthermore, \( v_t \) and \( e_t \) can either be random or nonrandom, and \( \epsilon_t \) is the classical error term with zero mean and a homoscedastic covariance matrix. The nature of the error structures leads to different estimation procedures depending on the specification. For this study, we estimated the models using one way and two way of fixed and random effects models with F tests and Hausman tests used to evaluate the appropriateness of the model specifications.

3. Data

\(^2\) See also Seldon and Song (1994). Hypothesis of a negative relationship between population density and water pollution may only be viable in a developed country. In developing country, the relationship between population density and pollution could be argues as positive. In either case, the hypothesis is open to empirical testing.
The disaggregated nature of the data used in our study, a unique feature, should make it easier to demonstrate the existence of EKC. We used data on nitrogen, phosphorus, and dissolved oxygen concentration in water from each watershed collected by the Louisiana Department of Environmental Quality. Because each parish contains portions of several watersheds (Figure 2), a weighted arithmetic mean was used to measure the level of water pollutants for a given parish in a given year. Given that observations from several parishes were not available in some years, the pooled data consisted of observations from 1985 to 1999 for 53 of Louisiana’s 64 parishes.

We focused on three kinds of ambient quality data for conventional pollutants dissolved oxygen, phosphorus (P), and nitrogen (N). Dissolved oxygen (DO) is a direct indicator of water quality. Contamination of watersheds by human sewage or industrial discharges increases the demand for dissolved oxygen, resulting in less oxygen for fish and other forms of aquatic life. At a considerably high level of contamination, one would expect that fish populations start to decline due to pollution. A similar problem may arise when water is enriched with nutrients such as nitrogen and phosphorus through runoff and leachates from intensively fertilized agricultural areas (Grossman and Krueger, 1995). This has been commonly observed in Louisiana where prolonged uses of agricultural fertilizers and broiler litter have caused P and N build up in waterbodies.

Per capita income measures the relationship between economic growth and environmental quality. It also directly measures the endogenous characteristics of
growth such that it accounts for industrialization, urbanization, and other
development factors (Shafik, 1994). Per capita income by Louisiana parish was
obtained from the Bureau of Economic Analysis (BEA). Population density is
measured in persons per square mile and is calculated by dividing population in a
parish by its corresponding area.

4. Results and Discussions

Summary statistics of the sample data are presented in Table 1. Water
pollutants (N, P, and DO) are measured in milligrams per liter of water, per capita
income is in US dollars, and population density is measured in persons per squares
mile. As shown in Table 1, the range of N, P, and DO is quite large. The income
level was quite wide ranging with the minimum being $6,013 (Madison Parish) and
the maximum being $16,269 (Jefferson Parish), while the Louisiana average was
$10,353. Population density ranged from minimum of 5 people per square miles
(Cameron Parish) to a maximum of 2,572 people per square mile (Orleans Parish).

The regression results for the fixed effects models are presented in Table 2
and Table 3. As shown in Table 2, the signs of the estimated coefficients for one-way
fixed effects were as expected, although statistical significance was found only in the
nitrogen equation. The estimated turning points were about $12,000 for both the N
and DO equations. In contrast, results from the phosphorus equation indicated a
relatively low turning point ($7,357). The F statistics for testing the joint significance
of the individual effects are given in the last column of Table 2. As the critical value is about 1.50, the results strongly suggest an individual specific effect in the data.

Table 3 showed the two-way fixed effects model. Notice that in some cases, the parameter estimates produced by the two-way model are higher compared to the one-way model; in other cases, however, these numbers are smaller. We also found that the coefficients of all income variables are significant in the N equations. The F statistics indicated the presence of individual specific and time effects. The turning points produced by the two-way method are somewhat different from those produced by one-way model, especially for P and DO.

The regression results for the random effects model are given in Table 4 and Table 5. The Hausman statistics reported in Tables 4 and 5 are lower than the critical values from the chi-squared table, except for DO equations of two-way random effects model ($\chi^2_4 = 9.49$ and $\chi^2_3 = 11.07$), and thus the hypothesis that the individual effects are uncorrelated with the other regressors in the model cannot be rejected. Further investigation also demonstrated that the values of the parameters estimates presented in Table 5 were not substantially different from the results in Table 4, except for DO equations. Thus, the use of specification that assumed errors depend on both cross section and time series did not lead to increased efficiency. In addition, the Hausman tests for DO equations were higher than the critical values, suggesting that the two-way random effects model is not better than two-way fixed effects model. Based on the Hausman test as well as the efficiency gain, we were able to conclude that one-way random effects model was a better model. Therefore, our
additional comments are based on the one-way random effects model presented in Table 4.

As shown for the nitrogen equation in Table 4, the coefficients for income in both quadratic and cubic forms have the expected signs and are statistically significant at the 1% level. These empirical results provide evidence of an inverted U-Curve relationship between income and nitrogen level. Using the quadratic specification, we obtained a turning point of $12,993. Although the coefficient on population density possessed the expected sign, it is not significant. This result is consistent with the study by Selden and Song (1994). The dummy variable for coastal areas has the expected sign but it is not significant. Therefore, we did not find the spill over effect. The lack of significance of the dummy variable might be explained by the fact that any given parish generally has more than one watershed, so upstream and downstream relationships may not always apply.

In the phosphorus equation, we found a similar pattern for the income-pollution relationships. They were not, however, statistically significant. The estimated coastal and population density coefficients also provided the expected results in terms of the signs, but neither were significant. An estimated turning point for phosphorus was found to be $6,636. The estimated turning point generated by the P equation is lower than the N equation. Estimated coefficients for the DO equation have the expected signs for income variables. The level of DO initially decreased as income went up, but reached a turning point at $12,758 (using the quadratic form).
Thus, the DO equation possessed a U-curve relationship between income and dissolved oxygen.

6. Concluding Comments

Using a 14-year series of water pollutants (N, P, and DO) data for 53 parishes in Louisiana, the environmental Kuznets curve was estimated using both fixed effects and random effects models under one-way and two-way specifications. The F tests provided evidence for the existence of individual effects in the data while the Hausman tests suggested that the one way random effect model was preferred. In general, the estimated parameters on income had the expected signs and results showed that per capita income and the level of N, P, and DO followed a standard environmental Kuznets curve relationship. The turning points calculated based on the quadratic specification were $12,993, $6,636, and $12,758 for N, P, and DO equations, respectively. Economic prosperity appears to improve environmental quality in many parishes so policies to stimulate economic growth are recommended. Stringent environmental policies regarding nonpoint source pollution could have been responsible for improved water quality in some of the regions indicating the need for such policies in the state if water quality is to be improved in a significant manner.
Table 1. Characteristics of Sample Data

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<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Number of Observation</th>
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<td>Income per capita ($)</td>
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<td>Income Cubes</td>
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Note: Numbers in parentheses are standard errors
*** Significant at 1% level
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<tr>
<th>Independent Variables</th>
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**Note:** Numbers in parentheses are standard errors
*** Significant at 1% level
### Table 4. One Way - Random Effects Model

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**Note:** Numbers in parentheses are standard errors  
*** Significant at 1% level
Table 5: Two Way - Random Effects Model

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<th>Dummy Coastal</th>
<th>Population Density</th>
<th>Trend</th>
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</table>

Note: Numbers in parentheses are standard errors
*** Significant at 1% level
Figure 1. Spatial location of Louisiana Parishes
Figure 2. Spatial Location of Louisiana Watersheds
REFERENCES


"Application of GIS and Spatial Analysis in Natural Resource Economics"

Mr. Gandhi Raj Bhattarai,
Auburn University, Dept. of Agricultural Economics and Rural Sociology
Application of GIS and Spatial Analysis in Natural Resource Economics

Gandhi R. Bhattarai
Graduate Student

(Advisor: Dr. Upton Hatch
Professor & Director, AUEI)

Department of Agricultural Economics and Rural Sociology
Auburn University

SERA-IEG 30 Annual Meeting, May 16 – 17, 2002
Starkville, Mississippi
Geographic Dimensions in NRE

• *Spatial influences in space*
  – Resources spread over geographical space
  – Beneficiaries clustered around the resources
  – Externalities spread downstream or to an area around the source

• *Measuring the influence:*
  – Where? (Zone of Impact)
  – How much? (Degree of influence)
  – In what way? (Nature of spatial relationship)
Geographic Information System (GIS)

- A set of Software, Hardware and the Operator [ESRI, 1999]
- Facilitates analysis of geo-referenced data in space
- Data availability:
  - Digitized data recording by many institutions
  - Different forms: grids, shape files, coverages, images etc.
- Application packages:
  - Different packages for different uses
  - ArcView, ArcGIS, ArcInfo etc.
Spatial Analysis

• Application of statistical methods to the solution of geographical research questions – Gattrell
• Relatively new area
• Two perspectives (Anselin)
  – Data-driven: exploratory, descriptive, geo-visualisation
  – Model-driven: spatial econometrics, spatial prediction, spatial statistics, hypothesis testing and model fitting
• Limited functionality available in existing statistical softwares like SAS
• Spatial Analysis software: SPACESTAT
Usefulness of GIS and Spatial Analysis

• Accuracy
• Easy in operation
• Great Analytical Capabilities
• Applied to Precision Agriculture, Land Use planning, Environmental Quality, Forest Planning etc…

• Two examples follow this slide
Task I:

Potential site selection for block forest plantation in Henry county in Alabama

Selection Criteria:

- Within 5 km from any major roads
- Not within 50 meters from any streams
- Not within 1 km from any urban areas
- Current land use as transitional, shrub land or fallow land (Classified as grid-code)
- At least 50 acre in one block
Activities

• Digitization of maps or use of available digitized maps
• Delineation of buffer areas
• Geo-processing – clip, merge, identity etc.
• Spatial overlay
• Reselection using selection codes
An example of spatial operation (Buffer)
Selected Areas for Forest Plantation

<table>
<thead>
<tr>
<th>SITE#</th>
<th>AREA (HA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3767</td>
<td>20.610</td>
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<tr>
<td>4556</td>
<td>27.178</td>
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<td>7882</td>
<td>28.800</td>
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<tr>
<td>10556</td>
<td>85.410</td>
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<tr>
<td>14762</td>
<td>217.637</td>
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<tr>
<td>28689</td>
<td>112.683</td>
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<td>62796</td>
<td>33.660</td>
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<tr>
<td>64581</td>
<td>51.482</td>
</tr>
<tr>
<td>83251</td>
<td>73.710</td>
</tr>
<tr>
<td>85493</td>
<td>35.025</td>
</tr>
</tbody>
</table>
Task II:

Estimating a regression model to explain farmland values in Alabama counties in the presence of spatial effects

GIS steps

• Geo-referenced polygons or centroids from GIS
• GIS data to database/text conversion

Spatial Analysis Steps

• Formation of Contiguity Matrix
• Formation of Spatial Weight Matrix
• Running Spatial Regression Models in SpaceStat
• Display results in GIS or in Tables
Contiguity
County \( j \) in any direction from County \( i \), measured from centroid to centroid within a hypothesized limit for spatial influence.

Contiguity Matrix
nxn matrix of observations based on contiguity
\( W_{ij} = 1 \) for contiguous counties; 0 for others

Spatial Weight Matrix
Inverse Distance Matrix based on contiguity, Row standardized; N by N positive, Symmetric Matrix
Example: Detecting Spatial Dependence

a. GIS Map visualisation  

b. Moran Scatterplot of relationship
**Example: Diagnostics for Spatial Dependence**

<table>
<thead>
<tr>
<th>TEST</th>
<th>MI/DF</th>
<th>VALUE</th>
<th>PROB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moran's I (error)</td>
<td>0.0069</td>
<td>0.664</td>
<td>0.507</td>
</tr>
<tr>
<td>Lagrange Multiplier (error)</td>
<td>1</td>
<td>0.014</td>
<td>0.905</td>
</tr>
<tr>
<td>Robust LM (error)</td>
<td>1</td>
<td>1.209</td>
<td>0.271</td>
</tr>
<tr>
<td>Kelejian-Robinson (error)</td>
<td>8</td>
<td>8.848</td>
<td>0.355</td>
</tr>
<tr>
<td>Lagrange Multiplier (lag)</td>
<td>1</td>
<td>4.981</td>
<td>0.026</td>
</tr>
<tr>
<td>Robust LM (lag)</td>
<td>1</td>
<td>6.176</td>
<td>0.013</td>
</tr>
<tr>
<td>Lagrange Multiplier (SARMA)</td>
<td>2</td>
<td>6.190</td>
<td>0.045</td>
</tr>
</tbody>
</table>
Spatial Lag Model

• The weighted average effect of the values from contiguous counties to County $i$

  Model: $\mathbf{y} = \rho \mathbf{W} \mathbf{y} + \mathbf{X} \mathbf{\beta} + \mathbf{\varepsilon}$ \hspace{1cm} $\mathbf{\varepsilon} \sim \mathcal{N} \left( \mathbf{0}, \mathbf{\sigma}^2 \mathbf{I}_n \right)$

Spatial Error Model

• The weighted average effect of the errors from contiguous counties to County $i$

  Model: $\mathbf{y} = \mathbf{X} \mathbf{\beta} + \mathbf{u}$

  $\mathbf{u} = \lambda \mathbf{W} \mathbf{u} + \mathbf{\varepsilon}$ \hspace{1cm} $\mathbf{\varepsilon} \sim \mathcal{N} \left( \mathbf{0}, \mathbf{\sigma}^2 \mathbf{I}_n \right)$

General Spatial Model

$$\mathbf{y} = \rho \mathbf{W} \mathbf{y} + \mathbf{X} \mathbf{\beta} + \mathbf{u}$$

$$\mathbf{u} = \lambda \mathbf{W} \mathbf{u} + \mathbf{\varepsilon} \hspace{1cm} \mathbf{\varepsilon} \sim \mathcal{N} \left( \mathbf{0}, \mathbf{\sigma}^2 \mathbf{I}_n \right)$$
An Example of SAR-ML Regression Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coeff</th>
<th>Z-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial lag ($\rho$)</td>
<td>0.273</td>
<td>2.396</td>
<td>0.017</td>
</tr>
<tr>
<td>Constant</td>
<td>9.526</td>
<td>0.035</td>
<td>0.972</td>
</tr>
<tr>
<td>Farm income</td>
<td>1.379</td>
<td>2.477</td>
<td>0.013</td>
</tr>
<tr>
<td>Farm size</td>
<td>-0.079</td>
<td>-0.263</td>
<td>0.793</td>
</tr>
<tr>
<td>Farm investment</td>
<td>3.040</td>
<td>3.675</td>
<td>0.000</td>
</tr>
<tr>
<td>Land use change</td>
<td>120.875</td>
<td>2.009</td>
<td>0.044</td>
</tr>
<tr>
<td>Population density</td>
<td>1.932</td>
<td>5.084</td>
<td>0.000</td>
</tr>
<tr>
<td>Metropolitan</td>
<td>214.556</td>
<td>2.942</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Log-likelihood: -454.6

n=67
Future Research

• Socio-economic and environmental impact of land use change in the South
  – Land use and micro-climate variability
  – Urbanization and externalities to the environment
  – Land values, hedonic models
Methodology (Extensive use of spatial analytical tools)
Data sources includes (not limited to)
  – USGS; USDA; Population Census; USFS

GIS analysis
  – Impact zones
  – Area measurement

Spatial Analysis
  – Spatial weight based statistical models
  – Multivariate regression models
COMMENTS ?
SUGGESTIONS ?

I am here to learn from you!
"Can Aquaculture Be Insured?"

Drs. Keith Coble and Terry Hanson,
Mississippi State University, Dept. of Agricultural Economics
Can Aquaculture be Insured? Part 1

Dr. Keith Coble and Dr. Terry Hanson
The National Risk Management Feasibility Program for Aquaculture

The purpose of this program is to conduct a large-scale study into the feasibility of developing and implementing risk management programs for U.S. aquaculture producers, and to provide FCIC risk management products, policies, and related materials necessary to implement these programs.
A Unique Synergism

Aquaculture Science & Management

National Risk Management Feasibility Program for Aquaculture

Risk Management & Insurance
Specific Objectives

1. Organize and initiate a multi-year national program of integrated research that will support an assessment of the possibility of providing risk management tools for aquaculture producers.

2. Conduct four national workshops on aquaculture risk and insurance. These conferences will bring together experts from the various disciplines, producers, USDA officials, and industry representatives.
Specific Objectives

3. Collect data from published sources and conduct original research. The project will conduct listening sessions in aquaculture production and marketing areas, and gather information from interested parties.

4. Produce risk management studies for the aquaculture species (catfish, salmon, trout, baitfish) with the greatest economic value. These studies will provide the information to assess the viability of alternative risk management designs.
Specific Objectives

5. Provide a final project report comprised of a summary and overview of the entire project. This report will incorporate information from all interim species reports into the final research report.

6. Develop risk management program elements and documents necessary to implement a risk management program.
# Project Timetable

<table>
<thead>
<tr>
<th>Month</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organize activity and get contracts and staff in place. Recruit advisory committee members and meet to discuss program.</td>
</tr>
<tr>
<td>6-12</td>
<td>Conduct the first Risk Management for Aquaculture workshop and start species investigations; conduct listening sessions; conduct follow-up meetings with individual groups to determine research focus</td>
</tr>
<tr>
<td>16</td>
<td>Conduct a second Risk Management for Aquaculture workshop</td>
</tr>
<tr>
<td>18</td>
<td>Conduct listening session.</td>
</tr>
<tr>
<td>24</td>
<td>Conduct a third Risk Management for Aquaculture workshop.</td>
</tr>
<tr>
<td>30</td>
<td>Develop potential program designs, draft policy, loss adjustment handbooks data submission elements, and underwriting procedures.</td>
</tr>
<tr>
<td>36</td>
<td>Conduct a fourth Risk Management for Aquaculture workshop. Conduct listening session and analysis of demand.</td>
</tr>
<tr>
<td>42</td>
<td>Draft final report</td>
</tr>
</tbody>
</table>
The Balancing Act of Developing Viable Products
Perils and Risks

- **Peril**: An event that causes losses.
- **Risk**: Uncertainty concerning the likelihood of a given peril or the associated magnitude of loss.
Why is Risk a Problem?

- People tend to be risk-averse.
- Risk reduces incentives for investment and thus retards economic growth.
  - Reluctance to invest if one must accept the full risk of a potential loss.
  - Idle “emergency funds.”
Risk Management Methods

- Loss control (taking steps to reduce the likelihood and/or magnitude of loss).
- Retention (self-insurance).
- Transfer (insurance or other contingent-claims contracts).
- These methods are not mutually exclusive.
- These methods are all costly!
Insurance

- A legal contract whereby risks are transferred from one party to another in exchange for a premium.
- The purchaser of an insurance policy is willing to accept a small loss with certainty (the premium) rather than face the risk of a much larger loss.
Insurance

- Insurer agrees to pay the insured a specified amount contingent on a measurable index exceeding some threshold.
- Typically, the index is a measure of losses resulting from a specified peril.
Risk and Insurance

- Not all risks are insurable!
- Insurance works only for risks that exhibit specific requirements.
- If the government is the seller of insurance, we can probably ignore one of these requirements.
- However, all other requirements are still necessary.
Insurance Product Development

- What is the peril of concern?
- What can I measure?
  - Can an objective third party determine whether the realized value of the index has exceeded the threshold?
  - Can an objective third party accurately measure the magnitude by which the realized value of the index has exceeded the threshold?
Hidden Action

- Are index realizations truly random occurrences (or can index realizations be affected by the insured individual)?
  - Can an insured individual engage in “hidden actions” that would increase the likelihood of loss?
  - Can an insured individual engage in “hidden actions” that would increase the magnitude of loss?
Hidden Action

– Hidden action can be fraud. It can also be simple carelessness as a result of having insurance protection.
– Deductibles can reduce incentives for hidden action.
– Pervasive hidden action will increase insurance payouts. The insurer will typically respond by increasing premiums for all. Those not practicing hidden action are then likely to quit purchasing insurance.
Insuring Against Management

- Suppose that the realized value of the index is highly dependent on management decisions (e.g., actual farm yield losses).
- It will be very difficult to overcome the effects of hidden action.
- Old insurance maxim: *You can’t insure against bad management!*
Hidden Information

Can the insurer accurately classify potential policyholders according to their risk exposure?

- Insurance underwriters attempt to sort potential policyholders into different classifications according to their risk exposure.
- The same premium rate (based on average expected payout) is charged to everyone within a given risk classification.
Hidden Information

– If potential policyholders have “hidden information” about their risk exposure, then they will be misclassified.

– Some high risk individuals will be incorrectly placed in low risk classifications. They will be inclined to purchase the insurance.

– Some low risk individuals will be incorrectly placed in high risk classifications. They will be disinclined to purchase the insurance.
Hidden Information

- A disproportionate number of policyholders will be those who have been misclassified to their benefit.
- When high payouts occur, the insurer will raise premium rates for everyone.
- This only compounds the problem because those who were accurately classified will be less likely to continue purchasing insurance.
Setting Premiums

- Must be able to estimate the distribution of the index.
  - Given sufficient historical data, the distribution can be estimated empirically.
  - Otherwise, research will be needed to simulate an estimate of the distribution.
Why worry, it’s only government money

- Why worry about the impacts of hidden action or hidden information?
- Why worry about setting the price correctly?
- “It’s only government money.”
Why Worry, It’s only government money

- Hidden action problems cause premium increases.
  - Those not exploiting hidden actions can be priced out of the market for insurance.

- Hidden information problems cause premium increases.
  - Lower risk producers can be priced out of the market for insurance.
Summary

- Index. What can I measure?
- Hidden action.
- Hidden information.
- Setting premiums. What is the distribution of the index?
Why Worry?

- If premiums are set too high, few producers will purchase.
- If premiums are set too low, can stimulate increased acreage and lower market prices.
A Unique Synergism

Producers

Industry

RMA & MSU

Other Educational Institutions

Other Government Agencies
Species Examined

Conduct feasibility studies for the aquaculture species (catfish, salmon, trout, baitfish) with the greatest economic value.

These studies will provide the information to assess the viability of alternative risk management designs.
In cases where it can be accurately measured, the actual realized loss may serve as the index.

Otherwise, an alternative index must be used.
- Can the peril itself be measured (e.g., temperature)?
- Is there any other measurable index that is highly correlated with this risk?

One can’t insure what can’t be measured!
Distribution of Index

The graph shows the distribution of index values in terms of probability. The x-axis represents the number of bushels per acre, ranging from 0 to 50, while the y-axis represents the probability, starting at 0% and going up to 16%. The bars indicate the percentage probability for each bushel value. For instance, the probability for 0 bushels is 10%, 5 bushels is 12%, and so on, with 25 bushels having the highest probability of 16%.
Expected Payout

- 10% of the time the insurer will have to pay a 5 bushel per acre indemnity.
- 6% of the time the insurer will have to pay a 10 bushel per acre indemnity.
- 5% of the time the insurer will have to pay a 15 bushel per acre indemnity.
- Expected Payout = Break-Even Premium = $(10\% \times 5) + (6\% \times 10) + (5\% \times 15) = 1.85$ bushels per acre.
Break-Even Premium

- Of course, in reality, yields do not occur in discrete 5 bushel per acre increments, instead they are continuous.
Distribution of Index

Bushels per acre vs. Probability
Distribution of Index

- Probability distribution for bushels per acre.
National Risk Management Feasibility Program for Aquaculture

Part II. **Summary of the First Annual Workshop**

Dr. Terry Hanson

[Department of Agricultural Economics]
National Aquaculture Risk & Insurance Workshop: Objective 2

“…conduct annual conferences to bring together experts from the various disciplines, producers, USDA officials, and industry representatives…”
Formed Steering Committees

- **Catfish:** 4 res/ext, 3 producers, 1 industry rep
- **Trout:** 3 res/ext, 2 producers/industry rep
- **Salmon:** 1 industry rep, 1 govt. (3 producers)
- **Baitfish:** 2 res/ext (3 producers)
- **Risk:** 5 researchers
- **RMA:** 3 administrators
- **MSU:** 4 res, 2 admin
Workshop Goals

1. Introduce program
2. Define risk and risk management
3. Discuss insurability characteristics
4. Discuss fundamentals of aquaculture production and associated peril areas
5. Develop a cadre of interdisciplinary personnel
Objectives

1. Develop a list of priority peril areas
2. Determine if peril meets insurability criteria
3. Determine if info is currently available to measure a peril's magnitude of loss and frequency of occurrence
4. Identify the nature of required peril information and determine how best to obtain this information
5. Identify experts in each peril area
Breakout Session

- Identify perils for each aquaculture species

- Get group feeling about the economic effect of each peril and prioritize them

- Discuss perils using the Aquaculture Peril Evaluation Form
  - Ranked peril questions using
    1 = strongly disagree to 5 = strongly agree
Aquaculture Peril Evaluation Form

- Does peril pose significant economic loss?
- Does peril occur on a consistent basis? To the same degree?
- Can losses be clearly identified from a specified peril?
- Can the magnitude of the loss be measured?
- Could an insured producer:
  - engage in “hidden actions” affecting the random nature of peril?
  - increase the magnitude of the loss?
- Does data exist to estimate likelihood of loss and magnitude?
  - If not, can research be conducted to generate the likelihood estimates?
- Are insurance products currently available for this peril?
Potentially Insurable Perils for Catfish (1 = strongly disagree to 5 = strongly agree)

- Power outages
- Diseases
- Bird predation
- Toxic algae

- Losses can be clearly identified
- Poses significant economic losses to producers
- Risk occurs on a consistent basis
- Poses significant economic losses to producers in W. AL
Catfish - other key points

- Simple formulas exist for estimating catfish inventory and losses
- Toxic algae concern concentrated in West Alabama
- Data on power outages thought to be available
- Some diseases are manageable and others just have to run their course
- Revenue insurance appealing to producers
- Initial interest in flood insurance low, but is inexpensive
- Tailor product to ‘core’ states first then adapt to other regions
Potentially Insurable Perils for 
Salmon  
(1 = strongly disagree  to 5 = strongly agree)

- Escapes
  - Risks occur on a consistent basis; losses are truly random

- Diseases
  - Risk poses significant economic losses; losses can be clearly identified; magnitude of loss can be identified
  - losses identifiable; magnitude can be id’ed; random; no ‘hidden actions’; research possible

- Algal blooms
Salmon - other key points

- Concerns expressed about conflict between analysts’ need for data and producers’ desire for privacy
- Canada has income reduction insurance to compensate producers for excessive imports from Chile
- Produced in public waters so there are perils from water contamination
- Regulatory changes frequently occur
Potentially Insurable Perils for Trout (1 = strongly disagree to 5 = strongly agree)

- Floods
- Diseases
- Water supply

- Insurer could distinguish differences in the extent to which farms are exposed to risk
- Poses significant economic losses to producers
- Poses significant economic losses to producers
Trout - other key points

- Diseases are a fact of life, but producers would like consideration given to catastrophic disease coverage
- In Idaho heavy rains cause intake screens to clog
- In NC producers face declining flow of water from natural springs (more managerial than insurance risk)
- Idaho producers have to deal with property rights issues on spring flows and surface waters
Potentially Insurable Perils for Baitfish (1 = strongly disagree to 5 = strongly agree)

- Power outages
- Diseases
- Bird predation
- Floods/storms

- Insurer could distinguish differences in the extent to which farms are exposed to risk
- Poses significant economic losses; risk occurs on a consistent basis
- Risk occurs on a consistent basis
- Losses are truly random
Baitfish - other key points

- Major differences in industry characteristics of AR and Great Lakes regions
- Clearer definition of aquaculture needed
  - In Great Lakes region, aquaculture operations are very extensive compared to intensive operations in AR
  - For insurance purposes, where should the line be drawn?
- Different stages of production have different associated perils and may require different insurance products
- Producer owns fish during transportation
  - Could losses that occur during transportation to distributors / retailers be insured?
Summary of Workshop

- Brought together diverse
- Introduced program of aquaculture risk management
- Presentations introduced:
  - Risk management concepts to aquaculture representatives
  - Familiarized risk management specialists with various aspects of the aquaculture industry
- Q&A period allowed attendees to ask questions about the project (goals, timetable, potential outputs)
- Breakout sessions assessed perils of each industry
Summary of Workshop

- Species peril surveys completed
- Information gathered will be used to guide research emphases in next step of the project
- Potential researchers identified for future project activities
Project website

- For more information on this project visit our website at:
- http://www.agecon.msstate.edu/aquaculture
"Constructed Wetlands and Aquaculture Effluent Reduction"

Mississippi State Extension Service, Coastal Research and Extension Center
Constructed Wetlands in Pond Effluent Reduction

Benedict C. Posadas
Assistant Economics Extension/Research Professor

May 16-17, 2002
Participating Agencies

- MSU-Coastal Research and Extension Center, Biloxi, MS
  - David Veal, Head
  - Mark LaSalle, Estuarine Ecologist

- MSU-Coastal Aquaculture Unit, Gulfport, MS

- Mississippi Power Company, Gulfport, MS

- Delta Pride Catfish, Inc., Indianola, MS
Funding Agencies

- U.S. Department of Agriculture
  - NRI -1992-94
  - NRI - 1995-98
- U.S. Department of Commerce
  - SK - 1995-98
Objectives

- evaluate effectiveness of constructed marsh systems toward improving water quality in aquaculture ponds
- determine optimal design and operating criteria for constructed wetlands
- determine the concomitant reductions in risk of crop loss, incidence of off-flavor, and release of nutrient-laden effluent into the environment
Objectives

- determine the improvement in fish growth and feed conversion, and
- document the costs versus benefits of using this technology in pond culture
Methods

- Pond Size:
  - 1/4-acre ponds
  - 125 ft. long
  - 85 ft. wide
  - 4 ft. deep
Fish Species

- Channel catfish (*Ictalurus punctatus*)
- Phase II fingerlings (6-7 inch)
Wetland Plants

- **Duck Potato**
  (*Sagittaria lancifolia*)

- planted at 1/2- ft.
  centers
Experimental Design

- Control ponds (no marsh, simulated water flow)
- Treatment ponds (marshes of “standard” size and flow rate).
Wetland Size Variations

- % of pond surface area
  - small, 15%
  - standard, 25%
  - large, 35%
Flow rate Variations

- **Slow**
  - 3.25 gal/min
  - 3-day retention

- **Standard**
  - 6.5 gal/min
  - 2-day retention

- **Fast**
  - 13.0 gal/min
  - 1-day retention

- **Very fast**
  - 26.0 gal/min
  - 1/2-day retention
Monitoring

- Water Quality in Wetlands (inlet and outlet)
  - Weekly: salinity, pH, ammonia, nitrite, nitrate, total phosphorous, total suspended solids
Water Quality in Ponds

- **Daily (twice per day):**
  - dissolved oxygen
  - temperature

- **Weekly:**
  - same as for wetlands
  - chlorophyll a
  - phaeophytin
Statistical Analysis

- Analysis of Variance using General Linear Model (GLM)
- Means compared using SNK multiple range test
- All tests conducted at significance level of 0.05
Constructed Wetlands
MSU-CAU, 1997
Percent changes of inlet to outlet values of weekly water quality variables in wetlands of variable sizes, 1997

![Graph showing percent changes of various water quality variables across different wetland sizes.](image)
Pond Aeration
MSU-CAU, 1997
Mean values of daily pond water quality variables in ponds with wetlands of variable sizes, 1997

![Graph showing mean values of pond water quality variables with wetland size as a factor.]

- **Control**: A.M.D.O., P.M.D.O., Aeration time
- **Wetland Sizes**: 15%, 25%, 35%

May 16-17, 2002
SERA-IEG 30
Mean values of weekly water quality variables in ponds with wetlands of variable sizes, 1997

---

**Wetland Size**

- Control
- 15%
- 25%
- 35%

**Variables**

- Ammonia
- Nitrite
- pH
- Nitrate

**Concentrations**

- mg/L

---

May 16-17, 2002  
SERA-IEG 30
Mean values of weekly water quality variables in ponds with wetlands of variable sizes, 1997

- Solids
- Chlorophyll
- Phaeophytin
- Phosphorous

May 16-17, 2002
Dried Matter from Water Samples
MSU-CAU, 1997

- 14P - Sample from Pond 14
- 14I - Sample from Inlet
- 14O - Sample from Outlet
Catfish Stocking Densities
Per Production Acre

- 5,000 3-4 inch in 1994
- 6,000 7-8 inch in 1996
- 8,000 7-8 inch in 1997
Catfish Survival Rate

- 75%
- 100%

May 16-17, 2002

Control 15% 25% 35%


May 16-17, 2002
SERA-IEG 30
Catfish Yield
Pounds Per Qtr Acre

Control | 15% | 25% | 35%


0 | 500 | 1,000 | 1,500 | 2,000 | 2,500

May 16-17, 2002  SERA-IEG 30
Wetland Electricity Use
KWH Per Week

May 16-17, 2002
SERA-IEG 30
Chemical Costs
$ Per Qtr Acre

<table>
<thead>
<tr>
<th>Control</th>
<th>15%</th>
<th>25%</th>
<th>35%</th>
</tr>
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<tbody>
<tr>
<td>1996</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>1997</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
</tbody>
</table>

May 16-17, 2002
SERA-IEG 30

27
Net Feed Conversion
lbs of feed per lb of fish gained

Control 15% 25% 35%

Catfish Pond-Wetland Systems

- Six 8-water-acre catfish ponds (CCF)
- Six constructed wetlands built adjacent to catfish ponds:
  - 15% of pond size or 1.2 acres each
  - 25% of pond size or 2.0 acres each
  - 35% of pond size or 2.8 acres each
Catfish Stocking and Production, 1997

- Stocking rate: 8,000 fingerlings per acre
- Stocking size: 7-8 inch CCF fingerlings
- Culture period: 8 months
- Survival rate: 57 percent
- Catfish yield: 6,744 pounds per acre
- Net feed conversion ratio: 1.0:2.4
- Catfish off-flavor scale: greater than zero
Total Investment Requirements

- Recycling system: $0
- Plants & planting: $100,000
- Vegetative cover: $100,000
- Gravel: $50,000
- Earth moving: $50,000
- Surveying: $0
- Land: $50,000

Wetland size:
- 15%: $100,000
- 25%: $200,000
- 35%: $300,000

Total Investment Requirements: $200,000

May 16-17, 2002 SERA-IEG 30
Average Investment Requirements Per Production Hectare

- 15% Wetland Size: $6,560
- 25% Wetland Size: $10,277
- 35% Wetland Size: $13,994
Added costs of constructed wetlands in recirculating catfish pond production $ per production hectare

<table>
<thead>
<tr>
<th>Wetland size</th>
<th>Added Cost</th>
<th>15%</th>
<th>25%</th>
<th>35%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$672</td>
<td></td>
<td>$960</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1,248</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Added costs of constructed wetlands in recirculating catfish pond production $ per kilogram of catfish yield

Wetland size

- 15%: $0.09
- 25%: $0.13
- 35%: $0.17
Conclusions

- Wetlands do appear to significantly reduce the levels of nutrients from catfish pond effluents.
- Wetlands that are sized to about 25% of pond area with a 2-day retention time appear to provide optimal treatment of effluents.
- No significant differences in the yield of marketable catfish.
- Higher investment requirements and operating costs.
Recommendations

- Testing in commercial farms.
- Use of other economically important culture species.
- Testing other plant species and methods of creating vegetation.
Constructed Wetlands Website

- http://www.msstate.edu/dept/crec/cwres.html
- http://www.msstate.edu/dept/crec/crec.html
  - Go to Aquaculture
- msucares.com
  - Go to Centers and Institutes
  - Go to Coastal Research and Extension Center
  - Go to Aquaculture
"Current EPA Aquaculture Effluents and Regulatory Costs"

Dr. Carole Engle (presented by Dr. Kwamena Quagrainie)
University of Arkansas at Pine Bluff, Aquaculture Center
Current EPA Aquaculture Effluents and Regulatory Costs

Carole Engle

Presenter: Kwamena Quagrainie
Production Systems

- Raceways
- Cages
- Re-circulating Systems
- Ponds
- Ditches
- Tanks
Aquaculture Applications: Raceways
Cages
Environmental Problems

- Effluents
- Escape of non-indigenous species
- Weed control
- Oxygen depletion
- High energy use
- Parasites / Pathogens
EPA & Effluents

- Clean Water Act provides for Effluent Limitation Guidelines (ELG).
- ELG’s used to regulate point sources of pollution.
- EPA has designated Aquaculture as a point source of pollution.
Rule # 12

- A 1992 Consent Decree to lawsuit by NRDC set timetable for ELG’s.
- In Consent Decree, EPA designated for Rule #12 the Industrial Container Cleaning Industry.
- In late 1999, EPA asked court to substitute aquaculture for the Industrial Container Cleaning Industry.
EPA’s Reasons

- Only relevant EPA guidance on aquaculture is over 20 years old.
- Aquaculture industry has changed in species raised and industrial processes.
- States identify aquaculture as common cause of water quality impairment (303d and 305b lists).
### Examples of 303d list

<table>
<thead>
<tr>
<th>State</th>
<th>Cause</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>LA</td>
<td>Mercury</td>
<td>Aquaculture</td>
</tr>
<tr>
<td>LA</td>
<td>Pesticides</td>
<td>Aquaculture</td>
</tr>
<tr>
<td>CA</td>
<td>Arsenic</td>
<td>Aquaculture</td>
</tr>
<tr>
<td>ME</td>
<td>Total toxins</td>
<td>Aquaculture</td>
</tr>
<tr>
<td>OH</td>
<td>Metals</td>
<td>Aquaculture</td>
</tr>
</tbody>
</table>
Follow-up survey by NC Dept. of Agriculture

Shows that majority of states’ environmental agencies do not consider aquaculture to be a problem: those that have had problems indicated that state regulations were adequate to correct it.
EPA Plans

Main Criterion (others are available):

**BEST AVAILABLE TECHNOLOGY THAT IS ECONOMICALLY ACHIEVABLE**

NB: EPA seeks guidelines are technology-based and **NOT** water-quality based.
EPA Plans contd.

2 Surveys

- Engineering portion to identify waste treatment options
- Economics portion to identify economic characteristics including production costs
EPA Plans contd.

• Engineers select technologies to be evaluated and estimate costs of compliance for technology selected.

• Economists add compliance costs to production costs to calculate how many farms would go out of business.
Economic Analysis

- Sales Test = compliance costs as % of total gross revenue (sales).
- Profit Test = compliance costs + production costs to see effect on net cash flow.
Complete Economic Analysis to include

- Impacts on small businesses.
- Impacts on local areas & communities.
- Regional impacts
- National impacts (trade, economic growth, negative environmental effects elsewhere).
Additional analyses

- Environmental benefits analysis
- Foreign trade
- Impacts on new farms
- Uncertainty and financial risk
- Ability of industry to pass through any cost increases
Current Site Visits and Sampling

- EPA & contractors visited 74 U.S. facilities.
- Sampled 2 trout flow-through (1 private; 1 public), 1 recirculating system facility.
Site Visits by Species

- 11 catfish farms
- 12 trout farms
- 4 hybrid striped bass farms
- 4 tilapia farms
- 9 ornamental fish farms
- 10 salmon farms
- 5 crawfish
- 5 mollusc
Site Visits by Species

- 7 shrimp farms
- 2 yellow perch
- 1 each red snapper, alligator, soft-shell crab shedding, lobster, mullet, and milkfish.
Joint Subcommittee on Aquaculture

National Aquaculture Effluents Task Force:

to support a nationally coordinated, systematic process to identify and report the best available and appropriate science and data relating to discharges from aquaculture.
Current Status of Rule-Making Effort: SBREFA Panel Stage

- SBREFA: Small Business Regulatory Enforcement Fairness Act
- Law that requires federal agencies to be subjected to scrutiny over impact of their regulations on small businesses.
- SBREFA panel = 1 EPA, 1 OMB, 1 SBA representative
- SBREFA panel advised by SER’s.
SER’s for Aquaculture include:

- Jerry Williamson, catfish, AR
- Tom Foshee, catfish, LA
- Norma Jean Williams, crawfish, LA
- Betsy Hart, general, NAA
- Carole Engle, general
- Jack Waggener
- SER’s submit comments, questions on materials sent by EPA.
Timeline

- SBREFA panel convened Jan. 21.
- Panel runs 60 days.
- After 60 days, panel prepares report as official part of process.
- EPA completes rule.
Timeline (Cont.)

• EPA will complete its rule.
• Rule will undergo internal review by EPA.
• Rule will then undergo review by OMB.
• Proposed rule will be published in the Federal Register by June 30, 2002.
• Comment period July-August, 2002.
The Way the Rule is Put Together

• “Model” facilities developed based on different farm sizes & different regions.
• National “pollutant” loading (TSS, BOD, N, P) has been estimated.
• Treatment options have been drafted.
• Reduction in total “pollutant” loading has been estimated by treatment option.
• Costs of each treatment option have been estimated.
Survey

• EPA has received approval from OMB to conduct the survey.

• EPA conducted an outreach activity on the survey at the San Diego meetings.

• Questionnaire is the full version to be administered in February.
The Survey

- Site map
- Water sources/discharges
- Any treatment of discharges
- Production
- Production costs
- Balance sheets & income statements for 1998-2000 or Tax Returns
Survey Timetable

- EPA says that they plan to mail out the private sector survey in late February.
Final Rule

- Proposed 2002

- Implementation: 2004
Treatment options Pond Systems:

1. Best Management Plan (HACCP)
   - Practices to control discharges.
   - Health management plan.
   - Non-native species escapement plan.
   - Drugs & chemicals management plan.

2. Settling Basins

3. Constructed Wetlands
Treatment options for Flow-through Systems

Baseline

- Feed management
- Quiescent zones
- Sedimentation basins

- Option 1 = Baseline + BMP’s
  - Health management
  - Non-native species plan
  - Drug & chemical management plan
  - PACCP (regulatory structure)
Treatment options for Flow-through Systems

- Option 2 = Numeric limit for TSS of 30 mg/L
  - Microscreen filters
  - Polishing ponds
  - Chemical additives

- Option 3 = Disinfection
  - Chlorine
  - Ozone
  - UV
Effluent & Pollution

• Aquaculture pollution concerns the discharge of nutrients

• Control measures
  – source reduction of nutrients or
  – reduction in nutrient concentration
In-Pond Treatment

- Natural treatment of nutrients
  - 55 - 57% of N & P utilized by planktons, volatilized or adsorbed to mud particles
  - plankton demand for oxygen exceeds that of fish
  - plankton & bacteria constitute waste treatment unit in ponds
## In-Pond Treatment Costs

**TABLE 1. Pond production costs ($) partitioned into costs of waste treatment and costs of fish production (Valderrama and Engle 2001).**

<table>
<thead>
<tr>
<th>Cost</th>
<th>64 ha (160 acre)</th>
<th>256 ha (640 acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fish production</td>
<td>Waste treatment</td>
</tr>
<tr>
<td>Repairs and maintenance</td>
<td>120</td>
<td>11,880</td>
</tr>
<tr>
<td>Pond renovation</td>
<td>72</td>
<td>7,128</td>
</tr>
<tr>
<td>Aeration</td>
<td>3,029</td>
<td>13,799</td>
</tr>
<tr>
<td>All fuel</td>
<td>1,870</td>
<td>-</td>
</tr>
<tr>
<td>Chemicals</td>
<td>485</td>
<td>-</td>
</tr>
<tr>
<td>Telephone</td>
<td>2,000</td>
<td>-</td>
</tr>
<tr>
<td>Water quality</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fingerlings</td>
<td>42,000</td>
<td>-</td>
</tr>
<tr>
<td>Feed</td>
<td>215,600</td>
<td>-</td>
</tr>
<tr>
<td>Labor</td>
<td>14,664</td>
<td>21,996</td>
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<tr>
<td>Management</td>
<td>21,000</td>
<td>-</td>
</tr>
<tr>
<td>Harvesting/hauling</td>
<td>28,000</td>
<td>-</td>
</tr>
<tr>
<td>Accounting/legal</td>
<td>1,800</td>
<td>-</td>
</tr>
<tr>
<td>Bird scaring</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Int. operating cap.</td>
<td>27,319</td>
<td>4,563</td>
</tr>
<tr>
<td>Total variable costs</td>
<td>358,459</td>
<td>59,866</td>
</tr>
<tr>
<td>Total fixed costs</td>
<td>17,113</td>
<td>78,188</td>
</tr>
<tr>
<td>Total costs</td>
<td>375,572</td>
<td>138,054</td>
</tr>
<tr>
<td>Cost/kg</td>
<td>1.17</td>
<td>0.44</td>
</tr>
</tbody>
</table>
Best Management Practices (BMPs)

Proposals include:

• 6/3 water management rule
• harvesting without discharge
• water reuse
• feeding practices
Settling Basin

Fingerling ponds

Grower ponds

Settling basin

Stream
Settling Basins

Disadvantages:

• Settleable solids are minor constituents
• Land availability - new or pond retrofits
• Engineering design, size & operating costs
• Effect of hydraulic residence time (HRT)
<table>
<thead>
<tr>
<th>Foodfish pond size (ha)</th>
<th>Layout</th>
<th>Portion of effluents/overflow</th>
<th>Required settling area (ha)</th>
<th>Total investment costs ($)</th>
<th>Total annual operating costs ($)</th>
<th>Total annual fixed costs ($)</th>
<th>Total annual cost ($)</th>
<th>Unit cost ($)</th>
<th>Unit cost ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Construction of settling basins on new land/drainage (HRT=1–20)</td>
<td>Retrofitting foodfish production ponds/drainage (HRT=1–20)</td>
<td>Construction of settling basins on new land/overflow (HRT=1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Single</td>
<td>last 20%</td>
<td>0.8–1.2</td>
<td>28,648–40,932</td>
<td>443–560</td>
<td>3,442–4,828</td>
<td>3,385–5,388</td>
<td>$0.012–$0.017</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Single</td>
<td>all</td>
<td>4–6</td>
<td>$27,194–188,916</td>
<td>1,381–1,967</td>
<td>14,569–21,540</td>
<td>15,950–23,507</td>
<td>$0.050–$0.074</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Double</td>
<td>last 20%</td>
<td>0.8</td>
<td>57,296</td>
<td>677</td>
<td>6,884</td>
<td>7,561</td>
<td>$0.024</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Double</td>
<td>all</td>
<td>4</td>
<td>254,387</td>
<td>2,553</td>
<td>29,138</td>
<td>31,691</td>
<td>$0.10</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Single</td>
<td>last 20%</td>
<td>1.2</td>
<td>40,932</td>
<td>560</td>
<td>4,828</td>
<td>5,388</td>
<td>$0.017</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Single</td>
<td>all</td>
<td>6</td>
<td>188,916</td>
<td>1,967</td>
<td>21,540</td>
<td>23,507</td>
<td>$0.074</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Double</td>
<td>last 20%</td>
<td>1.2</td>
<td>81,864</td>
<td>912</td>
<td>9,657</td>
<td>10,569</td>
<td>$0.033</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Double</td>
<td>all</td>
<td>6</td>
<td>377,832</td>
<td>3,725</td>
<td>43,081</td>
<td>46,806</td>
<td>$0.147</td>
<td></td>
</tr>
</tbody>
</table>

*Overflow from an 8-cm storm event in m³.

*Includes construction costs of basins and acquisition of pumps.

*Includes copper sulphate and pumping costs.

*Includes depreciation and interest on investment.

*Equal to the sum of total annual operating and fixed costs.
Settling Basins: highlights

- Lost revenue due to retrofitting
- Large investments for construction

Recommendations:

- Tucker et al (2000): use production pond as settling basin
- Hold last 20% of water after harvesting
**Production/Storage (P&S) Costs**

<table>
<thead>
<tr>
<th>Pond configuration</th>
<th>Infiltration rate (mm/d)</th>
<th>Total investment cost ($</th>
<th>Total annual operating cost ($)</th>
<th>Total annual fixed cost ($)</th>
<th>Total annual cost ($)</th>
<th>Unit cost ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-ha ponds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:1</td>
<td>0</td>
<td>76,123–215,088</td>
<td>(12,223)–(21,845)</td>
<td>5,125–14,820</td>
<td>(7,098)–(6,025)</td>
<td>$0.022–0.019</td>
</tr>
<tr>
<td>1:1</td>
<td>1</td>
<td>76,163–215,088</td>
<td>(10,089)–(16,155)</td>
<td>5,125–14,820</td>
<td>(4,965)–(1,335)</td>
<td>$0.016–0.004</td>
</tr>
<tr>
<td>3:1</td>
<td>0</td>
<td>44,782–115,947</td>
<td>(6,214)–(14,749)</td>
<td>2,839–7,964</td>
<td>(3,375)–(6,785)</td>
<td>$0.011–0.021</td>
</tr>
<tr>
<td>3:1</td>
<td>1</td>
<td>44,782–119,352</td>
<td>(5,697)–(11,603)</td>
<td>2,839–8,517</td>
<td>(2,858)–(3,086)</td>
<td>$0.009–0.010</td>
</tr>
<tr>
<td>6-ha ponds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1:1</td>
<td>0</td>
<td>75,366–214,291</td>
<td>(12,223)–(21,845)</td>
<td>5,125–14,820</td>
<td>(7,098)–(6,025)</td>
<td>$0.022–0.019</td>
</tr>
<tr>
<td>1:1</td>
<td>1</td>
<td>75,366–214,291</td>
<td>(10,089)–(16,155)</td>
<td>5,125–14,820</td>
<td>(4,965)–(1,335)</td>
<td>$0.016–0.004</td>
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<td>3:1</td>
<td>0</td>
<td>43,587–114,752</td>
<td>(6,214)–(14,749)</td>
<td>2,839–7,964</td>
<td>(3,375)–(6,785)</td>
<td>$0.011–0.021</td>
</tr>
<tr>
<td>3:1</td>
<td>1</td>
<td>43,587–118,157</td>
<td>(5,697)–(11,603)</td>
<td>2,839–8,517</td>
<td>(2,858)–(3,086)</td>
<td>$0.009–0.010</td>
</tr>
</tbody>
</table>

*Table 3. Total investment and annual costs for production/storage ponds for reduction of effluent discharge and groundwater use on catfish farms, 64-ha farm (Valderrama and Engle 2001). Numbers in parentheses are negative. Ranges are for additional storage depths of 30–90 cm.*
Other Treatment Options

- Constructed wetlands
- Water source for irrigation
- Sand filters
- Water recycle
# Constructed wetlands

## Table 4. Investment and annual operating costs for constructed wetlands for the treatment of effluents from catfish ponds. Adapted from Kouka and Engle (1994), Posadas (1998), and Hebicha (1989).

<table>
<thead>
<tr>
<th>Farm size (ha)</th>
<th>Wetland size (ha)</th>
<th>Investment cost</th>
<th>Operating cost</th>
<th>Lined ($)</th>
<th>($/ha of farm)</th>
<th>($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Unlined ($)</td>
<td>Current land base</td>
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<td></td>
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</tr>
<tr>
<td>65</td>
<td>11</td>
<td>800,832</td>
<td>12,320</td>
<td>1,123,249</td>
<td>1,654</td>
<td>25</td>
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<tr>
<td>130</td>
<td>22</td>
<td>1,655,103</td>
<td>12,732</td>
<td>2,311,254</td>
<td>3,065</td>
<td>24</td>
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<tr>
<td>260</td>
<td>44</td>
<td>3,301,355</td>
<td>12,698</td>
<td>4,595,558</td>
<td>5,827</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expanded land base</td>
<td></td>
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</tr>
<tr>
<td>65</td>
<td>13</td>
<td>984,036</td>
<td>15,139</td>
<td>1,378,170</td>
<td>1,961</td>
<td>30</td>
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<tr>
<td>130</td>
<td>26</td>
<td>1,959,903</td>
<td>15,076</td>
<td>2,734,510</td>
<td>3,559</td>
<td>27</td>
</tr>
<tr>
<td>260</td>
<td>52</td>
<td>3,910,213</td>
<td>15,039</td>
<td>5,440,495</td>
<td>6,790</td>
<td>26</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posadas (1998)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.2</td>
<td>0.5</td>
<td>21,250</td>
<td>1,107</td>
<td>-</td>
<td>2,796</td>
<td>146</td>
</tr>
<tr>
<td>19.2</td>
<td>0.8</td>
<td>33,284</td>
<td>1,734</td>
<td>-</td>
<td>3,204</td>
<td>167</td>
</tr>
<tr>
<td>19.2</td>
<td>1.1</td>
<td>45,318</td>
<td>2,360</td>
<td>-</td>
<td>4,235</td>
<td>221</td>
</tr>
<tr>
<td>Hebicha (1989)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>1.2</td>
<td>3,706</td>
<td>904</td>
<td>-</td>
<td>69</td>
<td>17</td>
</tr>
<tr>
<td>4.1</td>
<td>2.4</td>
<td>7,051</td>
<td>1,710</td>
<td>-</td>
<td>136</td>
<td>33</td>
</tr>
<tr>
<td>4.1</td>
<td>4.1</td>
<td>11,565</td>
<td>2,821</td>
<td>-</td>
<td>230</td>
<td>56</td>
</tr>
</tbody>
</table>
Cotton irrigated from ditch stocked with tilapia in Marana, AZ
Tilapia and catfish grown in tanks with effluent going to cotton, Safford, AZ
Raceways

- Idaho: sales more than 9000kg/yr & use of more than 2270kg feed/month require permit

- Waste management system in place, mostly settling unit
Conclusions

• Pond aquaculture poses little risk to environmental degradation

• Settling basins, P&S ponds, constructed wetlands, & filtration units are costly to justify benefits

• Land application may be applicable in some areas

• BMPs are feasible alternatives
"Deep Pond Aquaculture Management for Water Conservation and Effluent Regulation"

Mississippi State University, Dept. of Agricultural and Biological Engineering
Reduction of Effluent Discharge and Groundwater Use in Catfish Ponds – Field Validation

D.W. Rutherford, T.P. Cathcart, and J. Hargreaves

Mississippi State University
Introduction About 10 years ago, Pote and Wax modeled a “drop – add” method to reduce ground water use and effluent release (the “6/3 scheme”).

Projected reductions in water use and release averaged about 30 percent.
The next logical step was to consider deepening production ponds to increase rain water storage.

Considerations:

• How to bring such a system online gradually as part of routine maintenance.
• How to allow producers to partly drain ponds when needed without throwing away stored water
A solution: When ponds are being reconstructed, deepen them to increase their water holding capacity and then allow adjacent ponds to drain into them instead of into a ditch.
During rainy periods, conventional production ponds would discharge to the production / storage ponds instead of receiving waters.
Stored water would be used for filling production ponds for as long as the water was available.
This idea was modeled using a 26 year meteorological record. Two scenarios were modeled:

1:1 configuration

P & S

P

P & S

P

1:3 configuration

P & S

P

P

P

P & S = production & storage;  
P = production
Simulations using the model predicted:

• Up to 70% reduction in effluent release and groundwater use (depending upon configuration and storage depth);

• Some years with no effluent release or groundwater use at all;

• In years when effluent release occurs, most will be during late fall, winter, and early spring (when dilution is greatest).
Effluent discharge and groundwater use have both become issues of concern in the catfish industry.

- Non-point source pollution has become a hot topic in all sectors, including agriculture. Producers would like to have additional water management options should the regulatory climate become more severe.
- Producers are also aware of their dependence on groundwater and want to be prepared for possible future restrictions.
With this in mind, a study to test this approach was funded in 1999 by the Southern Regional Aquaculture Center (USDA).

• The purpose of the study is to test the reliability of the model and determine whether there are unforeseen problems associated with the use of this approach.
• 7 one acre ponds at DREC are being used;
• The study has a 3 year duration (data collection began March, 2000).
To look for unforeseen consequences of this approach, we will monitored water quality and fish growth.

• The ponds have been stocked at commercial rates.
• Standard water quality analyses were conducted biweekly.
• The ponds were monitored as per standard practice.
Testing the model (1:1 and 3:1 configurations).

- We had to deepen 2 ponds.

Production/storage pond being deepened and reworked.
Partially completed production/storage pond

New outflow

New drains from adjacent ponds.
A Deepened Pond

Drain depth: 1.25 m depth

60 cm of storage

1.25 m depth

Pipe to flume
Pond modifications:

- We had to re-route the drainage (from production to production/storage ponds).
- We had to re-route the drainage out of production/storage ponds through the outflow measuring system.
Drain from adjacent pond

To Flume
Measurements required for model inputs:

- Evaporation and precipitation data (already measured on site).

- Pond geometry (depth and surface area of catchment) – carefully surveyed before and after pond modifications.
Measurements required for model inputs:

- Pond depths (for infiltration estimates).
Model dependent variables to be measured:

- Volume of stored water and groundwater pumped into production control and production/storage ponds.
Dependent variables:

Volume of water discharged from control and Production/storage ponds.
Dependent variables: Volume of discharge
This is the hardest one. We’re using H flumes:
Dependent variables:

- Pressure transducers in still wells (used to compute volume flow rates):
Automated data collection:
Dependent variables:
The systems were calibrated prior to installation
and then installed on site.

- One CR-10 and 1 sensor have been damaged (lightning).
- Data collection appears to be progressing satisfactorily.
After a very dry January – February, the discharge measuring system was finally put to use in late March, early April.
System performance:

The system performed Reliably for the 2 years that it has operated.

This summer we will be working up most of the Data from the project.

We have (rather hurriedly) assembled some results from the “6 / 3” control pond (results from Deepened ponds are not ready for viewing).
During the first 200 days of operation, there were approximately 50 days that rain occurred.

Discharge from the 6/3 pond occurred on 4 days.
Treating the 2 consecutive days of rain as 1 “event”, you can see how the available storage reduced effluent release.
Effluent release:

3/20: 808 ft$^3$, 0.22 acre-in

4/2: 19,862 ft$^3$, 5.47 acre-in

4/3: 2,706 ft$^3$, 0.75 acre-in

5/5: 2,447 ft$^3$, 0.67 acre-in
Model Validation (only 3 points so far):

Predicted vs Observed
"Geographical Information Systems Methodology for Assessing Socioeconomic and Environmental Impact Studies"

Dr. Osei Yeboah, Auburn University,
Dept. of Agricultural Economics & Rural Sociology

Dr. Upton Hatch, Director,
Auburn University Environmental Institute.
Geographic Information Systems
Methodology for Assessing Socioeconomic
And Environmental Impacts Studies.

By

Osei Yeboah and Upton Hatch
Auburn University.
Current Research Activities

1. Collection and Conversion of Socioeconomic Data into Spatial Format.

- Data Type Examples: Age, Income, Population, Income, Employment, Business, Housing, and Race.
- Scale: County, Zip Code, and Watershed Levels.
2. Environmental Justice Issues

• Effects of Interstate Highways and the Distribution Of Superfund Sites.

• Toxic Waste Sites in Alabama (Zip Code Level).

• Spatial Distribution of Pulp and Paper Mills in the Southeast.
3. Valuation of Technology

Locations of Superfund Sites by County in the Southeast United States, 1990
## Results of Multivariate Logit Regression: 1980

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Observation 403

Percent of Right Predictions 90.81

Log Likelihood Test Statistics 38.69 * * *

Maddala $R^2$ 0.090

* * p[less than] 0.05  * * * p[less than] 0.01
## Results of Multivariate Logit Regression: 1990

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Observation 403
Percent of right Predictions 90.57
Log Likelihood Test Statistics 38.31 * * *
Maddala R² 0.092
Figure 1: Distribution of Hazardous Waste Sites
By Zip Code, 1990

Waste Sites
None
Waste Site

N
Scaling County Level Data Down to Zip Code Level

• 1990 Zip Codes Shape Files are Used to Approximate the Proportions of data in each Zip Code that form the County Data.

• County Data Rescaled to Cell Level and the Number of Cells in Zip Code Estimated.

• Each Zip Code is then Converted to a Shape File.

• Software: “Two Themes” in Arcview.
Figure 1: Spatial Distribution of Pulp and Paper by County: 1990.
# Results of the Final Probit Model

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* * p[less than] 0.05    * * * p[less than] 0.01
"History of USEPA Aquaculture Effluent Regulatory Effort and Research on Pond Water Management"

Mississippi State University, Dept. of Wildlife and Fisheries
History of USEPA Aquaculture Effluent Regulatory Effort

John A. Hargreaves
Mississippi State University
Department of Wildlife & Fisheries
Overview:

- history of the EPA regulatory effort
- characterization of catfish pond effluents
- management of catfish pond effluents
The Clean Water Act: 1972

- Goal: “to restore and maintain the chemical, physical and biological integrity of the Nation’s water”.
The Clean Water Act: 1972

- restricts types and amounts of pollutants discharged into the Nation’s waters
- wastewater must be treated with the best economically achievable technology
- “point source” discharge permitted under NPDES
Ponds that discharge at least 30 days per year, but...

• not ponds that discharge only during periods of excess runoff; or

• not facilities that produce less than 100,000 lbs per year
“Concentrated aquatic animal production facility”

“Facilities determined on a case-by-case basis by the Director to be significant contributors of pollution to the waters of the United States.”
Draft Effluent Limitation Guidelines: 1977

- recommended effluent limitations for settleable solids and fecal coliforms
- recommended harvest and draining practices
- no standards issued
Consent decree: 1992

- Natural Resources Defense Council vs. Environmental Protection Agency
- established schedule for proposing and developing national effluent guidelines for new industries
• recommended that EPA implement the Clean Water Act for aquaculture by developing national effluent limitations

• catfish ponds not directly described as an environmental threat

• “guilt by association”
EPA’s Notice of Proposed Effluent Guidelines Plan:

- aquaculture
- petroleum refining
- inorganic chemicals
- steam electric power generation
- photographic processing
- chemical formulators and packagers
- urban storm water
- airport deicing

1998
Why is EPA interested in regulating aquaculture effluents???

• **stated reason:**
  – environmental protection

• **actual reason:**
  – consent decree (litigation)
EPA’s rulemaking process

**Sept 1998** - Federal Register notice lists aquaculture as a candidate industry

**Feb 1999** - Office of Water announces preliminary study of aquaculture industry

**Jan 2000** - announcement of formal rulemaking process

**Jan 2000 - present** - data analysis, literature review, site visits, sampling, stakeholder involvement, screener survey
EPA’s rulemaking process

Nov 2001-Feb 2002 - SBREFA process
Feb 2002 - EPA management selects options
Mar 2002 - interagency review
Aug 2002 - proposed rule
mid-summer 2003 - notice of data availability
mid-March 2004 - interagency review
Jun 2004 - final rule
SBREFA process

- Small Business Regulatory Enforcement Fairness Act
- law that requires federal agencies to be subjected to scrutiny over impact of their regulations on small businesses
- SBREFA panel = 1 EPA, 1 OMB, 1 SBA representative
- advised by SER’s (Small-Entity Representatives)
EPA’s rulemaking process

Nov 2001-Feb 2002 - SBREFA process
Feb 2002 - EPA management selects options
Mar 2002 - interagency review
Aug 2002 - proposed rule
mid-summer 2003 - notice of data availability
mid-March 2004 - interagency review
Jun 2004 - final rule
What will this mean to catfish farmers?

- Catfish ponds included in regulation?
- No standards issued?
- Regulation of discharge?
- Best Management Practices vs. numerical limits?
Potential problems with pond effluents

- N & P in effluent cause nuisance blooms of algae
- organic matter loading causes oxygen demand
- sedimentation of receiving waters
Why the level of waste discharge from catfish ponds is low:

- Effluents are dilute relative to amount of feed added to ponds.
- Ponds are managed so that not much water is discharged.
Within-pond waste reduction

- natural processes allow profitable fish production
  - no direct costs for waste treatment
  - decomposition, nitrification / denitrification, sorption, etc.

- enhanced by practice of not draining ponds between fish crops
Pond effluent volume is low

- **mass discharge = concentration x volume**

- **two common water management practices**
  - water not drained between successive fish crops
  - water level maintained below the top of drain pipe ("drop-fill" schemes)
Managing ponds to reduce mass discharge

- reduce effluent volume
- reduce waste production within ponds
- enhance within-pond removal of nutrients and organic matter
Reduce effluent volume

- reuse water for multiple fish crops
- maintain some capacity to store rainfall
- production/storage pond modules
- eliminate water exchange
Reduce waste production within ponds

- *feed carefully to improve feed conversion*
- *manipulation of dietary P concentration ineffective*
- *reducing feeding rates not practical*
Enhance within-pond removal of nutrients and organic matter

- aeration or circulation to improve dissolved oxygen supply
- precipitate inorganic P with gypsum or alum
- bioaugmentation
- aquatic plants for nutrient assimilation
Management practices to reduce environmental impacts

- pond operation and management
- harvest and draining practices
- pond construction and renovation practices
Pond operation and management

- operate production ponds for several years without draining
- capture rainfall to reduce effluent volume
- use high quality feeds and efficient feeding practices
- manage within pond assimilative capacity
- provide adequate aeration and circulation of pond water
- position mechanical aerators to minimize erosion
- eliminate water exchange
Harvest and draining practices

• allow solids to settle before discharging water
• reuse water that is drained from ponds
• treat pond effluents in settling basins or constructed wetlands prior to discharge
• where possible, release pond effluents into natural wetlands
• use effluents to irrigate terrestrial crops
**Pond construction and renovation practices**

- Optimize the ratio of watershed to pond area
- Divert excess runoff from large watersheds away from ponds
- Construct ditches to minimize erosion and establish plant cover on banks
- Protect embankments in drainage ditches from erosion
- Maintain plant cover on pond watersheds
- Avoid leaving ponds drained in winter
- Close drain valves when renovating ponds
- Use sediment to repair levees
- During pond renovation, excavate to increase operational depth
"National Wildlife Research Center"

Mr. Tommy King,
USDA/APHIS/WS, Research Wildlife Biologist
Presented in lieu of Dr. Michael Thomas, Florida A & M University, Agribusiness Program "A New Safety Protocol for the Establishment of Aquaculture", who could not make the meetings for personal reasons
National Wildlife Research Center (NWRC)

USDA/APHIS/Wildlife Services

Tommy King
Research Wildlife Biologist
NWRC/Wildlife Science Building
Fort Collins, Colorado
NWRC Mission

• Apply scientific expertise to develop practical methods to resolve problems caused by the interaction of wild animals and society while maintaining the quality of the environment shared with wildlife.

• Reduce damage and hazards that wildlife causes to agriculture, forests, industry, and other areas of human involvement.
NWRC Objective

The National Wildlife Research Center’s objective is to increase the effective methods available for wildlife damage management through:

• Assessing damage and other problems caused by wildlife to agriculture, the environment, and human health & safety

• Investigating the biology & behavior of problem animals

• Developing and improving technology to reduce wildlife problems

• Transferring scientific information to our customers, stakeholders and the public
National Wildlife Research Center:

Is the only research center in the world devoted exclusively to the study of wildlife conflict/damage management.

Develops and applies strategies and methods to reduce conflicts between wildlife and humans in rural and suburban/urban areas.
National Wildlife Research Center

NWRC Director’s Office

- Information Services
- Quality Assurance
- Administration
- Animal Care

- Bird Research Program
  - Bird Research Program Field Stations
- Product Development Research Program
- Mammal Research Program
  - Mammal Research Program Field Stations
Research Activities

• Strategies and methods to manage
  - damage from blackbirds to crops
  - damage from predators to livestock
  - predation of migratory birds on aquaculture facilities
  - damage from mammals to agriculture and forest resources
  - wildlife hazards to aviation
  - brown tree-snake problems and risks
  - damage caused by vultures

• Development of infertility agents to manage overabundant/problem mammalian and avian species

• Integrated methods for mammal and bird damage to agriculture

• Analysis of taste and olfaction in wildlife species for development of non-lethal chemical repellents

• Alternative capture systems and aversive stimulus applications for managing predation
NWRC Bird Research Program
NWRC Bird Research Program

⇒ Bird predation at aquaculture facilities in southeastern U.S.
⇒ Blackbird damage to ripening sunflowers and rice
⇒ Wildlife hazards to aviation
⇒ Canada geese as disease vectors in urban and agricultural landscapes
⇒ Depredation and nuisance problems caused by vultures
⇒ Analysis of taste and olfaction in selected wildlife species
⇒ Chemical repellents for bird/damage management
NWRC Mammal Research Program
NWRC Mammal Research Program

- Ecology, behavior, and management methods for predators to protect livestock and wildlife resources
- Alternative capture systems and aversive stimulus applications for managing predation
- Reproductive intervention strategies for managing coyote predation
- Selective targeting of adult territorial coyotes to manage sheep depredation
- Methods to reduce wildlife damage to forest and agricultural resources
- Holistic management of rodents and other introduced vertebrate pest species in Hawaii
NWRC Product Development Research

- Chemistry based tools for wildlife damage management
- Effective and economical oral infertility agents in problem wildlife species
- Methods for the control of the brown tree-snake
- Integrated methods to reduce wildlife damage to crops and property by rodents
- Drug and chemical registrations
Selected Cooperating Universities and Research Organizations

- Colorado State University
- Mississippi State University
- North Dakota State University
- Oregon State University
- Penn State University
- Utah State University
- University of California – Berkeley
- University of Nebraska
- University of Florida
- University of Hawaii
- University of Vienna
- University of Zagreb
- University of Wyoming
- University of Georgia
- Cornell University
- Louisiana State University
- Smithsonian Institution
- International Association of Fish & Wildlife Agencies
- Monell Chemical Senses Center
- Hawaii Agricultural Research Center
- U.S. Department of Commerce
- U.S. Department of Interior
NWRC is Committed to:

• Providing valid, objective, science-based information and methods through research
• Being responsive to concerns/values of the public
• Contributing to the well-being of wild animals and the quality of the environment through research
• Encouraging employees’ high morale, growth and development while maintaining a quality work environment
• Providing equal opportunity for employment and advancement
National Wildlife Research Center

Solutions to Problems Depend Upon Knowledge Which Only Research Can Provide
Mississippi Field Station
Selected Research Studies

• Congressionally mandated research:
  – Regional and continental movements of Double-crested Cormorants captured near southeastern aquaculture
  – Potential for piscivorous birds to serve as hosts of trematode infections

• Distribution and abundance of cormorants on catfish ponds in the delta region of Mississippi
Regional and continental movements of Double-crested Cormorants captured near southeastern aquaculture
Acknowledgements:

• Cooperative Study with
  – Harry K. Dupree National Aquaculture Research Center

• Assistance provided by
  – Wildlife Services personnel
  – Catfish Producers
Objectives:

- Determine migratory corridors and breeding locations
- Determine winter movements
- Provide information for regional and/or flyway-based pop. management strategies
Study Design

• Nov. 1999-Mar. 2000: 25 satellite transmitters installed in AL, AR, LA, MS
Satellite Transmitter
Potential for Piscivorous Birds to Serve as Hosts of Trematode Infections

Tommy King (WS/NWRC)
Linda Pote (CVM/MSU)
Stephen Curran (GCRL/USM)
Objectives:

- Determine potential of American White Pelicans, Double-crested Cormorants, Great Blue Herons, and Great Egrets to serve as hosts for trematodes of channel catfish
- Determine the species of digenetic trematode tentatively identified as *Bolbophorus* sp. in catfish production areas
Bolobophorus sp.
(external blemishes)
Study Design

- Birds captured and transported to NWRC’s captive research facility
- Birds treated with antihelminth
- 7 day later birds infected with larval stages of trematode removed from catfish
- Necropsy birds 4 days post infection
- Trematodes identified and counted
American White Pelican
Results

• Adult forms of the trematode were only found in the AWPE
• DNA analysis show the trematode to be a new species of *Bolobophorus*
Distribution and Abundance of Cormorants on Catfish Ponds in the Delta Region of Mississippi

Brian Dorr, Wildlife Biologist, NWRC
Greg Ellis, Wildlife Biologist, WS
Pat Gerard, MSU, MAFES Experimental Statistics
Study Objectives

- Determine the extent of cormorant depredations on catfish aquaculture in the delta region of MS
- Determine the types (e.g. foodfish, fingerling,) and characteristics (e.g. size, stocking rate) of ponds used by cormorants
- Determine the association between night roost locations and depredations on farms
- Develop a model of the economic impact of cormorant depredations on catfish aquaculture in MS
- Provide management strategies to alleviate impacts and a technique for pond level evaluation and monitoring of management efforts
• **Preliminary findings:** Cormorants foraged on over 11% of all ponds aerially surveyed from October, 2000 to April, 2001 and peaked at over 25% of all ponds from February to April 2001

• The number of birds per pond ranged from 1 to over 1000 and averaged from 5 to over 46 depending on the month of the survey.
"Overview of U.S. Aquacultural Practices"

Mississippi State University, Dept. of Agricultural Economics
Overview of U.S. Aquacultural Practices

SERA-IEG 30 Meeting, May 16-17, 2002

Dr. Terry Hanson
Mississippi State University
Department of Agricultural Economics
Topics

• What is aquaculture?
• World & US production trends
• Species selection
• Production systems
  – Levee ponds
  – Raceways
  – Pens and cages
  – Recirculating systems
Aquaculture is...

- Farming of aquatic organisms
- Implies some form of intervention in the rearing process to enhance production
- Implies individual or corporate ownership of the stock being cultivated
FIGURE 2
World capture fisheries and aquaculture production

Note: 1997 data are preliminary. Aquaculture quantities prior to 1994 are estimates.
Source: FAO
Aquaculture Sales

U.S. Total Sales = $978,012,000

Source: 1998 Census of Aquaculture, USDA-NASS
U.S. Aquaculture Production Value
(US $millions)

$692

$36

$89

$47

$7

$69

$37

Source: USDA/NASS, Census of Aquaculture, 1998
Species Selection

- Producer’s expertise
- Marketability
- Climate
- Profitability
- Species biology
- Production methods
Ex. Water Temperature

- Warmwater Range
- 75º – 90º F
- Example: Catfish
Water Temperature

- Coolwater Range
- 60° – 80° F
- Example: Hybrid Striped Bass
Water Temperature

- Coldwater Range
- 48° – 65° F
- Example: Trout
Production Facility Types

1 - Levee Ponds
2 - Raceways
3 - Pens and cages
4 - Recirculating systems
Production Phase

• Securing and spawning of brood stock
• Hatching of eggs
• Growing fry to produce fingerlings
• Stocking and grow-out of fingerlings to marketable size
1 - Levee Pond
Levee Ponds

- Common food species
  - catfish
  - trout and salmon
  - hybrid striped bass
  - yellow perch
  - tilapia
Levee Ponds for Catfish Production

- 91% of total acreage
- Average Size
  - 10 - 12 acres
- Average Depth
  - 4 - 5 feet
Pond Water Supply

- Ponds should be able to fill in 7 days or less
- Use gate or alfalfa valves to control flow
Levee Pond Construction

- Ponds last decades when properly constructed
- $1-3 K per acre
- Components
  - levee
  - depth
  - slope
  - water supply
  - drains
Pond Levee

- 20 ft wide main levee
  - harvesting equipment

- 16 ft wide side levee
  - feed trucks
Pond Depth

- **Shallow end**
  - 2.5-3.5 ft
  - prevents rooted plant growth

- **Deep end**
  - 6-7 ft (drain)
  - prevents unnecessary draining to harvest
Pond Freeboard

- Freeboard
  - height of the levee from the water surface to the top of the levee

- 2 ft recommended
  - prevents overflow
  - erosion control
Pond Types

• **Spawning**
  – less than 1 acre
  – easy to drain/fill

• **Fingerling**
  – 1-5 acres
  – easy to drain/refill

• **Finishing**
  – 5 acres or larger
  – draining
    • continual -- no
    • batch -- yes
Fingerling Farm
Broodstock

- 5,046 acres
- Stocking Rate
  - 1,200 – 2,500 pounds / acre
- Size Range
  - 4 – 10 pounds

Catfish Hatcheries

- 40 – 45 in MS
- Operated from April – July
- Dependent on constant water and electrical supplies
Fingerlings

- 27,920 acres
- Stocking Rate
  - 80,000 – 200,000 fish / acre
- Size Range
  - up to 100 pounds / 1000 fish

Stockers

- Acreage reported under Fingerlings

- Stocking Rate
  - 50,000 – 60,000 fish / acre

- Size Range
  - 100 – 250 pounds / 1000 fish

Finishing
Foodfish

- 162,355 acres
- Stocking Rate
  - 3,000 – 10,000 fish / acre
- Size Range
  - 1.5 pounds
- Multiple batches in pond
- 20 – 30 months (egg to harvest)

Carrying Capacity

- Maximum weight that an area can support expressed either as lbs/acre or lbs/gal/min

- 300 lbs/acre
- Feed 2,000 lbs/acre
- Feed and aeration 2,000 - 8,000 lbs/acre
Wells & Electrical Supply
Generators
Aeration Equipment
Fish Feed

Catfish

- Crude protein not less than 32.0%
- Crude fat not less than 3.5%
- Crude fiber not more than 7.0%

Hybrid Striped Bass

- Crude protein not less than 36.0%
- Crude fat not less than 4.0%
- Crude fiber not more than 6.0%
Pond Production Rates

- Variables
  - feed
  - aeration
  - harvest method
    - continual
    - batch
- 1,000 to 10,000 lbs./acre
2 - Raceways
US Trout Industry

- 561 farms nationwide
- Farms located in 42 states
- Average sales per farm - $129,473
- 108 farms account for 86% of total sales
Raceways

- Site selection
  - water supply
  - location
  - topography
- Types
  - series
  - parallel

- Construction
  - material
  - dimensions
  - earthen construction
  - concrete construction

- Production rates
Raceway Site Selection

• Water supply
  – use large quantities of water
  – gravity springs are most economical
• Location
  – near water supply
• Topography
  – 8-10 percent slope
  – 18-24 inch water drop
Raceway Types

• **Series**
  – flow through multiple races

• **Parallel**
  – flow through one race
Raceway Construction

- **Materials**
  - “any” non-toxic material
  - must hold water
Trout Culture
Raceways

• Yield
  - 15-20,000 lbs for every 500 gallon/min flow

Concrete Raceway

Earthen Raceway
Raceway Dimensions

• Ratio of 30:3:1
  – aids in water flow
  – self-cleaning
  – easier harvest

For Example: 120 ft x 12 ft x 4 ft
Water Supply - Sources

- Groundwater (spring or well)
- Surface water (stream or lake)
Water Supply - Quantity

• Hatchery – 50 to 100 gpm minimum
  • Dependent on size of farm to be supplied

• Production farm – 40 to 80 lb trout harvested per gpm water flow
  • Applicable limiting factors will determine production capacity
Water Supply - Quality

- Optimum temperature range for trout production is 12° - 18°C
- Oxygen at saturation, minimum 7 mg/L at inflow
- pH 6.5 to 8.5
- Free CO₂ < 20 mg/L
- Total alkalinity 10 – 400 mg/L
- Total gas pressure near 100%
The Beginning – Trout Eggs
Early Rearing

- Usually purchase eggs
- Transfer to shallow tanks in hatchery
- Begin feeding when swim-up, 7 to 10 days post-hatch
- Usually moved outdoors when they reach 3 inches
Feeding Trout

- Hand feeding
- Timer operated feeders
- Demand feeders
- Blower/other mechanical
Grading Trout

- Grade or sort 2-4 times during production cycle
- Better size uniformity
- Increased fish performance
- Selecting market-size trout
Raceway Production Rates

- **Variables**
  - feed
  - aeration
  - harvest method
    - continual
    - batch

- **20,000 to 45,000 lb/ft^3/sec.**
  - (449 gals/min)
3 - Cages & Pens

- Site selection
  - water sources
  - water quality

- Types
  - round
  - rectangular

- Construction

- Production rates
Cage Site Selection

- **Types**
  - Farm Ponds
  - Barrow pits

- **Specifications**
  - 1 acre minimum
  - 4-5 ft. average depth
  - no wild fish (best)
  - few aquatic plants

20 acre barrow pit
Cage/Pen Types

- **Types**
  - Round
  - Rectangular

- **Size**
  - is based on economics and management
Cage Culture

- Allows deep farm ponds or lakes to be used for production
- Low investment
- Decrease in production rate
Construction

• Sizes
  – small cages less than 200 ft^3
  – large net pens for salmon production

• Materials
  – non-toxic
  – durable
  – retains fish
  – allow floatation
Salmon Pen Culture
HAVE BEEN HERE 1500 DAYS
STILL WAITING FOR A PERMIT
HELP!
Cage/Pen Production Rates

- **Variables**
  - feed
  - aeration
  - harvest method
    - continual
    - batch

- **Carrying capacity**
  - 10-20 lb/ft³
  - no more than 1,500-2,000 lb/acre
4 - Recirculating Aquaculture System
Recirculating Systems

• Site components
  – pump house
  – emergency generator
  – 3-phase electricity
  – bulk feed storage
  – oxygen supply
  – building

• System components
  – oxygen
  – biological filter
  – buffering system
  – heaters/chillers
  – solids filter
  – lighting
  – tanks

• Production rates
RAS Production Rates

- Variables
  - feed
  - aeration
  - harvest method
    - continual
    - batch
- ¼ to 1 lb/gallon
Summary

- Ponds, raceways, cage/pens, and recirculating systems are predominant production facilities in use today.
- All require large quantities of quality water.
- All systems have production inputs, discharges, and products.
- Aquaculture is a growing industry in US and world and is coming under regulation.
- How to manage aquaculture effluents.
"Using MARORA to Assess Economic and Environmental Impacts of On-Farm Reservoirs"

Dr. J. Popp, K. Young, E. Wailes and J. Smartt,
University of Arkansas, Dept. of Agricultural Economics and Ag Business
Using MARORA to Assess Economic and Environmental Impacts of On-Farm Reservoirs

J. Popp, K. Young, E. Wailes, & J. Smartt
Department of Agricultural Economics and Agribusiness
University of Arkansas
Introduction

- Nearly 4 million of a total 7.7 million acres of harvested cropland are irrigated in Arkansas.

- Dominant crops: rice, cotton, & soybeans.

- The annual farm value is nearly $1.5 billion plus $2.5 billion in further processing (USDA,NASS,2000).
Introduction

- Rice, soybean and cotton production rely heavily on well water pumped from the alluvial aquifer.

- Extensive pumping is resulting in the steady depletion of this aquifer.

- At this rate, aquifer-dependent rice and soybean in much of eastern Arkansas will not be sustainable for more than 20 years.
Introduction

Farmers are turning to on-farm reservoirs and tail water recovery systems to assist in meeting their water requirements.

These reservoirs/recovery systems may produce an added benefit – reducing the amount of sediment that leaves a field.
Purpose

Evaluate the use of on-farm reservoirs/tailwater recovery systems in conjunction with other BMPs with regard to:
- economics
- water use
- sediment loadings

Evaluations conducted with the MARORA model
Presentation Outline

- Groundwater situation
- MARORA model
- Evaluation of management practices
- Results
- Conclusions
Groundwater Situation

Nearly half the state under current, future or proposed critical groundwater area designations.
Groundwater Situation

- Diversion of additional surface water
  - potential for ecosystem damage
  - potential for exacerbated sedimentation problems (focus of TMDL in Arkansas).

- TMDL requirements:
  - L’Angille River – reduce non-point source sediment loadings by roughly 40% during critical periods
On-farm Reservoir

Can reduce dependence on ground & other surface water sources
Tail Water Recovery

Designed to capture most farm runoff and reduce sedimentation of surface waters
MARORA Model

- **Modified Arkansas Off-stream Reservoir Analysis**
- Uses weather, farm, field, and economic data related to rice and soybean production to simulate income and expenses associated with on-farm reservoirs.
  - optimization mode: identifies reservoir size that will maximize NPV income over 30 years.
  - non-optimization mode: calculates costs and returns for a specified reservoir size
MARORA  Modified Arkansas Offstream Reservoir Analysis simulation program

Developed at the University of Arkansas Fayetteville

Principal investigators
Eric Wailes
Kenneth Young
James Smartt
### Field And Crop Data

<table>
<thead>
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<th>Parameter</th>
<th>Value</th>
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<tbody>
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<td>Average elevation of fields in feet</td>
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<td>Mean of solar radiation sine wave</td>
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<tr>
<td>Soil evaporation parm (usoil)</td>
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<td>Rice evapotranspiration coefficient</td>
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<td>Maximum expected rice crop yield</td>
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<td>Soybean crop yield reduction coefficient</td>
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<tr>
<td>Days until rice maturity</td>
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<td>Percent of acreage planted in rice</td>
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<td>Duck lease rate (dollars/acre)</td>
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<td>Available water in root zone</td>
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<td>Soil albedo (decimal)</td>
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<td>Discount rate</td>
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<td>Cost Item</td>
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<tr>
<td>Rice other cost</td>
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</table>
(MARORA Results)

*** SUMMARY OF RESERVOIR CHARACTERISTICS ***

DESIGN CHARACTERISTICS:
CAPACITY = 220.00 ACRE-FEET
EXCAVATED DEPTH = 1.85 FEET
STORAGE HEIGHT ABOVE GROUND LEVEL = 8.15 FEET
FREEBOARD = 1.50 FEET
TOTAL DEPTH = 11.50 FEET
LEVEE SLOPE OUTSIDE = 3:1
LEVEE SLOPE INSIDE = 3:1
BOTTOM BASE OF RESERVOIR = 971.44 FEET
TOTAL BASE OF RESERVOIR = 1067.44 FEET
AREA OCCUPIED = 26.16 ACRES
AREA OF FOREGONE PRODUCTION = 26.16 ACRES
REMAINING IRRIGATED AREA = 293.84 ACRES
TOTAL SOYBEAN ACRES = 195.99 ACRES
SOYBEAN ACRES AFTER YEAR 4 = 293.84 ACRES
TOTAL RICE ACRES = 97.85 ACRES
RICE ACRES AFTER YEAR 4 = 0.00 ACRES

ASSOCIATED COSTS:
EXCAVATION COST AT 1.00 /CU YD = $ 74375.04
SEEDING COST AT 700 /AC = $ 4829.14
COST OF LIFT PUMP(S) = $ 7000.00
COST OF SURFACE IRRIGATION PUMP(S) = $ 7000.00

TOTAL CONSTRUCTION COST = $ 88375.15

(MARORA Results)
--- SUMMARY OF SOIL LOSSES ---

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<thead>
<tr>
<th>YEAR</th>
<th>SOIL LOST (CU-YDS)</th>
<th>SOIL RECOVERED (CU-YDS)</th>
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<tr>
<td>1</td>
<td>3.4</td>
<td>13.4</td>
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<td>2</td>
<td>3.4</td>
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<td>3</td>
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<td>4</td>
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<td>5</td>
<td>18.6</td>
<td>74.6</td>
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<td>6</td>
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<td>61.4</td>
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<td>7</td>
<td>4.1</td>
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<td>8</td>
<td>16.0</td>
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<td>10</td>
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<td>53.0</td>
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<td>18.9</td>
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<td>24</td>
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<td>18.9</td>
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<tr>
<td>31</td>
<td>8.4</td>
<td>33.5</td>
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</tbody>
</table>
Analysis

- Evaluation of reservoirs and BMPs with respect to:
  - economics
  - water use
  - sedimentation losses

- Best Management Practices (BMPs):
  - shorter season rice
  - irrigation efficiency - underground pipe only
  - irrigation efficiency - underground pipe & laser leveling
Model Assumptions

Baseline model assumptions:

- 320 acre field; reservoirs result in the reduction of cropland area by the area occupied by the reservoir.
- Specified reservoir filled once in spring from surface water and field runoff; tail water returned throughout the system.
- Crop rotation: 2/3 soybean, 1/2 rice.
- Silty loam soil.
- Discount rate 8%.
- Crop prices adjusted to reflect price plus gov’t pmts.
- Production costs from the 2001 CES budgets.
- Laser leveling $300/ac.
Model Assumptions

Baseline model assumptions (con’t)

- excavation costs for reser construction $1.00/cu yd
- underground pipe cost $50.00/ac
- soybean yield 50 bu/ac and rice yield 160 bu/ac
  - laser leveling can increase yields by 8.5% in BMP scenarios
- irrigation efficiency: 50% rice; 45 % soybean
- water recovery efficiency: 80% (based on relift pump and temporary on field storage availability)
- good ground water: 50 ft sat thick, 0.5 ft annual decline
- poor ground water: 30 ft sat thick, 1.0 ft annual decline
- projection period: 30 years
Baseline Analysis - “Good” Ground Water Situation

Good ground water supply situation:
- 50 ft saturated thickness
- 0.5 ft annual decline
- 320 acre field

- Reservoir not profitable over 30 year period
- Sensitivity analysis shows profitability of reservoirs starts at roughly 35 ft sat thick
- Average annual sediment loss: 38.12 tons
Baseline Analysis - “Poor” Ground Water Situation

Poor ground water supply situation:
- 30 ft saturated thickness
- 1.0 ft annual decline
- 320 acre field

- 620 ac ft reservoir (251 ac left in production)
- Average yearly income $40,485
- Irrigation water: rice 42.6” soybean 24.8”
- Soil: lost 7.12 tons, recovered: 28.48 tons
### Short Season Irrigation

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<td></td>
<td>ac ft</td>
<td>$</td>
<td>in</td>
<td>in</td>
<td>tons</td>
<td>tons</td>
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<tr>
<td>Base Run</td>
<td>620</td>
<td>40,485</td>
<td>42.6</td>
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<tr>
<td>5 days</td>
<td>580</td>
<td>41,583</td>
<td>40.5</td>
<td>23.3</td>
<td>7.24</td>
<td>28.96</td>
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<td>10 days</td>
<td>580</td>
<td>42,303</td>
<td>38.9</td>
<td>23.8</td>
<td>7.24</td>
<td>28.96</td>
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<td>15 days</td>
<td>500</td>
<td>43,232</td>
<td>36.7</td>
<td>20.0</td>
<td>7.48</td>
<td>29.92</td>
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<td>20 days</td>
<td>500</td>
<td>44,009</td>
<td>34.9</td>
<td>20.6</td>
<td>7.48</td>
<td>29.92</td>
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### Increased Efficiencies – Underground Pipe and Laser Leveling

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<td>39,471</td>
<td>21.3</td>
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<td>40,400</td>
<td>21.4</td>
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<td>20.3</td>
<td>10.8</td>
<td>4.09</td>
<td>16.34</td>
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Summary and Conclusions

- On-farm reservoirs/tail water recovery systems have the potential to capture much of the sediment that would have left the farm.

- Sedimentation recovery is tied to efficiency of tailwater recovery system:
  - Tail water pit and pump: 5-25%
  - Tail water pit, pump and temp in-field storage: 10-40%
  - Reservoir, tail water pit and pump: 10-50%
  - Reservoir, tail water pit, pump and temp in-field storage: up to 90%
Summary and Conclusions

- Under good ground water supply conditions, sedimentation reductions do not pose a sufficient benefit to support construction of reservoir.
  - Regulatory environment could change that in the future.
  - Cost sharing opportunities might reflect benefit of reduced sedimentation to surface waters.
Summary and Conclusions

- Under poor ground water supply conditions, BMPS such as reservoirs, laser leveling and underground pipes can:
  - enhance profits
  - reduce ground water dependency
  - reduce surface water sedimentation

- Management practices such as shorter irrigation seasons that may increase profitability and reduce water usage, may actually increase sedimentation loss
On-going Research

- Incorporate salt and water balance model in order to blend surface and ground waters to reduce potential for crop (rice) damage due to salinization
Questions?
Using MARORA to Assess Economic and Environmental Impacts of On-Farm Reservoirs

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Introduction

Roughly 4 million of a total 7.7 million acres of harvested cropland are irrigated annually in Arkansas (USDA, NASS, 2002). More than 75 percent of the irrigated acres are in rice and soybean production; the remainder is in cotton. Irrigated agriculture in eastern Arkansas is heavily dependent upon ground water pumped from the alluvial aquifer. Extensive pumping is resulting in the steady depletion of this aquifer. At this rate, aquifer dependent rice and soybean production in much of eastern Arkansas will not be sustainable for more than 20 years. Eastern Arkansas is part of the Mississippi Delta region and these resource conditions are representative of the Mississippi Delta region as a whole.

Farmers are turning to on-farm reservoirs and tail water recovery systems to assist in meeting their water requirements. The reservoirs store rain water, ground water and surface water until water is needed on the field. Tail water recovery systems capture run off water as it is leaving the field so that it can be recycled throughout the production system. These reservoirs and tail water recovery systems may produce an added benefit by reducing the amount of sediment that leaves a farm. This is especially important as sedimentation is the number one problem affecting surface waters in Eastern Arkansas and is also the focus of the Total Maximum Daily Load (TMDL) discussions in the state.

Researchers at the University of Arkansas have developed a simulation model to study the use of on-farm reservoirs and tail water recovery systems in the management of rice and soybean production in Eastern Arkansas (Smartt et al., 2002). This model, the Modified Arkansas Off-Stream Reservoir Analysis (or MARORA) model, is a farm level irrigation management and investment simulation framework that evaluates the economics of multi-source (ground and surface) water supplies for Arkansas rice and soybean farms under various
farm resource conditions. The model can be used to provide an analysis of the economics of on-farm reservoirs in conjunction with other best management practices (BMPs) that can protect ground water availability, sustain irrigated agricultural production and perhaps improve surface water quality in the Arkansas Delta.

The purpose of this paper is to apply the MARORA model to evaluate the use of on-farm reservoirs/tail water recovery systems in conjunction with other BMPs with respect to: 1) economic costs and returns, 2) amount of water used in the production process and 3) sediment loadings captured in the field.

**Background and Literature Review**

*Water Quantity and Quality Concerns*

All of eastern Arkansas is underlain by the deep water Sparta aquifer and the more shallow water Mississippi River Valley Alluvial aquifer. Ground water from the Mississippi River Alluvial Aquifer has been the primary source of irrigation water in Eastern Arkansas. Due to intensive pumping of ground water in the Arkansas Delta the aquifer has developed major cones of depression. Recharge of the aquifer is limited by a hard pan soil stratum to 2 cm per year (Ackerman, 1996). The current irrigation system relies on ground water sources that are not sustainable in the long-run (Hays, Czarnecki and Terry, 2001). In addition to a quantity constraint, the cone of depression is altering the direction of ground water flow and causing salt water to migrate into fresh water zones (ASWCC, 1999). Excessive pumping has contributed to widespread problems of ground water salinity throughout the Arkansas delta, rendering the water unsuitable for sustainable irrigated agriculture (Baker et al., 1996; Gilmour, 2001).
Producers have responded to the depletion of the alluvial aquifer by drilling additional wells in the alluvial aquifer and drilling new wells to deeper aquifers such as the Sparta Sand and Memphis Sand. These deeper aquifers are confined aquifers with storage capacities that are less than that of the alluvial aquifer; hence, these sources are not predicted to sustain irrigated agriculture in the region due to aquifer characteristics and increased pumping costs. While the water quality from the Sparta Sands and Memphis Sands aquifer is excellent, municipalities in the region rely upon these aquifers and have priority over agricultural and industrial uses. Therefore, irrigated agriculture in eastern Arkansas is not sustainable at current levels in terms of quantity and quality of ground water sources.

To reduce the dependence on ground water use, some proposals such as the White River Diversion Project have called for large scale stream diversion of surface water for irrigation purposes (USACE, 1998). The White River Diversion Project has been challenged by environmentalists that are concerned about ecosystem damage associated with large scale water withdrawal. Large scale water divisions churn the surface waters as water is removed from the source. As a result, the in-stream flow of the surface water source may be reduced while the water itself may be more turbid. Thus water division at this scale may exacerbate the sedimentation problems that already plague surface waters in the Delta. In many parts of eastern Arkansas, the quality of the surface water is better than that of the ground water. While ground waters have had negative impacts on agricultural production, agricultural production has impacted the quality of surface waters. Water quality in the Delta Region is highly influenced by non-point source runoff generated from highly agriculturalized areas. Some research suggests that many of the Arkansas waterways do not support aquatic life due to elevated levels of siltation and sedimentation (turbidity) (FTN Associates, Ltd., 2001; ARDEQ, 2001).
Additionally the highest incidence of measurable pesticide residue in the water occurs in this region (FTN, Associates, Ltd., 2001). Some recommendations have suggested that in order to meet aquatic and human use criteria, turbidity levels must be reduced by nearly 50 percent in summer periods (FTN Associates, Ltd., 2001). It is likely that many of the suggested reductions will be imposed on agricultural producers. On-farm reservoir systems are designed to capture most farm runoff and thereby prevent sedimentation movement into surface waters.

*Best Management Practices for Irrigated Rice and Soybean Production*

Farms can decrease water needs for rice and soybean production by increasing irrigation efficiency with approved best management practices. Some of these practices include shorter season rice varieties, land leveling, irrigation pipelines, on-farm reservoirs and tail-water recovery systems. Shorter season rice varieties reduce the amount of time the field needs to be flooded. Some varieties can reduce the amount of flooded time by 5 to 20 days. Irrigation pipelines can increase irrigation efficiency by roughly 10 percent compared to open canals by reducing evaporation and seepage losses (Tacker, 1999). Land leveling eliminates high spots in a field, which decreases the irrigation flood depth requirement and allows better drainage. As a result, irrigation is approximately 10 to 20 percent more efficient because less water is needed to flood the field (Tacker, 1999). Land leveling and underground pipe may produce an added benefit. On-farm reservoirs collect and store runoff to use for irrigation during the cropping season. Tail-water recovery systems collect runoff water from the farm and channel it to a storage pit where the runoff is pumped into the on-farm reservoir if present. Tail-water recovery systems usually are constructed with a reservoir, but can function separately if the tail-water irrigation storage pit is large. Water management and water quality are improved by tail-water recovery systems by recycling water throughout the farm (USACE, 1998).
The MARORA Model

Previous research has estimated the net economic benefits of supplementing ground water with surface water sources, on-farm reservoirs, and tail-water recovery systems to the current ground water irrigation management (Wailes et al., 1999, 2002). This research has been conducted using the MARORA model. MARORA can be run two ways. When run in Optimization Mode, the model determines the optimal size and use of the on-farm reservoir needed to maximize a 30-year time-stream of net returns to the farming operation (Young, Wailes and Smartt, 1998). When run in Non-optimization mode, MARORA calculates costs and returns for a specified reservoir size.

The MARORA simulation model evaluates daily weather data to predict the crop yield response, irrigation demand, reservoir use and water balance, well use and well yield, and associated pumping costs in each growing season. The weather data are generated stochastically with the Wingen Model applied to Stuttgart, Arkansas. Major changes in the irrigation system include construction of on-farm reservoirs to supplement well use and access to surface water sources such as bayous and canals. These modifications are evaluated over a 30-year period to determine the impact on the discounted present worth of annual net farm income over the projected period.

This analysis uses the MARORA model to evaluate the impacts of on farm reservoirs and tail water recovery systems in conjunction with other BMPs with respect to economic returns, water use and sedimentation losses. Two baseline models were developed. The Strong Ground Water scenario assumes a 50 ft saturated thickness and a 0.5 ft annual decline in the water level. The Weak Ground Water scenario assumes a 30 ft saturated thickness and a 1.0 ft annual decline in the water level. These assumptions represent two general cases in Eastern Arkansas. Both
baseline models include the following assumptions. (1) Weather and silt loam soil conditions are used that are representative of Stuttgart, Arkansas, one of the largest rice producing areas of the state. (2) A reservoir is assumed to service a 320 acre field, and the construction of a reservoir would result in the reduction of the available crop land in the field by the amount of area occupied by the reservoir. (3) A reservoir is filled once in the spring from surface water and field runoff and tail water is returned throughout the system. (4) As rice and soybeans are grown in a 1 to 1 rotation in Stuttgart, Arkansas, the model field is comprised of 50 percent rice and 50 percent soybeans in the first year of the simulation. The ability to maintain that rotation in future years can be impacted by weather and water availability. (5) The maximum annual soybean and rice yields are 50 bushels per acre and 160 bushels per acre, respectively. This is a conservative estimate based on 10 year averages in Stuttgart, Arkansas. (6) Water recovery efficiency is 80 percent, based on relift pump and temporary on field storage availability (Fooks, 2002). (7) Baseline irrigation efficiency with no water conservation improvements is 50 percent for rice and 45 percent for soybeans (Tacker, 1999). (8) Production costs reflect those in the 2002 University of Arkansas Crop Production Budgets (Windham and Laferty, 2002a, 2002b, 2002c). (9) The discount rate used to calculate net present value of costs and returns is eight percent. (10) Crop prices are adjusted to reflect price plus government payments. (11) Laser leveling was priced at $300 an acre. (12) Excavation costs for reservoir construction were priced at $1.00 per cubic yard. (13) Underground piping was priced at $50.00 an acre. (14) The projection period is 30 years.

Using these assumptions, the two baseline models are run to determine if an on-farm reservoir is an economically efficient management practice for rice and soybean production on the 320 acre field under good and poor ground water situations. Economic returns, water use and
sedimentation runoff are monitored for the baselines. Next, in the event that a reservoir is deemed profitable, impacts of on-farm reservoir and tail water recovery systems in conjunction with other BMPs are examined. These BMPs include shorter season rice varieties which result in removal of flood waters 5, 10, 15 or 20 days earlier than full season rice; improvements to irrigation efficiency by adding underground pipe only; and improvements to irrigation efficiency by adding underground pipe and laser leveling the field. Underground pipe is expected to increase irrigation efficiency by 10 percent (such that rice/soybean irrigation efficiency increases from 50/45 to 50/55, respectively), whereas laser leveling can increase irrigation efficiency by 10 to 20 percent (Tacker, 1999).

Results

Baseline Scenarios

Rice and soybean production was first simulated using the Strong Ground Water and Weak Ground Water baseline characteristics. Results of these simulations are found in Table 1. The reservoir and tail water recovery system was not profitable in the Strong Ground Water scenario. Sensitivity analysis suggests that the reservoir does not become profitable until saturated thickness falls to 35 ft.

In this Strong Ground Water scenario, the manager of a 320 acre field earned an average annual return of $63,277 over the 30 year period. Water usage was relatively high - 39.9 acre inches and 26.2 acre inches for rice and soybeans, respectively - and contributed to average annual production of 160 bushels per acre of rice and 50 bushels per acre of soybeans. While economic returns to this system are great, sediment losses are also large, averaging 382 tons annually or 14,460 tons over the full 30 year period. As reservoirs are not profitable in this
Strong Ground Water scenario, no further analyses of the impacts of reservoirs and BMPs were conducted.

Reservoir construction for the Weak Ground Water scenario was profitable. A 620 acre-foot reservoir and tail water recovery system was constructed that removed 70.66 acres from the available cropping acreage. In utilizing the reservoir, a manager could use on average 38.9 acre-inches of water on rice and 25.4 acre-inches on soybeans. The remaining cropland averaged 49.5 bushels per acre annually for soybeans and 156 bushels per acre for rice, which are nearly as good as the yields in the Strong Ground Water scenario. Average annual returns were reduced from the Strong Ground Water situation to $49,280. Over the 30 year period roughly 66 tons of soil nutrients and pesticides were lost on average from the field annually (or 1,965 tons over 30 years), whereas 262 tons annually (or 7,863 tons over 30 years) were retained. While economic returns may be less than in the Strong Ground Water scenario, environmental benefits with respect to sediment control are created in two ways. First, reservoir construction reduces the amount of surface area from which soil can move. Total (lost and recovered) soil movement in the Weak Ground Water scenario was less (9,828 tons) than in the Strong Ground Water Scenario (11,460 tons). Secondly, reservoirs and tail water recovery systems have the capability to capture much of what is moved before it can leave the farm and potentially cause environmental damages elsewhere. That is, over the thirty year period, less than 2000 tons of sediment escaped the field in the Weak Ground Water scenario whereas more than 5 times that left the field in that same time period in the Strong Ground Water scenario.

As reservoirs were found to be profitable in the case where a Weak Ground Water situation exists, impacts of reservoirs along with other BMPs were examined to determine
whether the addition of other BMPs impacted the reservoir size, economic returns, water use and soil movement.

Shortened Season Varieties

Simulations were run next to determine what the impact of a reduction in the rice growing season would be on returns, reservoir size, water use and soil movement. Four scenarios were run assuming a five, ten, fifteen and twenty day reduction in the needed growing season. Results are presented in Table 2. Results from the Weak Ground Water baseline scenario are also presented again for comparative purposes. This study found that compared to the baseline scenario, the reduction in the growing season by 5 to 20 days can increase average annual income by $2,393 to $6,606, reduce needed reservoir size by 40 to 100 acre feet, and reduce total annual water needs by roughly 2 to 7 inches. Increases in economic returns are made mainly through reductions in costs. Total (lost and recovered) soil movement increased by up to 20 tons annually as less land area was needed for reservoir construction, however, the majority of that was captured within the system. At most, only an additional 3 tons annually was lost over the 30 year period. Thus, the inclusion of reduced season rice was found to greatly improve economic returns and reduce water needs without creating large additional amounts of sediment movement off farm.

Increased Irrigation Efficiencies

Increases in irrigation efficiencies over the baseline level were examined three ways: 1) 10 percent from added underground pipe, 2) 10 percent from pipe and 10 percent from laser leveling and 3) 10 percent from pipe and 20 percent from laser leveling. These three scenarios
represent an increase in irrigation efficiencies for rice/soybeans from 50/45 to 60/55, 70/65 and 80/75, respectively. As expected, results suggest that the greater the irrigation efficiency, the smaller the reservoir needs to be. Actual reservoir sizes fell from 620 acre feet in the baseline scenario to 560 acre feet with the addition of underground pipe and finally to only 440 acre feet when irrigation efficiency increased to 80/75 for rice/soybeans with underground pipe and laser leveling. While each additional water conservation practice did result in additional water savings, as shown in Table 3, these savings accrued at a diminishing rate. Economic returns increased slightly. For reasons stated earlier, annual total soil movement increased as optimal reservoir size decreased. However, when compared to the Weak Ground Water baseline scenario, the magnitude of the changes in soil lost off the field (6 tons annually or 10 percent increase) was minor compared to the changes in water use (24.7 inches or 38 percent reduction) and changes in annual returns ($5,528 or 11 percent increase).

**Summary and Conclusion**

This research was conducted to determine the impacts of reservoirs and tail water recovery systems in conjunction with other BMPs on annual returns, water use, and sediment movement along and off the field under two assumed ground water situations. A Strong Ground Water scenario was developed that assumed an initial saturated thickness of 50 ft and an annual decline rate of 0.5 ft. Results suggest that reservoir construction under these ground water conditions is not profitable. However, the lack of reservoir and tail water recovery systems results in a missed opportunity to reduce sediment losses from the field. Under the current regulatory environment irrigators do not have a financial incentive to prevent sediment losses
with irrigation reservoirs and tail water recovery systems. Further incentives are needed in order to produce benefits of reduced sedimentation to surface on from fields where strong ground water situations exist.

Under the assumed weak ground water supply conditions, reservoirs and tail water recovery systems may become a profitable way to manage scarce water conditions and control the amount of runoff that leaves the farm. When used in conjunction with other BMPs such as shorter season rice varieties, laser leveling, and underground pipe, profits may increase further while water needs are reduced. However, reductions in water needs may reduce the optimal reservoir sizes which in turn increase the amount of available cropland and possibly the amount of sedimentation movement. However, the economic and water savings benefits provided from these practices likely offset any costs brought on by minimal increases in sediment movement off the farm.

Evidence from this study supports the use of on farm reservoirs and tail water recovery systems as an effective method of supplying needed irrigation water. In addition, these systems can provide an additional benefit by controlling the amount of sediment that leaves the farm. Increased public awareness of these conservation benefits may further promote the use of on-farm reservoirs and tail water recovery systems in areas affected by sedimentation problems.
References


### Table 1 Results of Baseline Scenarios

<table>
<thead>
<tr>
<th>Ground Water Situation</th>
<th>Optimal Reservoir Size</th>
<th>Average Annual Income</th>
<th>Average Annual Water Use Rice</th>
<th>Average Annual Water Use Soybeans</th>
<th>Average Annual Soil Loss</th>
<th>Average Annual Soil Recovered</th>
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### Table 2 Impacts of Short Season Varieties and On-farm Reservoirs and Tail Water Recovery Systems, for “Weak Ground Water” Situation

<table>
<thead>
<tr>
<th>Rice Season Shortened By</th>
<th>Optimal Reservoir Size</th>
<th>Average Annual Income</th>
<th>Average Annual Water Use Rice</th>
<th>Average Annual Water Use Soybeans</th>
<th>Average Annual Soil Loss</th>
<th>Average Annual Soil Recovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Weak Situation” Baseline</td>
<td>620</td>
<td>49,280</td>
<td>38.9</td>
<td>25.4</td>
<td>65.5</td>
<td>262.1</td>
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<tr>
<td>5 days</td>
<td>580</td>
<td>51,673</td>
<td>37.1</td>
<td>25.3</td>
<td>66.8</td>
<td>267.0</td>
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<tr>
<td>10 days</td>
<td>580</td>
<td>53,376</td>
<td>35.5</td>
<td>25.5</td>
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<td>15 days</td>
<td>540</td>
<td>54,672</td>
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<td>25.0</td>
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Table 3  Impacts of Various Irrigation Efficiencies and On-farm Reservoirs and Tail Water Recovery Systems, for “Weak Ground Water” Situation

<table>
<thead>
<tr>
<th>Increase in Irrigation Efficiency (Improvements to rice yields)</th>
<th>Optimal Reservoir Size</th>
<th>Average Annual Income</th>
<th>Average Annual Water Use Rice</th>
<th>Average Annual Water Use Soybeans</th>
<th>Average Annual Soil Loss</th>
<th>Average Annual Soil Recovered</th>
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</thead>
<tbody>
<tr>
<td>“Weak Situation” Baseline</td>
<td>ac ft</td>
<td>$</td>
<td>in</td>
<td>in</td>
<td>tons</td>
<td>tons</td>
</tr>
<tr>
<td>10% - pipe only</td>
<td>620</td>
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<td>20% pipe and leveling</td>
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<td>14.9</td>
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"The Value of Winter Flooded Rice Field as a Surrogate Wetlands: Some Preliminary Findings From Market and Non-Market Perspectives"

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Market and Non-Market Valuation of
Winter Flooded Rice Land in Mississippi Delta

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ABSTRACT

This study consists of three parts. The first is based on a biophysical-optimization model developed to evaluate the on-farm cost of controlling non-point pollution (NPP) through winter flooding practices in the Mississippi Delta. The model estimates the amount of land to be allocated for rice production, as well as acreage of land to be winter-flooded, to obtain optimal profit. Next, a travel cost model based is used to derive consumer surplus from flooding of agricultural land. Consumer surplus obtained from the model provides estimates of potential fees for leasing winter-flooded rice fields for waterfowl hunting. Finally, a logistic model was used to examine the socioeconomic characteristics of farmers who choose to adopt winter-flooding practices. Economic variables such as yield are positively associated with flooding, while operating costs deter farmers from adopting the practices.

Introduction

Rice production is important for Mississippi’s agricultural economy with a farm value of about $1.34 billion in 2001. In 1977, rice contributed only about 3% to Mississippi’s net farm value for crop items only (excluding cattle, poultry, and aquaculture). By 1999, rice represented about 13% of the net farm value, placing it as the third most important crop in Mississippi after soybeans and cotton (MAFS, 2001). Nevertheless, Mississippi rice production is relatively small in monetary terms as compared to average U.S. production, ranking fifth after Arkansas, California, Texas, and Louisiana. However, Mississippi’s average yield is as high as, if not higher than, the national average yield and has been increasing for the last 30 years; almost 99 percent of Mississippi’s rice production is in the Delta Region.
In addition to the obvious market value of rice production, it has implications for providing extra social benefits in the form of ecological/environmental services as well as for recreation. For example, rice fields make an excellent stopover point for migratory birds and Mississippi Delta rice fields are a resting ground for an astonishing 2.5 million waterfowl every year (FWRC-MSU, 1998). The region also serves as over-wintering habitat for migratory birds along the Mississippi Flyway. With naturally occurring wetlands disappearing, winter-flooded rice fields serve as a surrogate wetland or habitat. In relation to these benefits, studies have shown that rice is one of the most environmentally friendly crops; among other things, it absorbs approximately 4 tons of atmospheric carbon out of the atmosphere per acre per season (Howart and Kessel, 1998). In addition, winter-flooding practices are a more environmentally sound way to decompose rice straw as compared to open burning. Rice straw that is rolled or incorporated into winter-flooded fields can act as a source of nitrogen for rice, and can reduce weeds, thereby limiting herbicide applications to reduce weeds (Horwart and Kessel, 1998, Elphick, 1998 and Manley, 1999).

Many scientific studies in the ecological and agronomic disciplines have discussed the benefits of winter flooding. Pioneering work by Neale in 1918 led to subsequent research and interest in the ecology of winter-flooded rice. However, analysis of the same issues within a framework incorporating economics and ecology has been rare, and this study attempts to narrow the gap.\(^1\) The results of the analysis conducted here suggest flooded fields represent an economically viable conservation practice for Mississippi rice producers, which can provide substantial social benefits.

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\(^1\) Details of the models presented in this paper can be found in Kani, 2002.
Bioeconomic Modeling of Agricultural Pollution Abatement

The first part of the analysis combines biophysical and economic optimization models to analyze impacts of winter flooding in the Mississippi Delta. The results indicate that alternative farm systems will be impacted differently. Across various farm systems, those practicing winter flooding have relatively higher returns than those using conventional practices. This study shows that reducing nitrogen, phosphorus, and soil erosion, as would be the case with imposition of standards on total maximum daily loads (TMDL), imposes additional costs on farmers. Costs of pollution abatement are higher the higher the restriction imposed on nonpoint pollution (NPP).

The bioeconomic model was used to simulate income variability under various assumptions about pollution abatement and crop systems. Overall, the shadow prices generated from the study indicate that winter-flooded rice fields have a higher market value than non-flooded fields. The on-farm marginal cost of pollution abatement can be used as a tool to determine resources used for water quality improvement. Alternatively, the marginal cost can be used as an indirect measure of how much farmers should be compensated for water quality improvements. The shadow price of winter-flooded land is positively correlated with the acreage flooded, and such information can be indirectly used to assess the value of wetlands as winter-flooded rice fields represent surrogate wetlands. Leasing winter-flooded land for waterfowl hunting may reduce the variability of net revenue due to changes in operation costs and a declining crop price.

These results have several significant implications for policy. The model demonstrates that unnecessarily stringent regulations will result in increasing rates of farm income loss. To avoid such impacts, policy must be designed to minimize the cost of meeting environmental objectives. A cost flexibility ratio was derived in the study that can be used to evaluate the effectiveness of a pollution
reduction plan, given as $\lambda_{VC} = \frac{MC}{AVC}$, where $MC$ is marginal abatement cost and $AVC$ is average variable abatement cost.

In this study, it was found that runoff reduction beyond 40% result in increasingly higher cost flexibility ratios, after which the cost of pollution abatement will increase at an increasing rate. Table 1 reports the marginal costs associated with different levels of nitrogen abatement; these range from $2.55 for a 15% reduction in N ppm to around $120 for reduction over 40%. The analysis also shows the possible impact of regulations that limit levels of different types of agricultural NPP. The study establishes that pollution abatement for nitrogen would be much more expensive than phosphorous and sedimentation limits in the Mississippi Delta; Table 2 reports different expected values of marginal abatement costs for nitrogen, phosphorous and sediment. In this regard, the study provides a simple method to establish criteria to implement policies related to different sources of NPP.

An important finding of this study is that water quality improvements can be achieved by assigning more acreage for winter flooding as part of farm management practices. Similarly, the marginal cost of pollution abatement derived in the study indicates that on-farm cost tends to rise at an increasing rate as pollution is reduced (Qiu et al., 2001). Different types of pollution abatement (nitrogen, phosphorous, and sedimentation rate) produce different on-farm marginal costs, and environmental constraints will reduce farm profit irrespective of policy type (i.e., per farm abatement or aggregate abatement). However, an aggregate abatement policy applied to the entire Delta region was found to generate a much lower reduction in profits as compared to abatement policies imposed at the level of individual farms. In this regard, aggregate abatement may be a better policy choice. Winter-flooded rice fields can reduce runoff and improve water quality as compared to conventional practices. Fields that adopt winter flooding have a profit 2% to 7% higher than for conventional
practices. This study narrows the information gap between the economic, ecological and agronomic sciences, allowing policy makers to make use of multi-disciplinary information to formulate water quality improvement policies for rice farmers.

**Nonmarket Valuation of Winter Flooded Rice Fields**

An important objective for policy makers is to better understand the social value of wetlands. In the ecological and agronomic sciences, many studies have demonstrated similarities between flooded rice fields and natural wetlands. Thus, this study uses the nonmarket value of flooded rice lands as a proxy to measure the nonmarket value of wetlands. Even though nonmarket benefits are difficult to estimate and may be incomplete value measures, consumer surplus derived from nonmarket techniques can still be used to justify support programs for certain environmental services.

It is estimated that nearly of all agricultural land and 64% of rangelands are privately owned. In addition, 71% of all U.S. forestland is privately owned. As a result, a high percentage of the 141 million registered hunters across the U.S. must rely on private lands and the natural resources they offer (Jahn, 1990). Based on demand for hunting, winter-flooded land can offer recreational activities related to waterfowl hunting.

A recreation demand model is estimated from which consumer surplus is calculated as a measure of social benefits of the recreation opportunities offered to wildlife hunters. The calculated value of consumer surplus derived in this study falls within the range of values reported in similar studies that have attempted to measure the non-market value of natural wetlands, suggesting that winter-flooded fields may provide an adequate substitute for some services provided by natural wetlands.
The study uses a count data model to estimate recreation demand for flooded rice land. Recreation demand is based on preferences revealed through actual travel expenditures that are used to estimate a demand curve from which consumer surplus can be calculated (Fix et al., 2000). From the consumer surplus, the benefit of providing hunting opportunities can be determined.

Table 3 contains the descriptive statistics used in the recreation demand model, and the estimated demand model is found in Table 4. Individual willingness to pay is affected by market factors such as the expenditures spent on hunting trips. In the estimated model expected signs of major parameters of interest are theoretically consistent and similar to those of other studies that focus on the relationship between own price and consumer surplus derived from hunting waterfowl on private and public land.

The monetary value of estimated consumer surplus from the basic model is within the range of other estimates for hunting of migratory birds. Table 5 shows welfare estimate based on expected increase in the flooded acreage as compared to baseline scenario. Annual consumer surplus for Mississippi ranks the highest in terms of net benefit given a 5 to 20 percent increase in expected number of hunting trips for private and public land. Given such potential, economic incentive-based policies can be designed to encourage rice farmers to adopt environmentally desirable practices that can provide income support and compensate them for providing public amenities such as clean water and wildlife habitat. At the very least, the results of the current study suggest that researchers involved in waterfowl hunting should examine waterfowl hunting on both private and public land, as they may be jointly determined in the market. Welfare estimates obtained for winter flooded rice in Mississippi and other states provide a baseline value of the non-market benefits of winter flooding. The calculated non-market value for each state can be used to quantify environmental amenities where
acres with highest dollar value after accounting for cost should be priority areas for conservation reserve programs as shown by Table 5.

This study also uses the recreation demand model to estimate consumer surplus related to hunting on private land in Mississippi. A simple simulation procedure is applied where the estimate in the main model is used as a baseline scenario. Subsequently, a welfare estimate is calculated for every state allowing for a percentage increase in average hunting trips. In addition, a welfare estimate is also calculated for winter flooding in Mississippi based on an increase in flooded fields. The result of the simulation exercise on consumer surplus shows that physical variables such as the size and location of hunting sites as well as the number of hunting trip affect the value of non-market benefits as shown in Table 6 and 7. In Mississippi, the average farm size of was about 442 acres in 1999, as compared to 243 acres in 1985; the average size is largest of all U.S. farms. Over the same period, Mississippi’s average farm size has increased by about 81% as compared to 56% in other states (Chambers and Childs, 2000). Similarly, Mississippi total rice acreage from 1990 to 2000 increased by 27% as compared to 14% in Arkansas and 9% in Louisiana.²

Thus, it can be shown in Mississippi, nonmarket benefits can be increased through land management that could change biological parameters such as habitat quality and wildlife population. These altered environmental conditions are ultimately reflected in society’s willingness to pay for environmental amenities. Assuming these linkages hold, the results of this study show that physical and biological changes in environmental amenities will ultimately affect consumer welfare. Thus, these linkages can be enhanced by devising policy measures that could protect wildlife habitat associated with agricultural practices. Given this scenario, a model based on a non-market valuation method can be used to identify land that should be managed in order to achieve greater recreational

² Texas recorded a 32 percent decline in acreage over the same period.
benefits. From Table 5, it can be seen that the welfare estimate for Mississippi is relatively higher than other states in the region. This fact could be used to design a program based on spatial targeting where payments would be made to those producers who can achieve the largest environmental gains relative to cost. Assuming cost of winter flooding remains constant, the size of winter-flooded fields can be used as a payment base for cost-sharing program. Nevertheless, agri-environmental payments will also need to address individual farmers' property rights, which are directly affected by ecosystem and other biological characteristics of wildlife habitats.

An extension of this study would be to conduct an actual survey of hunters who only hunt on flooded rice fields in the Mississippi Delta. With such a survey, other techniques, such as the contingent valuation method and hedonic travel cost model, could be used to estimate willingness to pay for winter flooding. This would provide a more direct and realistic estimate of the social surplus associated with increasing winter flooding. Perhaps the same survey could help identify the physical, biological and behavioral relationship between environmental and non-market benefits of recreation activities. Devising approaches for including the physical and biological interactions of wildlife habitat and recreation demand is the major challenge facing recreation demand valuations.

Alternatively, a possible extension of this research would be to conduct a green marketing study for rice produced under winter-flooding practices. Such a study would use a survey to assess consumer willingness to pay for rice grown under winter flooding practices. Essentially this would capture demand for winter-flooded landscapes from consumer groups and from a larger segment of society. This would more accurately reflect society's willingness to pay for environmentally friendly farm management practices.
Willingness to Adopt Winter-Flooding Practices

The third model used in this study deals with farmers’ willingness to adopt winter-flooding practices. Farmers remain a crucial link between the agricultural economy and the environment. Many studies deal with farmers’ conservation attitudes, especially in relation to tillage, crop rotation and other best management’s practices. Winter-flooding techniques remain a unique form of conservation practice because they can save cost as well as generate income. The overall objective of the study is to assess farmers’ attitudes about, and awareness of, conservation practices such as waterfowl winter-flooding practices on rice farmland.

The data were obtained from a producer survey mailed to Mississippi rice producers in early October 2001 (Winter Flooding Survey, 2001). The first wave of 250 questionnaires generated a 40 percent return. A second wave of 250 questionnaires was mailed out to two different groups of farmers in early November 2001, yielding an additional 8 percent return. To avoid double sampling, a letter informed farmers to ignore the second wave if they had returned the first questionnaire. Respondents who were not involved in rice production were also removed from the database. These represented about 3 percent of the returned surveys. A total of 500 questionnaires were sent and the analysis in this study is based on 124 respondents that returned the questionnaire.

The survey collected information on costs and returns for winter-flooding practices, farmers’ support for the environment, their willingness to manage their land for waterfowl hunting, and future expectations regarding rice-farming activities. Questions were formulated to elicit farmers’ attitudes about adoption of winter flooding, other conservation practices, and other wildlife support and recreation activities on the farm. Survey questions were classified into four main categories: a) socio-economic status; b) winter flooding practices for waterfowl hunting; c) on-farm wildlife-related activities; and d) leasing arrangements, fees, and lease prices. Producers were asked to indicate
whether they practiced winter flooding for waterfowl hunting and if they had practiced winter
flooding for waterfowl hunting at any time during the last five years.

Table 8 contains mean values and descriptions of key variables that were obtained from the
survey. The analysis uses a logit model to assess willingness to adopt migratory habitat conservation
practices. The results reported in Table 9 indicate that economic factors such as yield, size, and costs
play an important role in farmers' decision to adopt winter flooding. Other factors such as green
membership indicate the important role of non-governmental organizations in channeling information
that influence farmers' decisions to adopt conservation practices.

The most important contribution of this section is the information it provides about specific
characteristics of farmers who practice conservation. Similarly, the study identifies major reasons why
farmers choose to adopt winter flooding as a conservation technique. The information generated in
the study could at least answer the critical question of why some farmers are willing to adopt winter
flooding given the economic and environmental benefits associated with such practices. Alternatively,
the study can be used to help understand why some farmers do not winter flood even though it is
economically viable and environmentally favorable to do so. Thus, information related to the
socioeconomic and farm characteristics of rice producers that adopt winter flooding would help policy
makers in designing agri-environmental programs. For example, good conservation practices must
not only include winter flooding of land, but also adoption of additional practices such as building
nesting structures, planting food plots and having green open space around farms. Such practices will
enhance wildlife population and hunting sites on rice farms.
Conclusion

The issue of declining rice acreage is of importance to the agricultural community as a whole. Studies conducted in other major producing regions such as Texas have shown that declines in rice acreage will lead to the problem of permanent loss of land for rice cultivation as well as winter-flooded acreage. Economic losses related to permanent loss of rice cultivation are also associated with disappearance of the rice support industries such as drying, on-farm and private storage facilities, transportation, processing, and marketing of rice in Mississippi. Once these facilities disappear, it will be extremely costly to rebuild them if there is an upward swing in domestic and global markets for rice. The declining size of winter-flooded rice along with the permanent loss of rice acreage indicates a continuous decline in wildlife sanctuary. The declining wildlife habitat associated with wetland disappearance is indeed a measure of environmental degradation.

Overall, this study provides the basis for a cost-benefit analysis of winter flooding as a conservation technique. Such a procedure is relevant in evaluating the economic value and environmental benefits of winter flooding. Given the certainty assumption used in the biophysical model, winter flooding offered a conservation alternative that benefits the environment and is economically viable. As such, monetary benefits through leasing of farm land for hunting could encourage such practices. Hence, recreation revenues might mean the difference between an unprofitable and a profitable year for a rice producer. However, the actual implementation can pose a risk to farmers. Nevertheless, winter flooding will remain attractive as long as the risk and uncertainty related to the practices does not affect baseline profits. Given the results of the analysis, there is a strong justification for why winter flooding practices should be promoted. In particular, the environmental outcomes of such practices are of significant benefit to society as a whole. A healthy
waterfowl habitat is also an index of environmental quality and sustainable development of such resources is an important policy issue.

In spite of their benefits, conservation practices will impose cost on farmers. Factor market condition such as profitability of rice production can affect farmers’ investments in land conservation. Conservation investment would be promoted if cost-sharing programs could be properly executed. At the same time, farmers face mounting conservation risk with uncertain returns. Compensation for any economic loss due to risk must also acknowledge the public good characteristics of winter-flooded fields. In the public good framework, costs are incurred by anyone willing to provide such resources, and the supply is therefore less than the marginal social benefits provided. Given such a mismatch, the results from the third essay can be used to formulate a better compensation mechanism for farmers who adopt winter flooding.

An obvious limitation of this study is that it does not address risk associated with winter-flooding practices (Cooke, 2002). The survey sent to rice farmers succeeds in obtaining baseline data regarding historical levels of land flooding. However, no attempt has been made to incorporate the risk that may affect farmers’ decisions. Risk can be in the form of soil loss, weather, and/or financial risk of winter flooding. Thus, extensions of this study should explicitly incorporate risk, as suggested by Qiu et. al (2001) and Kari (2002). Furthermore, by analyzing farmers’ attitudes towards risk, the impact of financial incentives in determining which farmers adopt winter flooding should be examined.

In conclusion, this study has succeeded in establishing baseline information on winter-flooding practices in the Mississippi Delta. Similarly, it has narrowed the information gap between the various disciplines, i.e. economic, ecology and agronomic research related to winter flooding. As such, policy formulation could be built on a better foundation using a multidisciplinary approach. More
importantly, and without ignoring the limitations addressed earlier, this study is a small step in understanding the delicate balance between markets and environmental conservation that can be achieved through agricultural practices.
REFERENCES


Table 1: Marginal Cost of Nitrogen Abatement

<table>
<thead>
<tr>
<th>Abatement %</th>
<th>Marginal Cost Range ($ Ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-15%</td>
<td>$1.78-$2.55</td>
</tr>
<tr>
<td>20-30%</td>
<td>$2.97-$3.85</td>
</tr>
<tr>
<td>30-40%</td>
<td>$4.00-$5.00</td>
</tr>
<tr>
<td>40% and above</td>
<td>$5.20-$121.00</td>
</tr>
</tbody>
</table>

Table 2: Abatement Costs for Different Targeted Pollutants

| Marginal Cost of Abatement for Nitrogen Runoff | $8.47 (Ppm) |
| Marginal Cost of Abatement for Phosphorous Runoff | $6.63 (Pounds/acre) |
| Marginal Cost of Abatement for Sediment Loss | $5.09 (Pounds/acre) |
Table 3: Summary Statistics for Hunting on Private Land

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>4,106.00</td>
<td>2,854.02</td>
<td>Personal Income ($)</td>
</tr>
<tr>
<td>Travel Cost</td>
<td>179.38</td>
<td>294.00</td>
<td>Hunting Expenditure ($)</td>
</tr>
<tr>
<td>Age</td>
<td>39.92</td>
<td>16.65</td>
<td>Number of years</td>
</tr>
<tr>
<td>College education</td>
<td>0.40</td>
<td>0.50</td>
<td>(1 = college, 0 = others)</td>
</tr>
<tr>
<td>Sex</td>
<td>0.95</td>
<td>0.20</td>
<td>(1 = male, 0 = female)</td>
</tr>
<tr>
<td>Marital</td>
<td>0.78</td>
<td>0.41</td>
<td>(1 = married, 0 = not married)</td>
</tr>
<tr>
<td>Race</td>
<td>0.95</td>
<td>0.20</td>
<td>(1 = white, 0 = non white)</td>
</tr>
<tr>
<td>Price of substitute</td>
<td>17.37</td>
<td>63.46</td>
<td>Price to hunt on public land</td>
</tr>
</tbody>
</table>
Table 4: Count Data Estimates for Hunting on Private Land

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-0.066</td>
<td>0.983</td>
</tr>
<tr>
<td></td>
<td>(3.156)</td>
<td></td>
</tr>
<tr>
<td>Travel Cost</td>
<td>-0.001**</td>
<td>0.100</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>Income</td>
<td>0.001*</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>-0.008</td>
<td>0.453</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
<td></td>
</tr>
<tr>
<td>College</td>
<td>0.007</td>
<td>0.988</td>
</tr>
<tr>
<td></td>
<td>(0.488)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>1.135</td>
<td>0.442</td>
</tr>
<tr>
<td></td>
<td>(0.455)</td>
<td></td>
</tr>
<tr>
<td>Marital Status</td>
<td>-0.314</td>
<td>0.579</td>
</tr>
<tr>
<td></td>
<td>(0.587)</td>
<td></td>
</tr>
<tr>
<td>Price of Substitute</td>
<td>0.003**</td>
<td>0.059</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>Distance Travel</td>
<td>-0.003</td>
<td>0.668</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td></td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.54</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at least at alpha =0.05 percent.
**Significant at least at alpha =0.10 percent.
Standard error in parenthesis.
Table 5: Consumer Surplus Based on Hunting Sites in Various States

<table>
<thead>
<tr>
<th>State</th>
<th>Annual consumer surplus incremental due to increase in number of hunting trips (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base</td>
</tr>
<tr>
<td>Mississippi</td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>$130,536.00</td>
</tr>
<tr>
<td>Public</td>
<td>$43,500.00</td>
</tr>
<tr>
<td>Arkansas</td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>$88,578.00</td>
</tr>
<tr>
<td>Public</td>
<td>$28,500.00</td>
</tr>
<tr>
<td>Louisiana</td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>$88,578.00</td>
</tr>
<tr>
<td>Public</td>
<td>$29,250.00</td>
</tr>
<tr>
<td>Texas</td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>$100,233.00</td>
</tr>
<tr>
<td>Public</td>
<td>$2,250.00</td>
</tr>
</tbody>
</table>

Note: Mississippi (N= 58), Arkansas (N= 38), Louisiana (N= 39), Texas (N= 43).

Table 6: Mississippi- Nonmarket Value of Winter Flooded Fields

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Increase in flooded acreage from base (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Private Land (Acres)</td>
<td>13,000.00</td>
<td>13,650.00</td>
</tr>
<tr>
<td>Nonmarket Value at $5.16/acre</td>
<td>$67,080.00</td>
<td>$70,788.00</td>
</tr>
<tr>
<td>Nonmarket Value at $4.43/acre</td>
<td>$57,590.00</td>
<td>$60,469.00</td>
</tr>
<tr>
<td>Nonmarket Value at $4.79/acre</td>
<td>$62,270.00</td>
<td>$65,383.00</td>
</tr>
</tbody>
</table>

Note: *based on flooded land as reported in Winter Flooding Survey (2001).
<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Increase in Average Number of Hunting Trip (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Private Land</td>
<td>$417,624</td>
<td>$438,111</td>
</tr>
<tr>
<td>Public Land</td>
<td>$132,000</td>
<td>$140,962</td>
</tr>
<tr>
<td>Per acre of flooded</td>
<td>$4.43</td>
<td>$4.65</td>
</tr>
</tbody>
</table>

Note: * 5% flooded land of 1996 total acreage
Table 8: Summary Statistics for MS Rice Farmers Adopting Winter Flooding for Waterfowl

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Practices</td>
<td>0.719</td>
<td>0.493</td>
<td>Practicing winter flooding and other waterfowl management practices (1 = yes, 0 = No)</td>
</tr>
<tr>
<td>Full Rent/Lease</td>
<td>0.293</td>
<td>1.630</td>
<td>Full rented/lease (1 = yes, 0 = No)</td>
</tr>
<tr>
<td>Share Tenancy</td>
<td>0.722</td>
<td>4.042</td>
<td>Partly own and partly rent (1 = yes, 0 = No)</td>
</tr>
<tr>
<td>Education</td>
<td>0.609</td>
<td>0.489</td>
<td>Number of years farm operators has attended school</td>
</tr>
<tr>
<td>Awareness</td>
<td>0.357</td>
<td>0.481</td>
<td>Green membership and having green open space near the farm (1 = yes, 0 = No)</td>
</tr>
<tr>
<td>Owner Operator</td>
<td>0.932</td>
<td>5.163</td>
<td>Owned (1 = yes, 0 = no)</td>
</tr>
<tr>
<td>Winter Flooded Acres</td>
<td>0.411</td>
<td>1.034</td>
<td>Ratio of winter flooded acres to total acres of land under rice cultivation</td>
</tr>
<tr>
<td>Operator's Age</td>
<td>52</td>
<td>11.603</td>
<td>Farm operator's age in years</td>
</tr>
<tr>
<td>Average Production Cost</td>
<td>292</td>
<td>62.580</td>
<td>In dollars per acre</td>
</tr>
<tr>
<td>Size of Rice Acres</td>
<td>656</td>
<td>701.178</td>
<td>Hundreds of acres under rice cultivation</td>
</tr>
<tr>
<td>Owner and Green Payment Program</td>
<td>0.195</td>
<td>0.397</td>
<td>Owner operator with green payment support program</td>
</tr>
<tr>
<td>Shared tenancy and Green Payment Program</td>
<td>0.138</td>
<td>0.346</td>
<td>Share operator with green payment program</td>
</tr>
<tr>
<td>Yield</td>
<td>137</td>
<td>139.300</td>
<td>In bushels per acre</td>
</tr>
</tbody>
</table>
Table 9: Logit Model Estimates for Willingness to Accept Winter Flooding Practices

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>p-value</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>0.016 (0.073)</td>
<td>0.932</td>
<td>1.016</td>
</tr>
<tr>
<td>Ages</td>
<td>-0.018 (0.027)</td>
<td>0.491</td>
<td>1.018</td>
</tr>
<tr>
<td>Owner Operator</td>
<td>2.410 (0.068)</td>
<td>0.687</td>
<td>11.167</td>
</tr>
<tr>
<td>Share Tenancy</td>
<td>2.895 (2.895)</td>
<td>0.063**</td>
<td>18.083</td>
</tr>
<tr>
<td>Full Rent/Lease</td>
<td>-6.252 (2.36)</td>
<td>0.006**</td>
<td>0.002</td>
</tr>
<tr>
<td>Yield</td>
<td>0.030 (0.015)</td>
<td>0.028*</td>
<td>1.030</td>
</tr>
<tr>
<td>Owner and Green Payment Program</td>
<td>0.711 (1.766)</td>
<td>0.687</td>
<td>2.036</td>
</tr>
<tr>
<td>Shared tenancy and Green Payment Program</td>
<td>3.025 (1.223)</td>
<td>0.013**</td>
<td>20.594</td>
</tr>
<tr>
<td>Average Operation Cost</td>
<td>-0.013 (0.005)</td>
<td>0.008*</td>
<td>0.987</td>
</tr>
<tr>
<td>Awareness</td>
<td>1.063 (0.552)</td>
<td>0.054**</td>
<td>2.895</td>
</tr>
<tr>
<td>Farm Size</td>
<td>0.001 (0.001)</td>
<td>0.100**</td>
<td>1.000</td>
</tr>
<tr>
<td>Winter Flooded Acres (WF SIZE)</td>
<td>2.681 (1.013)</td>
<td>0.012*</td>
<td>14.599</td>
</tr>
<tr>
<td>LR statistics</td>
<td>103.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at least at alpha =0.05 percent.

**Significant at least at alpha =0.01 percent.
Standard error in parenthesis
"Water Quality Impacts of Conservation Practices Under Environmental Constraints: The Case of the Mississippi Delta"

Dr. Walaiporn Intarapapong and Dr. Diane Hite,
Mississippi State University, Dept of Agricultural Economics
Water Quality Impacts of Conservation Practices Under Environmental Constraints: The Case of the Mississippi Delta

Walaiporn Intarapapong
Mississippi State University

Diane Hite
Auburn University

Natural Resource Economics Meeting, Mississippi State University
May 16 - 17, 2002
**Abstract:** To lessen the environmental disamenities in terms of nutrient, and sediment runoff, Total Daily Maximum Load Rules (TMDL) will soon be in effect. Crop rotations may be a viable alternative to comply with TMDL rules, while maintaining farm profits. In our study, nutrient runoff and sediment is simulated using Erosion/Productivity Impact Calculator (EPIC). Then, we optimize environmentally constrained using GAMS (General Algebraic Modeling Systems).

**Background**

Total Daily Maximum Load rules, which require agricultural producers to find ways to reduce nutrients, agricultural chemical and sediment runoffs into water ways are expected to become a reality in the near future. Farmers will need to adopt methods to comply with TMDL rules while maintaining profitability.

Best management practices including crop rotations may have the potential to reduce runoff of agricultural production especially in terms of sediment. Soybean production alone or in rotation with other row crops has the benefit that it does not require nitrogen fertilizer inputs, which results in lower input costs as well as in reductions in nonpoint pollution (NPP). In addition, compared to other crops, soybean cultivation may have an impact on field operations, thus impacting labor and capital costs. This study thus attempts to develop an environmental constrained economic optimization model of crop rotations, and then compare to the baseline model that assumes continuous crop production.

The Delta hypothetical farms that replicate physical and cropping conditions in the Mississippi Delta form the basis for bioeconomic modeling of the impact of introducing soybean rotations into traditional row crop operations. The Erosion/Productivity Impact Calculator (EPIC) model is used to estimate the effect of the rotations on yields, input usage and nonpoint agricultural pollution at farm level.
Farm budget data and information on nutrients, pesticides, herbicides, farm operations and management practices were obtained and used as inputs for the regional hypothetical farms. Nitrogen runoff, phosphorus lost in sediment, and soil erosion are the environmental parameters of interest.

The purpose of this study is to examine the economic and environmental impacts of crop rotations under various environmental policy scenarios. To meet this objective, an economic optimization model is developed that is constrained by environmental parameters that occur under different crop rotation practices. The study will determine the land allocation among the major crops under alternative environmental objectives.

**Methodology**

The EPIC model is used to simulate agricultural yields and related environmental parameters under various management scenarios (Sharpley and Williams, 1990, Model Documentation). However, the EPIC model is limited to measuring impacts at the edge of the field. Despite this limitation, EPIC has been widely used as a research tool to assess environmental and economic impacts associated with different management practices.

Because different types of practices result in different fixed and variable production costs, as well as changes in yields, an economic model will be developed that incorporates cost and revenue data from the different cropping. An economic optimization model is developed to obtain the optimal land allocation and crop rotation choice by taking into account environmental runoffs. The model is solved using GAMS. By taking into account heterogeneous soil types, and effluents (nutrient runoff and soil erosion), the optimization model maximizes net returns by choosing the optimal land
allocation arising from various continuous cropping, and rotation practices (i.e., soybean with cotton and corn).

Despite the potential environmental benefits of soybean rotations, profitability is the primary factor that will determine if such a practice will be adopted. Thus, optimal net returns will be estimated under two hypothetical environmental regulations: first a 15% reduction in sediment, and second a 15% nitrogen reduction standard. Then, economic and environmental performance of each scenario is estimated and compared with the unconstrained baseline.

Mathematical programming is used to model optimal net returns above variable costs. Management practices are constrained by available land and runoff standards. The model can be written as:

$$\text{(1)} \quad \max \pi \left[ p_i Y_{f,i,j} - C_{f,i,j} X_{f,i,j} \right]$$

Subject to:

$$\text{(2)} \quad \sum_{i,j} X_{i,j} \leq A$$

$$\text{(3)} \quad \sum_{f,j} S_{f,j} X_{f,j} \leq S$$

$$\text{(4)} \quad \sum_{f,j} N_{f,j} X_{f,j} \leq N$$

$$\text{(5)} \quad \sum_{f,j} P_{f,j} X_{f,j} \leq P$$

Where: $p_i, Y, X, C$ are crop price, vectors of crop yield and cropping acreage, and costs of production; $A$ is land available for each practice in each region; $S$ is soil erosion; $N$ is nitrate runoff; $P$ is phosphorus loss with sediment; $f, i, f, and j$ represent soil type,
crop, and cropping practices, respectively. Finally, per acre runoff of sediment, nitrate and phosphorus loss are represented by $S_{f,j}$, $n_{f,j}$, and $\rho_{f,j}$, respectively.

The objective function maximizes total value in terms of returns above total variable costs across crop, rotation, and soil type. Variable costs, denoted $C_{f,i,j}$ include nitrogen, phosphorus, chemicals, labor, capital, and miscellaneous costs.

Equation (2) represents land constraint, where $A$ is the sum of cropland across soil types and cropping practices. Equations (3), (4), and (5) represent constraints on the total amount of sediment, nitrate runoff and phosphorus lost in sediment for each cropping practice across all soil types. The per-acre rates of sediment, nitrate and phosphorus, $S_{f,j}$, $n_{f,j}$, and $\rho_{f,j}$ are multiplied by the number of acres of each practice within each soil type in order to calculate total soil erosion ($S$), nitrate ($N$), and phosphorus loss ($P$) leaving fields.

**Data and Empirical Results**

*Data*

The Delta representative farm is developed by first recognizing the predominant soil types and topographic features of different parts of Mississippi. The soil types that comprise at least 80% of the agricultural land within a region are included in the appropriate proportion for each of the representative farms identified. Meteorological data based on the nearest weather station have been compiled. In addition, topographic and geological data on slope length, roughness of terrain, watershed size and location of nearest streams have been obtained for each region. This study focuses on the Delta region.
The Delta representative farm forms the basis for bioeconomic modeling of the impact of introducing various rotations into traditional row crop operations. The EPIC model is used to estimate the effect of the rotations on yields, input usage and agricultural NPP on the representative farm over long periods of time under a wide range of climate and crop conditions. The environmental impacts of each practices are measured in terms of nutrient runoff (nitrogen and phosphorous) and sediments.

Production costs are obtained from the 1999 Planning Budgets at the Mississippi State University. Farm budget data and information on production costs for each of the cropping and rotation practices have been gathered as inputs for the regional representative farm. The crops in the analysis are major crops grown in Mississippi: cotton, soybeans and corn. The Delta representative farm has the opportunity to produce these crops on a continuous basis or in rotation. In this study, twenty-five year EPIC simulations were performed using different cropping systems in order to determine a base case for expected yields and expected environmental parameters as measured by nitrogen runoff, phosphorus loss in sediment, and soil erosion.

Empirical Results

In our model, we attempt to maximize net returns across the different types of cropping practices (cotton, corn, soybeans, cotton/soybeans, cotton/cotton/soybeans, corn/soybeans, and corn/corn/soybeans), soil types, and effluents (nutrient and sediment runoff), using General Algebraic Modeling Systems (GAMS). Variable costs of other inputs (N and P fertilizers, chemicals, labor, capital and miscellaneous inputs) for each rotation practice are included in the model.
Farm budget data and information on nutrients, pesticides, herbicides, farm operations and management practices are used as inputs. For the economic analyses, information on variable costs was obtained from 1999 Planning Budgets (Mississippi State University).

The results from EPIC simulation states the environmental benefits of crop rotations in terms of reduced sediment and nutrient runoff (Table 1). Crop acreages for the baseline scenario predicted by our model (Table 3) are similar to the planted acres data collected from NASS (Table 2), which indicates that the model performs well. Under the 15% reduction in sediment, a cotton/soybean, and a corn/soybean rotations are found to be preferable.

As compared to the baseline scenario, imposing a 15% reduction in sediment could result in a reduction in net returns of 0.71% (Table 4). Under this scenario, cotton planted acreage increases from 427,464 to 942,929 acres, while corn planted acreage decreases from 617,935 to 98,969 acres.

The shadow price represents the expected value of a change in a given resource, i.e. net returns with respect to changes in constraints, which in this case are limits to sediment and nitrate runoff. The shadow prices for sediment and nitrate indicate net returns forfeited in order to induce a unit reduction in sediment and nitrate runoff, respectively. Under a 15% reduction in sediment, the shadow price of sediment is $2.36 per ton per acre (Table 4). To reduce sediment by 15%, some cropland had to be taken out of production, which consequently helps reduce nitrate and phosphorus runoff. The results indicate a reduction of nitrate and phosphorus runoff by 63.68%, and 67.68%, respectively.
Comparing the second scenario with the baseline, a 15% reduction in nitrate runoff could cause a 8.65% decrease in net returns (Table 6). Shadow price of nitrate runoff is $2.98 per pound per acre. Under this scenario, cotton planted acreages are less than the baseline scenario, decreasing from 427,464 acres to 321,051 acres, while soybean planted acreages decrease from 1,045,400 acres to 938,987 acres (Tables 3 and 6). In terms of cropping practices, a cotton/soybean, and a corn/soybean rotations are the optimal practice (Table 5).

VI. Conclusions

We have examined the environmental and economic impacts of cotton/soybean and corn/soybean rotations as compared to conventional continuous cropping practices. Using mathematical programming, we have estimated optimal profits under environmental restrictions on sediment and nitrate runoff. Considering the two policy scenarios, sediment reductions are less likely to negatively affect income, as compared to restrictions on nitrate runoff, suggesting that implementing a sediment standard would be significantly less costly than a nitrogen standard. Net farm returns are higher with sediment standard in comparing with nitrogen standard.

Higher shadow price of nitrate in comparing with sediment could indicate a more reduction in net return under nitrogen standard rather than sediment standard. Overall, our research points out that policies should take into account both income impacts and shadow prices into account. In addition, this research demonstrates the importance of geophysical conditions on the cost of a policy. This paper has focused only on one type
of management practice, crop rotations; however, many alternatives exist, and will be the focus of future research.
References:

Mississippi State University, Agricultural Economic Department. 1999. The Delta 1999 Planning Budgets.

______ Soil Conservation Service and Forest Service, Soil Survey of County, Mississippi. County and year are varied.


USDA, 1998. Agricultural Outlook, Economic Research Service,
Table 1. Change in Environmental Parameters of Crop Rotations, as Compared to Continuous Cotton and Corn

<table>
<thead>
<tr>
<th></th>
<th>Nitrate (%)</th>
<th>Phosphorus (%)</th>
<th>Sediment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cotton</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton/cotton/soybean</td>
<td>-5.50</td>
<td>-9.04</td>
<td>-15.22</td>
</tr>
<tr>
<td>Cotton/soybean</td>
<td>-8.69</td>
<td>-12.36</td>
<td>-20.03</td>
</tr>
<tr>
<td><strong>Corn</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn/corn/soybean</td>
<td>14.90</td>
<td>-0.81</td>
<td>-20.21</td>
</tr>
<tr>
<td>Corn/soybean</td>
<td>6.11</td>
<td>-4.46</td>
<td>-20.27</td>
</tr>
</tbody>
</table>

Table 2. Planted Acreage in the Mississippi Delta, 1999

<table>
<thead>
<tr>
<th></th>
<th>Cotton</th>
<th>Corn</th>
<th>Soybeans</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>713,900</td>
<td>87,200</td>
<td>1,289,700</td>
<td>2,090,800</td>
</tr>
</tbody>
</table>

Source: National Agricultural Statistics Service
Table 3. Baseline Scenario

<table>
<thead>
<tr>
<th>Acreage (acres)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>427,464</td>
</tr>
<tr>
<td>Corn</td>
<td>617,935</td>
</tr>
<tr>
<td>Soybeans</td>
<td>1,045,400</td>
</tr>
</tbody>
</table>

| Net Returns ($1,000) | 350,009 |

<table>
<thead>
<tr>
<th>Environmental Impacts</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (1,000 lbs)</td>
<td>67,710</td>
</tr>
<tr>
<td>Phosphorus (1,000 lbs)</td>
<td>6,389</td>
</tr>
<tr>
<td>Sediments (1,000 tons)</td>
<td>8,835</td>
</tr>
</tbody>
</table>
Table 4. Scenario I. 15% Reduction in Sediment

<table>
<thead>
<tr>
<th>Acreage (acres)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>942,929</td>
</tr>
<tr>
<td>Corn</td>
<td>98,969</td>
</tr>
<tr>
<td>Soybeans</td>
<td>1,041,897</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Net Returns ($1,000)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Change</td>
<td>-0.71</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental Impacts</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (1,000 lbs)</td>
<td>24,591</td>
</tr>
<tr>
<td>% Change</td>
<td>-63.68</td>
</tr>
<tr>
<td>Phosphorus (1,000 lbs)</td>
<td>2,065</td>
</tr>
<tr>
<td>% Change</td>
<td>-67.68</td>
</tr>
</tbody>
</table>

| Shadow Prices of Sediment ($/ton) | 2.36 |
**Table 5. Planted Acres for Different Cropping Practices**

<table>
<thead>
<tr>
<th>Crop Combination</th>
<th>Sediment Reduction (15%)</th>
<th>Nitrate Reduction (15%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton/cotton/soybeans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton/soybeans</td>
<td>1,885,858</td>
<td>642,102</td>
</tr>
<tr>
<td>Corn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn/corn/soybeans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn/soybeans</td>
<td>197,938</td>
<td>1,235,870</td>
</tr>
<tr>
<td>Soybeans</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 6. Scenario II. 15% Reduction in Nitrate runoff

<table>
<thead>
<tr>
<th>Acreage (acres)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>321,051</td>
</tr>
<tr>
<td>Corn</td>
<td>617,935</td>
</tr>
<tr>
<td>Soybeans</td>
<td>938,987</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Net Returns ($1,000)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Change</td>
<td>-8.65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental Impacts</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus (1,000 lbs)</td>
<td>1,925</td>
</tr>
<tr>
<td>% change</td>
<td>-69.87</td>
</tr>
<tr>
<td>Sediment (1,000 lbs)</td>
<td>2,541</td>
</tr>
<tr>
<td>% change</td>
<td>-82.56</td>
</tr>
</tbody>
</table>

| Shadow Prices of Nitrogen ($/pound) | 2.98 |