Aquaculture Effluents and the Environment

CS Tucker, Mississippi State University
Characteristics of catfish pond effluents
Impacts of catfish pond effluents
Ways to reduce impacts of effluents
What is a pond?

“A small, confined body of standing water”
Implications of long hydraulic residence time

Most of the initial waste loading is removed before discharge
Net Pens

Raceways

Feed → Fish → Waste → Discharge
Effluent management in hydraulically connected systems

Improve FCR = less pollution
- Don’t waste feed
- Increase nutrient uptake efficiency

Use settling to remove solids
- Raceway design
- Offline settling basins
Feed → Fish → Waste → Discharge

In-Pond Processes
Annual feed loading, waste generation, and pollutant discharge from levee-style catfish ponds

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>In feed (lbs/acre)</td>
<td>500</td>
<td>100</td>
</tr>
<tr>
<td>Excreted (lbs/acre)</td>
<td>400</td>
<td>80</td>
</tr>
<tr>
<td>Discharged (lb/acre)</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>Percentage removed</td>
<td>93%</td>
<td>97%</td>
</tr>
</tbody>
</table>
Implications of long hydraulic residence time

Most of the initial waste loading is removed before discharge

Settling characteristics of solids are poor
Solids Settling Characteristics

Mass fraction with $V \leq V_s$

Settling velocity, $V_s$ (cm/sec)

Pond water

Municipal wastewater

Trout farm

0.0 0.1 1 10

0.0 0.5 1.0
Impacts on receiving water bodies

Alabama environmental assessment

Apportionment of waste loading to Wolf Lake, MS
5-day BOD in Alabama Streams Above and Below Catfish Farms

- **Above**
- **Below**
Oxygen in Alabama Streams Above and Below Catfish Farms

Dissolved Oxygen (mg/L)
Ammonia in Alabama Streams Above and Below Catfish Farms

Ammonia (mg/L)

Above and Below Catfish Farms

Above
Below

Sep Nov Jan Mar May Jul Sep

Ammonia (mg/L)

Sep Nov Jan Mar May Jul Sep
Wolf Lake Watershed

Northwest Mississippi

- Cropland: 44%
- Forest: 28%
- Pasture: 23%
- Ponds: 5%
- Residential: 1%
Solids Loading to Wolf Lake, MS

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (%)</th>
<th>TS (%)</th>
<th>TS/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Row Crops</td>
<td>44</td>
<td>82</td>
<td>1.9</td>
</tr>
<tr>
<td>Hardwood Forest</td>
<td>28</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>Pasture/Fallow</td>
<td>23</td>
<td>12</td>
<td>0.5</td>
</tr>
<tr>
<td>Catfish Ponds</td>
<td>5</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Residential</td>
<td>1</td>
<td>0.2</td>
<td>0.2</td>
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### Phosphorus Loading to Wolf Lake, MS

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<tr>
<td>Row Crops</td>
<td>44</td>
<td>80</td>
<td>1.8</td>
</tr>
<tr>
<td>Hardwood Forest</td>
<td>28</td>
<td>8</td>
<td>0.3</td>
</tr>
<tr>
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<td>11</td>
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## Nitrogen Loading to Wolf Lake, MS

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More than 90% of the N, P and organic load to catfish ponds is NOT discharged

Pond solids do not settle well

Catfish ponds are the lowest per-acre contributors of P and TSS of all land uses in the Yazoo-Mississippi River floodplain

Ponds can be significant source of N in regions with highly developed aquaculture

Significant opportunities exist for improvement
Pond effluent management

- No discharge
- Post-discharge treatment
- Pre-discharge treatment
- Reduce waste production
- Reduce effluent volume
No discharge: retention ponds

Retain water drained from ponds and normal overflow, plus storage for 25-yr storm

Levee ponds:
  1.5 acres of retention per acre of production

Watershed ponds (6.3:1):
  11 acres of retention per acre of production
Pond effluent management

No discharge

Post-discharge treatment

Pre-discharge treatment

Reduce waste production

Reduce effluent volume
Post-discharge treatment

Traditional wastewater treatment

Constructed wetlands

Settling ponds

Irrigation of terrestrial crops
Post-discharge treatment: economic constraints

- Discharge is sporadic
  - wet year (1979) = 23 discharge events (57 days)
  - dry year (1966) = 1 discharge event (2 days)

- Discharge is seasonal
  - wet year = 14 events in winter, 6 in early spring, 3 in late fall (November), 0 in summer
Constructed wetlands

Highly effective when properly constructed and managed

Most expensive treatment option generally considered for aquaculture
Settling basins

1) Determine settling characteristics of pond overflow effluent

2) Use settling rate curves to model settling basin design parameters

3) Assess economics of using settling basins
Solids Settling Characteristics

Mass fraction with $V \leq Vs$

Settling velocity, $Vs$ (cm/sec)

- Trout farm
- Municipal wastewater
- Pond water

$Vs \leq 0.5$

$0.01 \leq Vs \leq 10$
Settling basin areas (acre per acre of production) needed to treat maximum 24-hour rainfalls with return frequencies of 2, 10, and 25 years

<table>
<thead>
<tr>
<th>Storm frequency (yr)</th>
<th>Basin area (acre/acre)*</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>0.30</td>
</tr>
<tr>
<td>10</td>
<td>0.45</td>
</tr>
<tr>
<td>25</td>
<td>0.60</td>
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*assuming 1-m deep basin and 50% removal efficiency ($OFR_{50} = 0.005 \text{ cm/sec}$)
Farm-level impacts of using settling ponds

- Investment costs increase 15 to 20%
- Operating costs increase 5 to 10%
- Disproportionate burden on small farms
Irrigation

Sounds great

For most crops, timing is poor

The time when irrigation is needed (droughty late summer) does not coincide with the time when ponds discharge (late winter, early spring)

For rice, timing and supply are problems

The nutrient contribution is insignificant
Pond effluent management

- No discharge
- Post-discharge treatment
- Pre-discharge treatment
- Reduce waste production
- Reduce effluent volume
Pre-discharge treatment

Remove potential pollutants from ponds before water is discharged

Phosphorus precipitation
   Alum, gypsum, iron sulfate

Bioaugmentation
   Bacterial inocula
Bioaugmentation studies in Mississippi

Nine studies in catfish ponds

Various product types

Used according to label directions or advice of manufacturer

Most studies either single or double blinded

No effect on phosphorus or solids in any study
Pond effluent management

- No discharge
- Post-discharge treatment
- Pre-discharge treatment
- Reduce waste production
- Reduce effluent volume
Reduce feeding/stocking rates

Modify diets to improve nutrient retention or reduce waste production
Feed-effluent relationship in ponds

The feed-effluent relationship becomes very disconnected” as hydraulic retention time increases.

In true ponds (as opposed to quasi-flow-through systems), there is little opportunity to reduce solids and total phosphorus concentrations through feed manipulation.

However, total nitrogen concentrations do seem to respond to reduced feed nitrogen inputs.
Feed → Fish → Waste → Discharge

In-Pond Processes
Feed-effluent relationship in ponds

The feed-effluent relationship becomes very disconnected” as HRT increases.

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However, total nitrogen concentrations do seem to respond to reduced feed nitrogen inputs.
Feeding Rate (lbs/acre per day)

Total Suspended Solids or Total P

Feeding Rate (lbs/acre per day)
Feed-effluent relationship in ponds

The feed-effluent relationship becomes very disconnected” as HRT increases

In true ponds (as opposed to quasi- flow-through systems), there is little opportunity to reduce solids and total phosphorus concentrations through feed manipulation

However, total nitrogen concentrations do seem to respond to reduced feed nitrogen inputs
Protein content (satiation feeding)

36% protein feed = 5.0 mg/L mean total nitrogen
28% protein feed = 3.6 mg/L mean total nitrogen

(no change in fish production or FCR)

Feeding rate (across feed protein levels of 28 to 40%)

Satiation = 4.2 mg/L mean total nitrogen
Restricted = 3.3 mg/L mean total nitrogen

(11% reduction in gain and 12% improvement in FCR)
Pond effluent management

- No discharge
- Post-discharge treatment
- Pre-discharge treatment
- Reduce waste production
- Reduce effluent volume
Reducing discharge volume

Mass discharge = (concentration) x (volume)

Modeling showed that mass discharge responded more to achievable reductions in discharge volume than to achievable reductions in concentration.

Managing discharge volume may be easier than managing concentration.
Reducing effluent volume

Reduce or eliminate water exchange (flushing) for catfish; water exchange is not needed if you operate with the assimilative capacity of pond.

Reuse water for multiple crops

Maintain water storage capacity in the pond
Maintaining water storage capacity: drop-fill water-level management

Originally envisioned as a water conservation practice

Most farmers use it whether they know it or not

Can be formalized into a highly effective effluent-management practice

When combined with water reuse for multiple crops, it is the best way to manage effluents
“Drop/fill” water level management

Pond overflow level

Storage

Drop

Fill
Discharge as a function of drop-fill
(3-inch fill; 29-year model for Stoneville MS)

Predicted discharge with no storage = 104 cm
Assessment of effluent BMP effectiveness

Feed management

Reduce nitrogen loading by decreasing feed protein level from 32% to 26%

Already demonstrated to be nutritionally feasible

Discharge volume management

Increase water-storage capacity by using a 9-3 drop-fill routine

Already practiced for water conservation
Total Suspended Solids (mg/L, by season)

- **BMP**
- **Non**

TSS (mg/L)
Total Phosphorus (mg/L, by season)

- **BMP**
- **Non**

![Graph showing Total Phosphorus (mg/L) for different seasons with BMP and Non categories.](image-url)
Total Nitrogen (mg/L, by season)

- BMP
- Non

Seasons: Sum (Summer), Win (Winter)
Annual discharge volume reduced by 45%
Total phosphorus mass discharge reduced by 70%
Annual discharge by season

- **Summer**
  - BMP: 5 cm
  - NON: 30 cm

- **Winter**
  - BMP: 45 cm
  - NON: 70 cm

- **Annual**
  - BMP: 50 cm
  - NON: 100 cm
Total phosphorus mass discharge, by season

- Summer
- Winter

TP (kg/ha)

- BMP
- NON

Bar chart showing the comparison of total phosphorus mass discharge between BMP and NON for summer and winter seasons.
Total nitrogen mass discharge reduced by 70%
Total suspended solids discharge reduced by 65%
Annual groundwater use reduced by 64%
5-year average annual fish yield

BMP = 6,500 pounds/acre
Non BMP = 6,160 pounds/acre
Manage within the pond assimilative capacity

Make efficient use of feed protein

Use water for multiple crops, if possible

Minimize water exchange to the extent possible

Manage water levels to capture rainfall